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These proceedings would not have been made possible without the valuable contributions of our Track Chairs and reviewers for the time and effort they spent reviewing the papers.

We look forward to seeing you virtually at IEMS 2022!

Warm Regards,

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<table>
<thead>
<tr>
<th>REVIEWERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdulaziz Abdulaziz</td>
</tr>
<tr>
<td>Mohammad Kanan</td>
</tr>
<tr>
<td>Sue Abdinnour</td>
</tr>
<tr>
<td>Chris Kluse</td>
</tr>
<tr>
<td>Mohammed Ali</td>
</tr>
<tr>
<td>Jingyun Li</td>
</tr>
<tr>
<td>Abdelhakim Al Turk</td>
</tr>
<tr>
<td>Huitian Lu</td>
</tr>
<tr>
<td>Gordon Arbogast</td>
</tr>
<tr>
<td>Adam Lynch</td>
</tr>
<tr>
<td>Muhammad Attar</td>
</tr>
<tr>
<td>Roger Merriman</td>
</tr>
<tr>
<td>Mehmet Barut</td>
</tr>
<tr>
<td>Narasimha Nagaiah (Raju)</td>
</tr>
<tr>
<td>Enkhsaikhan Boldsaikhan</td>
</tr>
<tr>
<td>Sherisse Pierre</td>
</tr>
<tr>
<td>Deborah S. Carstens</td>
</tr>
<tr>
<td>Dennis Ridley</td>
</tr>
<tr>
<td>Tristan Davison</td>
</tr>
<tr>
<td>Lauren Schumacher</td>
</tr>
<tr>
<td>Andrzej Gapinski</td>
</tr>
<tr>
<td>Brooke Wheeler</td>
</tr>
<tr>
<td>Ed Hernandez</td>
</tr>
<tr>
<td>Xun Xu</td>
</tr>
<tr>
<td>Xiaochun (Steven) Jiang</td>
</tr>
<tr>
<td>Bayram Yildirim</td>
</tr>
</tbody>
</table>
# Table of Contents

## Quality Planning & Improvement

Bandar Alzahrani, Haitham Bahitham and Ahmad Elshennawy

1. Exploring The Applicability Of Quality 4.0 In Higher Education Institutions

Shaun Stearns and Isaac K. Gang

9. Real Time Employees Overtime Predictor Model

Eylem Asmatulu, Zaara Ali, Md Ahsan Habib and Muhammad M. Rahman

16. Using Six Sigma For Energy Conservation And Energy Efficiency Improvement

## Lean Systems

Md Ahsan Habib, Eylem Asmatulu and Muhammad Mustafizur Rahman

24. Applying Lean In Aerospace Manufacturing For Waste Reduction

## Automation, Modeling And Simulation

Ryan Rust and Ahmad Elshennawy

33. The Use Of Machine Learning For Electrical Component End-Of-Life Predictions

## Education Leadership

Ibrahim M. Alarifi, Muhammad M. Rahman and Ramazan Asmatulu

41. Comparing The Regional And International Accreditation Programs Of NCAAA And ABET For Undergraduate Engineering Education Evaluations

## Nanomaterials & NanoEngineering

Sina Davani and Ramazan Asmatulu

48. Theoretical Study On Instability Of The Base Solutions Of Lorenz System Via Ordinary Differential Equations

## SID Talk

Darren Wang and Robert Zhu

54. Real-Time Kinematics Directed Swarm Robotics For Construction 3D Printing

Kaustubh Sonawane and Aditya Rai

64. LungStat: Improving Lung Cancer Diagnostic Accuracy Through Computer Vision

Navya Ramakrishnan

70. A Brain Computer Interface System For The Improvement Of Cognitive And Communication Abilities For Patients With Neuromuscular Disorders
Anthony Shen
A VIRTUAL STEM OUTREACH PROGRAM FOR ELEMENTARY AND MIDDLE SCHOOL STUDENTS DURING COVID-19

Soham Joshi and Raaghav Malik
A MULTIPURPOSE ROBOTIC GLOVE DESIGNED TO TEACH SIGN LANGUAGE THROUGH GUIDED MANUAL MOTIONS
EXPLORING THE APPLICABILITY OF QUALITY 4.0 IN HIGHER EDUCATION INSTITUTIONS

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Abstract: As the world is being significantly impacted by the emergence of the fourth industrial revolution, quality-related practices in higher education institutions (HEIs) are not exceptions. Quality 4.0 is the fourth generation of quality that leads to digital transformation to achieve excellence, innovation, and performance. The application of Quality 4.0 practices in higher education institutions has the potential of driving innovation through technological advances in various aspects such as collaboration, data analytics, connectivity, and scalability. Therefore, the digital transformation would be leading to transformation in education to achieve a comprehensive set of practical and significant goals through formulation and execution of quality initiatives supported by Industry 4.0 related technologies such as the artificial intelligence and Internet of things. Such an approach would contribute to the achievement of scientific goals in teaching and learning, especially after the paradigm shift witnessed in the higher education field during the pandemic of COVID-19. Thus, exploring the applicability of Quality 4.0 in HEIs is vital in the present times. In this paper, the authors identified the gap that currently exists regarding the readiness of HEIs according to Quality 4.0 aspects presented in the literature.

1. INTRODUCTION

The past few years had some rapid advancements in mobility, connectivity, scalability, analytics, and data. This rapid development led to the fourth industrial revolution, also known as Industry 4.0. The fourth industrial revolution is known for digitalizing processes and resulting in the industry shift. (Zaidin, Diah, Yee, & Sorooshian, 2014). Organizations are experiencing a transformation because of digital technologies such as mobile devices, social media, Big Data, the Internet of Things, and cloud computing. The digital transformation presents challenges at various levels, namely in data governance, leadership processes, and integrating technologies to convert the organization. These challenges of type and magnitude not imaginable decades ago. (Sánchez, 2017).

The industrial revolution acts as the critical factor for human growth and development among the different sectors that fuel a nation's economy to make up the gross domestic product's (GDP) main constituent. When there are improvements in the education sector, there is an emergence of skilled and competent professionals who can work in diverse fields and generate increased employment (Zhu, Yu, & Riezebos, 2016).

According to Khan (2016), education is a priority for most countries worldwide, and many countries have devoted huge resources to guarantee high-grade education opportunities. The education system is being developed to meet the social and economic demands of the countries. Conventional education and system would no longer work in an era where there is a scope for optimal education through advanced technology (Pennington, 2017). According to Chik and Arokiasamy (2019), for taking prime advantage
of the set opportunities created by the latest technologies, there is a need to have a similar revolution in education. As the authors mention, proper use of faculty time and investments in facilities would yield the best results when Quality 4.0 is an integral element of the education system.

Quality improvement techniques, such as total quality management (TQM), quality function deployment (QFD), lean, and six sigma (LSS), have widely been implemented within higher education institutions (HEIs). TQM is among the first quality improvement techniques implemented by US and UK universities to improve customer satisfaction and organizational performance (Asif, Awan, Khan, & Ahmad, 2013). Also, LSS was used to improve the quality of HEIs. For instance, Gupta and his colleagues explored the application of LSS methodology to reduce student dropouts in HEIs (Gupta, Antony, Lacher, & Douglas, 2020). Although these quality improvement techniques have been widely implemented in HEIs, they have not explored the quality related digital transformation in HEIs. This is one of the primary roles of Quality 4.0.

2. **THE INDUSTRIAL REVOLUTIONS**

The world is witnessing great development in technology and artificial intelligence (AI) in recent years called the fourth industrial revolution. Therefore, it is important to know the previous industrial revolutions to give us an idea of how they were formed and the extent of their impact on the world. Steam engines were responsible for the start of the first industrial revolution. In the 1800s, water and steam-powered machines came into existence to help workers with their regular tasks. The outcome was increased capability and efficiency, leading to increased growth across sectors (Ionescu, 2018). Businesses expanded from individual interests to organizations. In particular, transportation and textiles benefited greatly from the process of industrialization (Trew, 2020). By the late 1800s, the fuel for the second industrial revolution was electricity that greatly increased manufacturing capacity using science and reached mass production. Also, electricity enabled the combination of power sources to machines (Endicott, 2020 & Andersson et al., 2019).

In the third industrial revolution, the integrated circuit chip brought about the first computer era in the last few decades of the 20th century. This period was marked by the invention of devices like the transistors that made it highly feasible to automate machines for aiding or replacing human operators (Daemmrich, 2017). New possibilities were explored considerably, and electronic hardware gained momentum and subsequently became easy to plan and track product flow (Melnyk et al., 2018). After that, the fourth industrial revolution appeared, which led to creative digitalization based on a combination of interacting technology and unlimited access to knowledge and the invention of smart devices, AI, and many new technologies. For example, the Internet of Things (IoT) is an important technology today that permits sharing and analyzing information in real-time (Penprase, 2018).

3. **INDUSTRY 4.0**

According to Radziwill (2018), Quality 4.0 comes from "Industry 4.0" - a term created at the Hannover Fair in 2011 to describe the fourth industrial revolution. The author stated that the fourth generation of quality intending to achieve excellence in innovation and efficiency through digital transformation. Also, the quality 4.0 strategy provides an excellent opportunity to have a realignment of quality with the organization's goals.

According to Rojko (2017), Industry 4.0 has been developed due to the need to convert regular machines to ones with self-learning and self-awareness that improve the comprehensive performance and maintain suitable alignment with the surrounding environment. The author mentioned that the aim of Industry 4.0 is to construct a smart and open manufacturing platform for information applications that are industrially networked. The main needs of Industry 4.0 are real-time monitoring of data, tracking product positions, and suitably controlling production processes.

As stated by Hermann, Pentek, and Otto (2015), There are principles for Industry 4.0. These principles are interconnection, information transparency, technical assistance, and decentralized decisions.
Interconnection refers to devices, sensors, machines, and individuals' ability to connect and subsequently communicate with each other through the concepts of IoT. Information transparency with Industry 4.0 gives a chance to operators through providing a large volume of information required for making suitable decisions. Also, technical assistance supports individuals to aggregate and visualize the available information comprehensively so that critical problems can be solved easily, and informed decisions can be taken. Therefore, technical assistance can create a safe environment for co-workers.

According to Lasi, Fettke, Kemper, Feld, and Hoffmann (2014), data and smart analytics are the core of Industry 4.0 capabilities. Industry 4.0 is primarily driven by the digitization of service and product offerings and integration of horizontal and vertical value chains, and development of digital business models. Industry 4.0 considers internal operations while in a vertical manner it integrates processes across a large area. Integration of methods of data collection helps organizations to generate data and refine services. The authors mentioned it is significant to focus on the preconditions required to achieve by introducing a new concept such as the stability of the processes to be undertaken, stepwise investment in processes, and a good knowledge of different processes.

Abdulrahim and Mabrouk (2020) noted that the fourth industrial revolution has a deep influence on higher education. The revolution has ensured that the universities have the preparation for facing the challenges cropping up as a result of the COVID-19 pandemic. Digital learning is replacing traditional learning owing to the pandemic. This holds the potential to bring improvement in students' learning outcomes and enhance the faculty members' capabilities while conducting their various academic, administrative, and research activities.

4. QUALITY 4.0

Within the context of Industry 4.0, the word Quality 4.0 applies to the future of operational performance and quality. It is important to accept the future of quality to ensure excellence by quality. Therefore, it becomes essential that quality professionals help their organizations establish the vital link between their ability to thrive in challenging times and quality excellence utilizing the quality principles. The primary objective is to enable growth and transformation through enterprise efficiencies, better performances, innovation, and unique business models (Zonnenshain & Kenett, 2020). According to Küpper, Knizek, Ryeson, and Noecker (2019), Quality 4.0 is characterized by evolving collaboration, culture, competency, and leadership. It is about using technologies and the influence of digitalization in processes, people, and quality practices. Quality 4.0 brings about several benefits such as real-time process monitoring, data collection, and analytics. Emblenstvåg (2020) pinpointed that quality management has evolved considerably since the beginning of industrialization. Quality 4.0 can be perceived as the application of the digital technologies of Industry 4.0 to quality management. This new generation has an essential role to play in the future of quality. For instance, Fonseca, Amaral, and Oliveira (2021) mentioned that the European Foundation for Quality Management (EFQM) 2020 model is an updated and comprehensive business model encompassing sustainability with Industry 4.0. It has its focus on the transformation of organizational efficiency, with verity theoretical and functional foundations. This model connects a technologically unbiased and strategic perspective to Industry 4.0 and provides an integrated business excellence framework for Quality 4.0.

5. THE RISE OF DIGITALIZATION IN HEIS

The HEIs have experienced rapid and drastic transformations as a result of digital transformation. The evolving changes are the combination of novice communication technologies and a new connection of people with information. There seems to be an acceleration towards a digital transformation that has the ability to generate a new vision of the future. Logically, HEIs need tools to achieve changes and develop suitable strategies (Barzman et al., 2021). The education industry is now tapping into the digital revolution, with key transformations brought into the process of learning and teaching (Sandkuhl &
Lehmann, 2017; Wilms et al., 2017). The authors mentioned the HEIs work to use advanced technology that is now undergoing a massive transformation. The digital transformation is witnessing an increased focus on digital classrooms, the IoT, and AI, all of which provide customized learning experiences to learners at different levels (Jackson, 2019). Castro Benavides, Tamayo Arias, Arango Serna, Branch Bedoya, and Burgos (2020) agree that digital transformation in HEIs will improve the student experience and enhance the campus environment-and teaching-and learning methods. Bond, Marin, Dolch, Bedenlier, and Zawacki-Richter (2018) pinpointed that intensive professional developments for educators, students, and staff almost utilize innovative technology in education. Also, evaluating the digital transformation's effectiveness is important to correct the path and find out its strengths and weaknesses with the continual use of such technological tools and procedures.

6. BARRIERS TO IMPLEMENT DIGITALIZATION IN HEIS

With the initiatives taken to implement new technologies in HEIs, there is a wide range of critical issues to be resolved with immense efforts and essential decision-making. Daniel (2015) mentioned that it is for sure that HEIs transformation is underway in the present times, as education leaders are starting on their digital journey. At the same time, current efforts for transformation are focused on the building blocks of experience, such as digitized learning content and administration efficiency. Recognizing this and resolving this matter remain pivotal for better educational outcomes (Strecker, Kundisch, Lehner, Leimeister, & Schubert, 2018). There are several challenges in integrating technology in higher education, and they come in various forms. Also, it is essential to handle them with diligence and care for ensuring positive outcomes (Cloete, 2017). Some notable challenges are data security, infrastructure, lack of IT staffing, digital integration, data governance, creation of data-enabled culture, and adaptation to change (Cloete, 2017; Toquero, 2020).

According to Castro Benavides et al. (2020), rapid technological advancement permeates HEIs that the Industrial Revolution 4.0 brings. The authors mentioned that the digital transformation approaches to HEIs had aroused interest in the complex relationships between the actors in the education domain that is increasingly supported by technology. Therefore, the holistic dimension of digital transformation is missing in many cases. García-Morales et al. (2021) mentioned that the present COVID-19 pandemic had compelled the education sphere to consider the digitalization of HEIs and undergo radical transformations. Also, the system at the university level is striving to remain competitive while providing high-quality education in the light of digital transformation and accelerated change brought about by disruptive technological innovations. The authors stated that the HEIs authorities face several barriers while using various tools and platforms such as video conferencing, learning platforms, and instant messaging tools.

Laats et al. (2019) highlighted that digital transformation implications for the higher education domain are multi-faceted, with possible problems faced by the actors. The interplay between openness for change of HEIs and technology determines how challenges crop up while utilizing the different advanced tools for learning and teaching in the contemporary era. The sustainability of the universities is a concern against increasing digitalization. Bejinaru (2019) explained that due to an accelerated pace of the growth of communication technology, digital society had become a real and specific challenge. The intellectual capital of HEIs is a significant challenge for the successful implementation of digital tools and procedures that support education. The students' digital skills are not up to the mark for embracing the striking changes brought about by the digital transformation of the higher education system.

According to Aldosari (2020), AI is being used in many HEIs worldwide. The author indicates that there is a lack of understanding of the mechanisms used to apply AI. Therefore, the professionals across HEIs need better training through planning, designing, developing, and implementing digital skills and gain the trust to use AI within HEIs. The potential of AI in augmenting education quality is explored by (Chen et al. 2020). However, there are many challenges in using AI in HEIs. These include a considerable high cost of AI technology, vulnerability to varied cyber-attacks, and lack of flexibility. Irrespective of the numerous benefits brought about by AI in the education sphere, the challenges are critical, drawing policymakers' attention.
O’Doherty et al. (2018) opined that the chief barriers that negatively impact the development and implementation of online learning methods include, absence of institutional strategies time constraints, inadequate infrastructure, poor technical skills and support and negative attitudes of all involved. Solutions that can address these concerns include better educator skills, rewards and incentives for the time involved with developing and delivering online content, and improved institutional strategies. El Turk and Cherney (2016) mentioned that administrators and faculty members at HEIs perceive the structural barriers to implementing the online education system: a lack of government policies guiding online classes, frequent failures in technology, lack of control over cheating, slow access to the internet, and lack of awareness. In addition, decisions makers perceive specific barriers that stem from the digitalization of higher education. It would be a pivotal step to blend conventional and online education instructions for better educational outcomes. Lloyd et al. (2012) indicated that in many institutions of higher learning there is an increased demand and need for online courses. However, the number of faculty members involved in developing and teaching such courses does not keep pace with the growth of online learning. The factors associated with a minimal provision of online courses are interpersonal barriers, cost/benefit analysis barriers, technology and training barriers, and institutional barriers. Administrative decisions are to be informed by such barriers for articulating solid policies. Table 1. show the summary of barriers to use digitalization transformation in HEIs.

Table 1. Summary of Barriers to Implement Digitalization Transformation in HEIs

<table>
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<th>Author</th>
<th>Major Findings</th>
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| Castro Benavides et al. (2020)| • Lack of infrastructure.  
                                    | • Lack of technological constraints.  
                                    | • Lack of financial support.  
                                    | • Barriers to compliance, security, and data protection and regulations. |
| Garcia-Morales et al. (2021)  | • Specific communication abilities for an online setting, and inadequate computer skills.  
                                    | • Lack of collaboration.  
                                    | • Lack of infrastructure. |
| Laats et al. (2019)           | • Lack of top management support.  
                                    | • Lack of organizational culture.  
                                    | • High cost of technologies.  
                                    | • Resistance to change. |
| Bejinaru, R. (2019)           | • Absence of technologies resources.  
                                    | • Lack of vision.  
                                    | • Lack of infrastructure. |
| Aldosari, S. A. M. (2020)     | • Lack of information technology  
                                    | • Lack of train professionals  
                                    | • Follow a traditional approach to education.  
                                    | • Lack of availability education technology |
| O’Doherty et al. (2018)       | • Resistance to change  
                                    | • Time limitations  
                                    | • Lack of technical skills  
                                    | • Lack of infrastructure  
                                    | • Lack of institutional strategies |
• An online course requires more commitment and development from faculty.  
• Lack of compensation.  
• Lack of technological infrastructure investment.  
• Resistance to online education methods.

Lloyd et al. (2012)  
• Lack of quality.  
• There are no rules or guidelines in place for online courses.  
• Lack of faculty involvement in course decision-making.  
• Lack of instructor training.  
• Lack of technology support.  
• Technology failures frequently.  
• Software or systems that change frequently.  
• Workload has increased.  
• Inability to adhere to a schedule.

7. CONCLUSION

The future of higher education seeks greater security, collaboration, and technology-driven ideas. This paper aims to explore the applicability of Quality 4.0 in HEIs for improving their performance with the help of digital transformation. New technology will be influencing the environment of education and help to develop HEIs. Educational institutions worldwide are taking initiatives for transforming and prospering in the fourth revolution of technology. Higher education policymakers and leadership teams seek to achieve the world of digitalization that provides learners with the knowledge and skills they need.

Many education initiatives aim to align knowledge, industry, and humanity. The implementation of Quality 4.0 in HEIs is worthy of attention due to weaknesses in digital integration, leadership, support, IT staffing capabilities, training, and digital culture.

8. REFERENCES


REAL TIME EMPLOYEES OVERTIME PREDICTOR MODEL

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Abstract: Employers often struggle with a cost-efficient way to schedule workers and handle overtime. Paying employees overtime is a very inefficient and expensive way to keep a department going. In this paper, we will analyze data from New York City public workers to explore what factors influence the amount of overtime workers have accumulated. We are particularly interested in the factors that predict an increase in overtime and how to possibly adapt them. To accurately answer these questions, we use R-Studio to analyze the predictor variables that would impact overtime for each New York City borough. We further analyzed the differences in overtime per Borough using ANOVA. Follow-up tests were performed using pairwise comparisons; differences per borough were corrected for multiple comparisons using Scheffe’s method. After thorough analysis, we perform multiple regressions on each Borough.

1. INTRODUCTION

Human resource management is an old problem that has been somewhat automated in the last decade, but efficiency continued to be a problem. Machine Learning and AI have risen to new heights and presented researchers and company CEOs alike a chance to reimagine how they tackle human resource problems. However, this has not been easy because it is nontrivial to measure the value of Machine Learning in human resources. But due to the recent advances and inherent sophistication of Machine Learning Algorithms, predicting employees’ attrition, overtime, work intensification, and turnover is not only valuable and possible, but it is measurable now. According to Faggella, “executives and leaders need information that helps them point people in the right direction; information—sales data, KPIs, etc.—change over time, and machine learning can react faster than people in helping draw out the insights and inferences that might otherwise take reams of manpower or not be uncovered at all” (Faggela, 2019). It is from this perspective that we embarked on this work. One specific area of interest to us is overtime prediction. Paying employees overtime is a very inefficient and expensive way to keep a department going. As such, we were interested in the factors that predict an increase in overtime and how to possibly adapt them. While our solution is generalizable, we specifically chose to analyze data from New York City public workers to explore what factors influence the amount of overtime workers have accumulated.

The act of requiring and expecting overtime can lead to a number of issues. Excessive overtime promotes a decrease in productivity and an increased likelihood for accidental injury (Golden & Wiens-Tuers, 2005; Thomas & Raynar, 1997). Overtime can also be highly disruptive to work-life balance, promoting burnout and possibly disengagement from one’s job (Bernstein & Eisenbrey, 2013; Thomas, et al., 1997). Aside from mandatory overtime, individuals will also seek overtime to supplement a low salary (Bernstein, et al, 2013). To tackle the specifics of this problem, we organized our paper in the following ways: We surveyed the literature in section 2. Section 3 delves into our method and discusses...
the details of our hypothesis and the standard Data Analytics life cycle. We summarized our results in 4 while providing further discussions on our specific hypotheses and future direction in section 5. We concluded our paper by providing access to our datasets and the code in section 6 and references in section 7.

2. LITERATURE REVIEW

While a decent amount of work has been done in this area, it is relatively new and the potential of Machine Learning and related algorithms has not been fully leveraged. However, several authors have managed to find interesting outcomes from related problems, though with slightly different sets of hypotheses. Avgoustaki (2015), for example, investigated a correlation between human resource practices and overtime as an indicator of work intensification. More specifically and using European Working Conditions Survey (EWCS), he used a negative binomial regression for modeling overdispersion. He used $y_i$, count of overtime, as his dependent variable, which depends on the observed $X_{ik}$ and an unobserved $u_i$, variables. Because the count variable, $y_i$, has negative binomial distribution, he specified his model as followed:

$$ y_i \sim \text{Negbin}(\mu_i, \sigma_y^2), i = 1, 2, \ldots, n $$

$$ \log \mu_i = \sum_{k=1}^{K} \beta_k X_{ik} + u_i, \quad k = 1, 2, \ldots, K $$

where $u_i = E\{y_i \mid x_i\}$, $\sigma^2_y = \text{Var} E\{y_i \mid x_i\}$, $X_{ik}$ is $n \times K$ dimensional matrix indicating the number of independent variables (training, task rotation, productivity pay, gain sharing, teamwork, discretion over methods, discretion over schedule) (Avgoustaki, 2015).

Barros and Araujo (2016) applied multi-objective optimization to learn overtime dynamics. In their work, they introduced formulation for the overtime planning problem specifically considering two variables namely the “positive effects of overtime on productivity” and its “negative effects on product quality.” Using heuristic search to explore close to optimal overtime allocations, they were able to analyze those allocations and concluded that concentrating overtime allocations in the second half of the project is desirable. They further cautioned that excessive overtime may lead a Project Manager to underestimate the project cost and duration by 5.9% and 9.2%, respectively. Lather et al. (2019) used Machine Learning Techniques to predict employee performance. Using a combination of algorithms in Support Vector Machine, Random Forest, Naive Bayes, Neural Network, and Logistic Regression, they were able to group employees based on clearly identified characteristics that included industry, educational level, and socioeconomic status. Then they classified the employees into 3 output classes indicating the level of their performances from low to high. Allen et al. (2009) conducted Regression Analysis to investigate employees’ retention and predict voluntary turnover. By contacting the National Association of State Government Chief Information Officers (NASCGO), the researchers were able to disseminate their survey to all the 50 state government IT Departments. They ultimately found mismatch between expectations for a career in IT with the IT workplace reality as one of the main contributing variables of voluntary turnover. Dhir and Chhabra (2019) proposed a neuro-fuzzy-based framework for performance evaluation in order to avoid manual processes that are marred with biases and nepotism. Their work resulted in the development of a framework known as the Artificial Neural Fuzzy Inference System (ANFIS), which can be used for learning and automated decision making and optimization in real time. “With an accuracy rate of 94.7% and an estimated RMSE error value of 0.0717, the proposed framework is fit for adaption in any real-life industrial scenario,” according to the Authors (Dhir and Chhabra, 2019). Wang and Shi (2009) conducted an exploratory study on the unpaid overtime working of China’s software engineers and discovered six reasons that motivate them to accept unpaid overtime work. Hammer (1979) reviewed
legal implications for overtime pay for Programmers. From these examples, it is clear that Machine Learning algorithms have paved the way for better human resource processes and management that is more autonomous and efficient.

3. METHODS

Data for the current study was collected from a publicly available data set from the City of New York. The collected data was from the 2016 fiscal year and was collected in the City's Citywide Human Resources Management System. For each state employee Agency, Agency Start Date, Work Location Borough, Job Title Description, Leave Status, Base Salary, Pay Basis, Regular Hours Paid, Regular Gross Paid, Overtime Hours worked, Total Overtime Paid, and Total Other Compensation (ie lumps, retro payments, settlement amounts) were collected and made publicly available.

3.1. Data Preparation

Only employees who reported some amounts of overtime were included in the analysis. The reason for excluding employees who did not report overtime is because we were interested in the factors that predict overtime and since numerous employees work under contract, overtime can go unreported.

Initially, we examined the data set for possible outliers and examined minimum and maximum values to remove extreme values likely caused by recording error. We replaced NA values with 0 where it made sense and actually represented a zero value (i.e. Total Other Pay). The data set was then split by NYC Borough and after examining the data, it was clear that some boroughs didn’t have the sample size to be included in the study. The decision was made to only include Boroughs with more than 500 employees and these boroughs were combined into a single dataset. Boroughs included in the final model were the Bronx, Brooklyn, Manhattan, Queens, Richmond, and Westchester.

After examining descriptive statistics, it was found that Base Pay, Total Overtime, and Total Other Pay were skewed (kurtosis > 3) and required transformation. All variables were normalized using log10 transformation to balance variability and maintain the amplitude of differences between Boroughs.

3.2. Statistical Analyses

The differences per Borough in base salary, overtime, and total other pay were analyzed using Analysis of Variance (ANOVA). All significant main effects were followed up with pairwise comparisons. With each borough having a different sample size, it was decided that Scheffe's Test of correcting multiple comparisons was the most appropriate method. In simple terms, the Scheffe Test (sometimes referred to as procedure or method) helps us find out which pairs of means are significant. The Scheffe Test corrects alpha for simple and complex mean comparisons. Complex mean comparisons involve comparing more than one pair of means simultaneously. Defined formally, let Let $\mu_1, \ldots, \mu_r$ be the means of some variable in $r$ disjoint populations, then an arbitrary contrast is defined by:

$$C' = \sum_{i=1}^{r} c_i \mu_i$$

where

$$\sum_{i=1}^{r} c_i = 0.$$
Other Pay, accounting for any significant differences observed from the ANOVA analyses. For these analyses, Base Salary was regressed on Overtime Hours for each Borough individually, then Multivariate Regression analyses were also performed for each Borough. Data was normalized prior to analysis, and As stated above, base salary was regressed on overtime hours for each borough individually, then base salary and total other pay were regressed on overtime hours for each borough. Standardized betas were also calculated separately for each regression model.

4. RESULTS

4.1. ANOVA

4.1.1 Omnibus ANOVA

Table 1: Fixed-Effects ANOVA results using OT Hours, Other Pay, and Base Salary as the criterion

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
<th>partial η²</th>
<th>partial η² 90% CI [LL, UL]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>83636.80</td>
<td>1</td>
<td>83636.80</td>
<td>204474.57</td>
<td>&lt;.001</td>
<td>204474.57</td>
<td>[.01, .01]</td>
</tr>
<tr>
<td>OT Hours per Borough</td>
<td>1021.94</td>
<td>5</td>
<td>204.39</td>
<td>499.69</td>
<td>&lt;.001</td>
<td>.01</td>
<td>[.01, .01]</td>
</tr>
<tr>
<td>Error</td>
<td>91162.36</td>
<td>222873</td>
<td>0.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Intercept)</td>
<td>248245.30</td>
<td>1</td>
<td>248245.30</td>
<td>603164.39</td>
<td>&lt;.001</td>
<td>603164.39</td>
<td>[.01, .01]</td>
</tr>
<tr>
<td>Other Pay per Borough</td>
<td>648.60</td>
<td>5</td>
<td>129.72</td>
<td>315.18</td>
<td>&lt;.001</td>
<td>.01</td>
<td>[.01, .01]</td>
</tr>
<tr>
<td>Error</td>
<td>90616.53</td>
<td>220172</td>
<td>0.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Intercept)</td>
<td>430438.53</td>
<td>1</td>
<td>430438.53</td>
<td>7888581.32</td>
<td>&lt;.001</td>
<td>7888581.32</td>
<td>[.00, .00]</td>
</tr>
<tr>
<td>Base Salary per Borough</td>
<td>27.44</td>
<td>5</td>
<td>5.49</td>
<td>100.57</td>
<td>&lt;.001</td>
<td>.00</td>
<td>[.00, .00]</td>
</tr>
<tr>
<td>Error</td>
<td>12161.28</td>
<td>222878</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1.2 Overtime Hours

Westchester indicated the lowest amount of overtime hours. Westchester overtime hours were significantly lower than Manhattan (p < .001), Brooklyn (p < .001), Bronx (p < .001), Richmond (p < .001), and Queens (p < .001).
4.1.3 Total Other Pay

Westchester reported the lowest amount of total other pay. Westchester other pay was significantly lower than Manhattan (p < .01), Brooklyn (p < .001), Queens (p < .001), Bronx (p < .001), and Richmond (p < .001).

![NYC Employee Total Other Pay by Borough](image)

Figure 2: Total Other Pay

4.1.4 Base Salary

Westchester employees started with the highest base salary. Westchester base salary was significantly higher than Bronx (p < .001), Brooklyn (p < .001), Manhattan (p < .01), and Queens (p = 0.05). Westchester base salary was not significantly different than Richmond (0.577).

![NYC Employee Base Salary by Borough](image)

Figure 3: Base Salary

4.2 Multivariate Regression Results

For Westchester only, base Salary was not a significant predictor of changes in overtime. Total other pay did predict an increase in overtime hours. But for all other Boroughs, Base Salary remained a
significant predictor of higher overtime (p < .001)

Table 2: Regression results using Overtime Hours as the criterion

<table>
<thead>
<tr>
<th>Predictor</th>
<th>$b$</th>
<th>beta</th>
<th>$sr^2$</th>
<th>$sr^2$ 95% CI</th>
<th>$r$</th>
<th>Fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td>-02</td>
<td></td>
</tr>
<tr>
<td>Base Salary</td>
<td>-0.02</td>
<td>-0.02</td>
<td>.00</td>
<td>[.00, .01]</td>
<td>-.02</td>
<td></td>
</tr>
</tbody>
</table>

$R^2 = .001$

95% CI[.00,.01]

| (Intercept)        | 0.25 |      |        |              | -02  |     |
| Base Salary        | -0.00| -0.09| .01    | [-.01, .02]  | -.02 |     |
| Total Other Pay    | 0.15**| 0.15 | .02    | [.00, .04]   | .12**|     |

$R^2 = .019**$

95% CI[.00,.04]

Note. A significant $b$-weight indicates the beta-weight and semi-partial correlation are also significant. $b$ represents unstandardized regression weights. beta indicates the standardized regression weights. $sr^2$ represents the semi-partial correlation squared. $r$ represents the zero-order correlation. LL and UL indicate the lower and upper limits of a confidence interval, respectively.

* Indicates $p < .05$. ** indicates $p < .01$.

5. DISCUSSION

5.1. Findings

H1: That the borough with the most employees (Manhattan) will have a higher base salary than any other borough.
Not supported, Westchester had the highest base salary.
H2: The borough with the highest base salary (Westchester) will have less overtime hours reported than any other borough.
Supported, Westchester reported less overtime than all other boroughs.
H3: The borough with the highest base salary (Westchester) will accumulate less total other pay than any other borough.
Supported, Westchester reported less total other pay than all other boroughs.
H4: A city employee’s base salary will predict an increase in overtime worked.
Supported, except Westchester indicating that their higher base salary no longer predicted a change in overtime hours.
H5: The more money employees make outside of the workplace will predict an increase in overtime hours worked above and beyond that of base salary.
Supported, for all boroughs.
5.2. Future Directions

It might be in the best interests of city officials to examine base salaries when they notice a significant jump in overtime hours and total other pay. We can also conclude and as noted by others that excessive overtime can cause high employee turnover. High employee turnover incurs substantial time and monetary costs when training new employees (Bernstein, et al., 2013; Golden, et al., 2005; Thomas, et al., 1997). Excessive overtime can also cause damage to quality of life. Excessive overtime and additional jobs/gig work could also result in increased accidents, negligence, and borough reputation damage.

6. APPENDIX

The dataset for this project was downloaded from the city of New York website (data may vary based on year). https://data.cityofnewyork.us/City-Government/Citywide-Payroll-Data-Fiscal-Year-/k397-673e

7. REFERENCES


Abstract: Energy is the backbone of human activity. Energy consumption is increasing rapidly worldwide to sustain the modern way of living with all amenities. Energy, being an indisputable input, optimizing its utilization helps minimize the cost and environmental pollution. Many companies worldwide are continuing to achieve improvements in business performance using the Six Sigma methodology. Six Sigma is a generally recognized approach that focuses on optimizing an enterprise's organizational efficiency, management strategies, and systems by detecting and avoiding 'flaws' in processes relevant to production and services. By developing a Six Sigma methodology-based energy management plan, a company can simultaneously find a systematic way to reduce energy consumption and operating costs. This study discusses a six-sigma-based energy management planning procedure, focusing on five significant steps: define, measure, analyze, improve, and control. An overview of the standard energy-consuming equipment in manufacturing industries is provided. Different energy-saving opportunities are then investigated. Finally, this article presents case studies of varying energy conservation and efficiency projects that successfully implemented the Six Sigma methodology.

1. INTRODUCTION

There has been a significant increase in demand of electrical energy in our daily livings day by day. Most of our daily activities would involve using electrical devices that require adequate electrical power depending on the types of devices being used and the frequency. For example, refrigerators, fans, computers, and internet use require electricity in this new globalization era. Energy, being an indisputable input, optimizing its utilization helps to minimize the cost and environmental pollution. Many companies worldwide are continuing to achieve improvements in business performance using the Six Sigma methodology. Six Sigma is a generally recognized approach that focuses on optimizing an enterprise's organizational efficiency, management strategies, and systems by detecting and avoiding 'flaws' in processes relevant to production and services. By developing a six-sigma methodology-based energy management plan, a company can simultaneously find a systematic way to reduce energy usage and operating costs.

2. ENERGY CONSERVATION AND ENERGY EFFICIENCY IMPROVEMENT

Energy conservation refers to the reasonable and productive use of energy to increase profits (reduce costs) and improve competitive positions. Another concept notes that energy management technique is to modify and maximize energy use efficiency, use systems and processes to minimize energy needs per unit
of production while retaining or reducing the overall cost of generating output from these systems. The method of monitoring, controlling, and conserving energy in a building or organization is energy management. The control of resources is not by chance/event/disaster. It is a mission with a target. It may not be achieved single-headedly or sitting on a bench but involves concerted action for a milestone to be developed by teams of energy-conscious individuals. An energy management policy must be built based on the energy efficiency goal.

Energy management is the way of managing and reducing the energy use of companies, and this is important because it allows you to:

1. Cost reduction: as electricity prices increase, this becomes more necessary.
2. The company may be willing to minimize its carbon footprint and foster a green, healthy reputation by eliminating carbon emissions and the environmental harm they cause, as well as the cost-related effects of carbon taxes and the like.
3. Reduce risk: the more energy you use, the higher the chance your profitability will be seriously impacted by energy price spikes or supply disruptions, or even making it difficult for your business/organization to survive. The first step in reducing energy-related risks is to improve energy efficiency within company processes. Moreover, industries that effectively use energy supplies are less vulnerable to fluctuations and price increases (Global business network, 2007). The three forms of business risk, including 1) competitive risk, 2) financial risk and 3) reputational risk, can be successfully mitigated by energy efficiency.

Lee et al. (2014) performed a complete study where the authors show Six-Sigma approach to energy management planning which is shown in figure 1.

![Energy management plan flow chart](image_url)

Figure 1. Energy management plan flow chart
3. SIX SIGMA METHODOLOGY

Using the Six Sigma approach, numerous firms worldwide continue to make advancements in corporate efficiency. Statistically, Six Sigma refers to a system in which at least six times the standard deviation of a process is the range between the mean of a process quality calculation and the closest design limit (Fursule et al., 2012). It is a disciplined approach and technique for removing defects in any operation, guided by results. Overall, Six Sigma's primary goal is to concentrate the procedure on the target and reduce the difference in the process. In practice, Six Sigma is also known as a problem solver that lowers costs and boosts customer loyalty. As a metric, if a method performs at the level of Six Sigma, it can create non-conformity (i.e., defects or errors) at a rate of not more than 3.4 defects per million opportunities (Ansari et al., 2009).

Six-sigma involves a systematic procedure that comprises five stages known as DMAIC. In other words, DMAIC phases stand for Define, Measure, Analyze, Improve and Control. The objectives, statistical techniques, and the variables involved in energy conservation are given below:

3.1. Define

The first step is to define a team and budget, like an Energy director, Project engineer, Maintenance supervisor, Department representative. For executing an energy conservation strategy, fair budgeting is crucial. Under market rules, this should be made available. At the start of the year, budget distribution should be known to the energy team. Define team and budget flow chart (Lee et al., 2014) is shown in figure 2.

![Define team and budget flow chart](image)

3.2. Measure

It is possible to use an energy audit to assess efficiency in energy management. Understanding how electricity is used will assist the company in evaluating existing efficiency and recognizing energy-saving opportunities. Either an internal audit team(s) or an outside service will carry out an energy audit. External assistance, including those offered in the US by Industrial Evaluation Centers, will look at simple energy use activities and not participate in particular core procedures necessary to develop or maintain a commodity. The value of an internal audit is that for a given process, the energy staff will be more familiar with the production process and more comfortable making recommendations for energy savings. After collecting data and performing an audit, the audit data needs to be analyzed. A flowchart is shown in figure 3 on measuring company energy performance (Lee et al., 2014).
3.3. Analyze

The audit review results allow a company to understand current energy demand better and evaluate the appropriate budgets for executing an energy management strategy. Opportunities for saving electricity are defined when the cost savings, cost of implementation, and payback time are measured. The findings will be included in the creation of targets for energy saving and an action plan. The first step is to identify any opportunity to save. For example, the audit data shows that a machine's surface temperature is above the safety requirements, so installing insulation is the saving chance for a device. Performing an economic analysis also helps in cost saving. Detail flowchart of how to analyze energy audit data is shown in figure 4 (Lee et al., 2014).

3.4. Improve

The next step is to maximize system performance until the audit data has been evaluated. The tasks include (1) the establishment of an energy conservation objective and (2) the planning of an action plan. After the action plan has been explicitly stated, the next move is to initiate the execution process. An energy management strategy can be made or destroyed by humans, so it is crucial to obtain the approval and participation of key entities within the organization at various levels. The system efficiency improvement flow chart (Lee et al. 2014) is shown in figure 5.
3.5. Control

A monitoring strategy is required in energy management to (1) track the success of implementation, (2) keep implementation manageable, (3) monitor the savings sustained, and (4) inspire personnel to pursue development. The testing progress will be carried out by annual/monthly updates indicating progress on any undertaken work. Per month, these reports will also track the electrical bills and show a decrease in electrical use. Precise control and monitoring strategy are shown in figure 6 (Lee et al., 2014).

4. CASE STUDY

4.1. Case Study 1

Razali et al. (2014) performed a case study to improve energy conservation using six-sigma at the Faculty of Computer and Mathematical Sciences, Universiti Teknologi Mara. The electricity consumption of the facility was increasing day by day. The total electrical consumption for 2011 was 1, 648, 791 kWh and 1, 657, 808 kWh in 2012, which increased by 0.5% (9017 kWh). From the results obtained, it showed that air-conditioner (57%) was the primary factor that contributes to high consumption of electricity, followed by lightings (22%), sockets (16%) and others (5%). They also found that the electrical consumption was almost doubled when the new semester began. After the campaign (Six sigma
implementation), there was a reduction of 2% in electrical consumption in this facility.

4.2. Case Study 2

Kaushik et al. (2008) performed a case study collecting data from a thermal power plant. In a thermal power plant pursuing energy efficiency, the Six Sigma approach has been introduced. A costly input content is de-mineralized (DM) water in this plant. It has been observed that a 0.1 percent increase in the use of DM make-up water raises the cost of generation by around US$ 0.2 million per year. Six Sigma project guidelines have been found to minimize the total water make-up from 0.90 percent to 0.54 percent of the cumulative, continuous rating (MCR), resulting in total energy savings of about US$ 0.74 million per annum.

In their study, they identified that DM water loses during regular service from the combined cycle due to the following reasons:
1. boiler tube leakage and more extended operation of boiler tube leaks
2. valve passing:
   a. passing due to undersize of actuators.
   b. passing of valves due to incorrect limit transfer setting.
   c. passing of drain and vent valves.
   d. blowdown opening for silica and conductivity test.
3. gland leaks from pumps
4. leaks from HP / LP pipelines.

4.3. Case Study 3

Kane et al. (2003) performed a case study to improve boiler soot blowing. The boiler operating procedure calls for soot blowing once per day to remove deposits formed on the boiler heat transfer surfaces because of burning fuel oil. The operator log indicated that soot was only being blown 39% of the time. Soot blowing frequency is set arbitrarily by procedure, with no attention to pre- and post-blow boiler efficiency or the cost of operating the soot blowers. Boiler stack temperature was averaging 81°F above standard, eroding boiler efficiency by 2% and costing $40,000/year in additional fuel costs. The study objective was to improve boiler efficiency by 1.2% by reducing the average stack temperature to 50°F. The team members measured initial SIGMA score was -0.86, and the final score was 0.58, which was a 1.44 Sigma improvement. After the SIX SIGMA implementations, the benefit was $26,000 per year of fuel savings.

4.4. Case Study 4

Kane et al. (2003) reported another case study to improve micronizer steam condensate heat recovery. The project team initiated an aggressive survey program to check the plant's instrument and tool airlines. Power operators were encouraged to find leaks and identify wasteful uses of instruments or tools air as well. Leaks were tagged as they were identified, and work orders were subsequently written to repair the leaks. The power operators followed up with the area to ensure that the work orders were completed. They also worked with the areas to correct wasteful practices. The survey program reduced the average plant air demand to 654 scfm, about 7% of the original demand. The control plan for the project established an ongoing survey program that had the operators auditing a portion of the air system every quarter. Survey activities were set up in the plant's preventive maintenance (PM) system, and a history of all compressed air work orders was maintained. A summary of all the case studies is shown in Table 1.
Table 1: Summaries of case studies

<table>
<thead>
<tr>
<th>Case study</th>
<th>Problem statement</th>
<th>Objective</th>
<th>Benefit after Six Sigma implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The electricity consumption at the Faculty of Computer and Mathematical Sciences, Universiti Teknologi Mara increased day by day. The total electrical consumption for 2011 was 1, 648, 791 kWh and 1, 657, 808 kWh in 2012, which increased by 0.5% (9017 kWh).</td>
<td>Decrease the electricity consumption of the facility</td>
<td>After the Six sigma implementation, there was a reduction of 2% in electrical consumption in this facility.</td>
</tr>
<tr>
<td>2</td>
<td>A costly input content is de-mineralized (DM) water in a thermal power plant. It has been observed that a 0.1 percent increase in the use of DM make-up water raises the cost of generation by around US$ 0.2 million per year.</td>
<td>Decrease the generation cost through proper use of de-mineralized (DM) water.</td>
<td>Six Sigma project guidelines had been found to minimize the total water make-up from 0.90 percent to 0.54 percent of the cumulative, continuous rating (MCR), resulting in total energy savings of about US$ 0.74 million per annum.</td>
</tr>
<tr>
<td>3</td>
<td>The boiler operating procedure calls for soot blowing once per day to remove deposits formed on the boiler heat transfer surfaces because of burning fuel oil. The operator log indicated that soot was only being blown 39% of the time. Soot blowing frequency was set arbitrarily by procedure, with no attention to pre-and post-blow boiler efficiency or the cost of operating the soot blowers. Boiler stack temperature was averaging 81°F above standard, eroding boiler efficiency by 2% and costing $40,000/year in additional fuel costs.</td>
<td>Improve boiler efficiency by 1.2% by reducing average stack temperature 50°F.</td>
<td>$26,000 / year fuel savings</td>
</tr>
<tr>
<td>4</td>
<td>190 million pounds of steam per year at a variable cost of $663,000 were required to heat filtration area wash water. Hot steam condensate from the micronizing process was recycled to a head tank and reduced the steam needed for heating. The condensate that was not recycled overflowed the seal tanks as waste. Waste heat was rejected at a rate of 184 million Btu/hour.</td>
<td>Reduce the steam required to heat the wash water through increased condensate recovery by 116 million pounds per year resulting in $405,000 savings.</td>
<td>$577,000/year energy savings</td>
</tr>
</tbody>
</table>

5. CONCLUSION

Applying Six Sigma shows that the market is taking a small step towards energy conservation. When Six Sigma finds its proper place in the energy-intensive process industry, it can still expect tremendous benefits from its application. The Six Sigma technique is highly effective for optimizing the efficiency of any industry. It is critical to have an energy management strategy and an energy management team in place as part of a company's effort to reduce energy costs. The energy team will pursue the process to develop management participation, execute energy assessments, enforce the action plan, control compliance, and create a quality performance rewards scheme. In making progress in energy management, having a well-organized and committed energy team is critical.
6. REFERENCES


[7] /p2_7/


Abstract: Lean manufacturing shows significant promise for addressing various simultaneous, competitive demands, including high process and merchandise quality, low cost, and reductions in lead times. These requirements have been found within the aerospace sector, and efforts are now well established to implement lean practices. Although lean manufacturing was originally developed for the automotive industry, aerospace manufacturing industries have found that these lean principles can also be applied in this high-precision industry to improve production efficiency significantly. In this paper, the main objective is to provide background on lean manufacturing, present a summary of potential wastes and introduce the tools and techniques that are used to transform the industry into a high-performing lean enterprise. The method applied in this article is divided into three major parts. Firstly, define lean manufacturing and lean cycle for the aerospace sector. Secondly, examine lean implementation in the aerospace manufacturing sector. Finally, discuss the lean action plan in the aerospace sector. The goal of lean implementation in the aerospace sector is to construct a learning organization and achieve continuous improvement. Thus, the aerospace manufacturing suppliers can increase their competence within the present competitive market.

1. INTRODUCTION

Initially, the word "lean" was popularized by the book the machine that changed the planet (Womack, et al., 1990). This word crystallized a broad range of practices and principles where continuous improvement was made possible through the systematic elimination of waste, the reduction of in-process inventory, the utilization of just-in-time delivery, in-station process control, continuous improvement suggestions, systems thinking, and other related elements (Krafcik, 1998; Womack and Jones, 1996). Lean practices and principles encompass longstanding quality principles (Deming, 1987; Juran, 1998) and newer developments, like Six Sigma (George, 2001).

Lean manufacturing is an approach to help factory to identify and eliminate production waste, improve product quality, and reduce production cost (Salunke and Hebbar, 2014). There are at least seven (07) types of production wastes which are shown in table 1.

<table>
<thead>
<tr>
<th>Types of waste</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste of overproduction</td>
<td>On some occasions, some finished products could not make their way to the customer. Those products are called a waste of overproduction. This waste occurs due to an earlier production timeline or a higher production than customer needs.</td>
</tr>
<tr>
<td>Waste of motion</td>
<td>The movement of employees in working on products is unavoidable. However, if there is a movement that does not provide added value to the product, it is</td>
</tr>
<tr>
<td>Waste Type</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Transportation waste</td>
<td>In a well-designed system, workplaces and storage areas are close together so that material transfer is nearby. The equipment is placed where it is used, and material is transferred to the process quickly.</td>
</tr>
<tr>
<td>Processing waste</td>
<td>In some cases, changes in product design often cause a reduction in some parts of the final product. Waste of processing occurs due to unnecessary processes or carry out inefficient processing.</td>
</tr>
<tr>
<td>Waste time</td>
<td>This type of waste can be divided into two categories, namely waiting time and queuing time. Waiting time occurs when a part has finished, but other parts that will be assembled with it have not yet completed. Queuing time occurs when a part has finished but cannot continue because the next machine is still doing another job.</td>
</tr>
<tr>
<td>Defective product</td>
<td>This waste arises from producing defective products or components or requires repair. Repairing or reworking, producing replacement goods, and inspections means that additional handling, time, and effort are needed.</td>
</tr>
<tr>
<td>Unnecessary Inventory</td>
<td>This waste arises from excessive inventory. Expenditures due to waste include warehouse costs, costs due to obsolete products, and damaged products.</td>
</tr>
</tbody>
</table>

The lean cycle (Plan-Do-Check-Action (PDCA)) cycle is shown in figure 1.

![Lean Cycle Diagram](image.png)

The aerospace industry allows a valuable place to examine lean implementation. It is a diverse sector of the economy surrounding airframes, engines, space and missiles, avionics, and a vast array of second and third-tier suppliers. There are huge competitive challenges in both the civilian and military parts of this industry, driven by the end of the Cold War, the rise of global competition, the development of new materials and new innovative technologies, and the emergence of what are termed "dominant designs" in many segments of the market (Utterback, 1996). In this mix, lean manufacturing practices and principles have been highlighted as central to the revitalization of the industry. For example, Norman Augustine, retired Chairman and CEO of Lockheed Martin, called for the application of lean principles from the machine that changed the world (Womack, et al., 1990) to this industry and commented that "The U.S. aerospace industry has restructured what it is now, it must restructure what it does and how it does it" (Murman et al., 2002).

In the 1990s, the aerospace company was trying to implement a lean manufacturing approach to production using Kawasaki Production System. Boeing, a renowned aerospace company, applied the lean manufacturing concept in 1997 and successfully constructed a moving assembly line in 1999 at Long Beach Plant by building 100-seat 717 aircraft. Boeing 747 final assembly line applied lean manufacturing technology in 2001. The results showed highly optimized production flows and processes, reducing cost and flow time from the traditionally 24 days to the targeted reduced 18 days (Koskela, 1992).
2. LITERATURE REVIEW

Lean aircraft designers think that a new 'right first-time' culture in aerospace manufacturing will do for aircraft what it did for the car industry a decade ago. Nowadays, panels and components damaged in operation can be quickly replaced at the front line without special customization in the same way that car parts are ordered up and fitted in the commercial world from a long time ago. Employees involved in Eurofighter production from the design to the logistic support are grouped in integrated production teams (IPTs). Each IPT is now responsible for its budget and accountable for its section of the aircraft (Cook, 1999).

The adoption of lean practices is evident in the USA and the U.K. aerospace sectors. In the USA, Lockheed Martin's Aeronautics Sector declared 1999 as the 'year of lean implementation and then rigorously applied lean techniques to the F-16 and F-22 fighter programs and the C-130J military transport aircraft. In the U.K., BAE Systems military aircraft plants had been heavily involved in implementing lean practices within their businesses from a long time ago. The Samlesbury site became the company's flagship manufacturing site, believing that lean manufacturing was central to controlling costs on the Eurofighter program. However, BAE Systems thought that the aerospace industry was 10-15 years behind the automotive sector in implementing lean activities (Flight International, 1998).

Lean ideas are now being transferred throughout the U.K. aerospace industry. Significant initiatives are also ongoing in many aerospace manufacturing firms, including Airbus U.K., Rolls-Royce plc, Smiths Aerospace, TRW Aeronautical Systems, etc. Lean improvement efforts are also being patronized in both the USA and U.K. by national research programs for example, the U.S. Lean Aerospace Initiative at Massachusetts Institute of Technology (MIT) and the U.K. Lean Aerospace Initiative, a consortium consists of the Universities of Warwick, Bath, Nottingham, and Cranfield.

Three factors have caused lean to become an issue within the aerospace sector. First, the end of the Cold War evoked drastic reductions in defense procurement budgets resulting in reduced military markets. The defense industry could no longer justify the cost-plus mentality that characterized the Cold War era and faced the challenge of seeking new markets (Aviation Week and Space Technology, 1992; Interavia, 1999). Second, passenger demand felled suddenly following the Gulf War, which forced airlines to cancel or postpone civil aircraft orders. This followed a time when civil aircraft orders increased at unprecedented higher levels. The inability of the industry to respond to unexpected changes in demand was reflected by long lead times (Aviation Week and Space Technology, 1999). Third, now with other sectors, globalization has become a central issue. The rise of globalization has necessitated a complete rethinking for some industries regarding how they can organize and reconfigure themselves to cope with it. These factors signaled radical changes for the global aerospace industry. There was now over-capacity in the market, and profits were declining (Cosentino, 1999). As a result of these factors, several significant players within aerospace are pursuing lean practices. For example, Boeing, a renowned aerospace company, was facing up to some of these challenges as it implemented urgent operational improvement strategies to:

1. Achieve more excellent quality on the first pass throughout Boeing—the goal is 90% improvement in manufacturing quality.
2. Organize corporate-wide work teams that are fully accountable for their work products, and all have the metrics they need to measure their performance.
3. Create a culture that encourages employees to propose better ways to meet performance goals.
4. Move up the value chain, i.e., focus on core competencies.
5. Reduce the company's cost structure substantially.

However, the applicability of lean practices to sectors other than automotive had been questioned (James-Moore & Gibbon, 1997). Lean had its roots within the automotive industry, and the contrast between this high volume setting and the low volume environment of the aerospace industry was enormous. Jina et al. (1997) provided insights into some of the sector differences between automotive and aerospace companies. However, they did not mention how this impacted the manufacturing
transformation process, and this was where the literature on manufacturing strategy became important. From a manufacturing point of view, Hayes and Wheelwright (1984) and Hill (1995) provided templates that showed profound differences between high volume (line production) processes, common to automobiles, and low volume (project-based) processes that pervaded aerospace. Hill (1995) pointed out that the differences between these two manufacturing environments extended beyond production transformation characteristics to competing priorities. To use the Hill (1995) terminology, there were significant differences between order-winning and order-qualifying criteria when contrasting high and low volume settings. The transfer of practices across different sectors could present difficulties. These sector-specific requirements could not be ignored and glossed over in the pursuit of a particular paradigm. However, differences such as volume levels should not necessarily present an obstacle to the implementation of lean in aerospace because numerous successful examples of the application of lean have been drawn from a variety of industrial sectors (Womack and Jones, 1996; Henderson and Largo 1999; Jenson et al., 1996). Womack and Jones (1996) prescribed a detailed account of the introduction of lean principles within Pratt & Whitney, one of the world's leading aero-engine manufacturers. Moreover, the aerospace sector might have advantages over automotive in terms of applying lean principles. The lower volumes mean that the aerospace sector (at prime and upper-tier levels mainly) was closer to the lean ideal of single-piece flow than the automotive sector. Another possible concern was that aerospace was ten years behind the automotive industry about implementing lean practices. Although this might provide learning opportunities, the time lag was an important issue. However, we should also keep in mind that the transfer of lean practices had not been fully disseminated even within the automobile industry, although the initial efforts began some ten years ago before the aerospace sector. For example, Kochan et al. (1999) showed that although lean production systems seemed to be diffusing throughout the world, there was much variation across countries and firms. In addition, the automotive sector might be accused of shop floor myopia, having concentrated on creating lean final assembly plants and supply chains over the past ten years. The automotive industry was only now coming to grips with applying lean in the extended enterprise (Womack and Jones 1996) by looking at ways to reduce waste throughout the distribution process and provided the final customer with their exact requirements. This had become evident in the '3-Day Car' ambition within the industry (Holweg and Pil, 2001). However, rather than 'catching up with such developments in the automotive sector, the aerospace sector already 'builds to order', only producing aircraft that their commercial and military customers required. The aerospace sector adopted lean practices with a "Lean Enterprise" mindset, particularly as 80% of the cost was built-in at the design stage. Therefore, the concern over the perceived ten-year gap might not be as much of a disadvantage as it first appeared. While the aerospace sector might have some benefits in implementing lean, the challenges of lean implementation were real and proved difficult for many other firms. As Karlsson and Ahlstrom (1996) pointed out, traditional ways of thinking and practices were difficult to shed, and we could thus expect such a radical change to be fraught with difficulties.

V. Crute et al. (2003) discussed the critical drivers for lean in the aerospace manufacturing industry. They informed that implementing lean within aerospace was not necessarily more complicated than implementing lean within high-volume sectors, automobiles. The challenges were different but not more difficult. They offered critical conclusions from their findings and tentative lessons for other companies. First, lean capabilities were not merely firm-specific but were, instead, plant-specific. There were differences in the rate of progress made and differences in the procedure taken to lean implementation. Second, it could not be assumed that the characteristics of the 'best performing' site within a firm that had multiple plants would, necessarily, be transferred to other plants within the same company. Techniques, including benchmarking between sites, might help but needed to be 'Lean Champions' between sites if lean practices were to be disseminated among plants within the same firm. Third, for lean to be implemented, plant-specific manufacturing strategies must be in place that was comprehensive and holistic in scope and content. Results might also be achieved more readily when improvement activities focused on all or a large part of an identified 'product value stream' rather than on a functional area that produces a range of products. Similarly, faster results seemed possible when established process ownership was rather than several products sharing production processes. Four, operations managers had
to be willing to take on a more strategic role than had been the case in past manufacturing paradigms. This was a problematic issue because lean production had emerged from the profound changes of manufacturing processes over time. However, as Brown (2000) found that the transition from craft through mass production to the current era of lean often resulted in operations management being absent from the most senior levels of the firm as enterprises became larger and more organized around functions and although there had been increasing importance placed on operations personnel in terms of their contribution to the firm's capabilities, including lean production (Womack, et al., 1990; Kenney and Florida, 1993). Their findings indicated the need for operations managers to have a strategic and not merely tactical role if lean implementation was to be successful. Senior management had an important role to play in presenting a coherent vision for their business, clearly communicating business strategy, and indicating how the lean philosophy and practices fitted with the needs of the business. There also needed to be an awareness of the impact of the consistency of senior management messages. Questions needed to be asked concerning whether the philosophies and initiatives being promoted were consistent, timely, and necessary. Five, their findings indicated that lean implementation could be achieved more rapidly in plants where the culture supported autonomous working and learning through experimentation. Where such a culture did not exist, senior managers should play a key role in creating a context where change was possible. This required leadership and a consistent message of support. Six, aspects of improving performance, such as changing factory layout, required time, and physical space, were available if significant results were to be achieved.

3. RESULTS AND DISCUSSION

It was found that most wastes occurred in aerospace manufacturing activities. Zahra et al. (2020) performed a study for the performance improvement in aerospace manufacturing through lean. They found that waste of motion was the highest among other waste with a score of 44, followed by waiting with a score of 24. The third highest waste was excess processing with a score of 2. The causes of these wastes were lack of facilities such as machines and tools and inefficient operators in picking and mixing sealant. The method that they applied was divided into three major phases. Firstly, they evaluated the current system performance using Value Stream Mapping (VSM). Secondly, they determined the dominant waste by cooperating waste finding checklist. Finally, they developed a lean action plan.

![Figure 2. Waste in Aerospace Production (Zahra et al. 2020)](image)

The overall processes led to 2 days and 12 hours of waiting time. In respect to that time, the next step was to group the activities into Value Added (V.A.), Non-Value Added (NVA), and Necessary Nonvalue Added (NNVA). Hence, the cause of waiting times could be identified. The results were as follows; Value Added was 44,520 hours; Non-Value Added was 418 hours, and Necessary Non-Value Added was 49,520 hours. Waste Finding Checklist (WFC) was used to find the wastes in the elevator production. A series of discussions with experts were performed to fill the WFC filled. From the WFC the waste of motion had the highest value of 44, then waste of waiting was in second place with 24. The complete result is shown in Figure 3.

Figure 2. Waste in Aerospace Production (Zahra et al. 2020)
After all types of wastes were identified, Fishbone Diagram was applied to determine the root cause of the problem. The waste motion caused by 18 production process activities caused by lots of unnecessary movements or excess movement could cause additional time in the production process. Improvement analysis focused on waste of motion in several production process activities. The result was a program to change the layout to make the JIG elevator closer. Another program was to add sealant space to the elevator production process location so that the operator did not have to bring the sealant too far from the elevator production process room. The last program was to restrict the operators from taking and mix sealant. In addition, the labeling of the machine or tools was done to facilitate the operator is working. Based on those improvements' program, it reduced cycle time and lead time. Future Value Stream Mapping by those programs is shown in figure 4.

V. Crute et al. (2003) performed a case study to implement lean in the aerospace manufacturing industry. They implemented lean in two sides (Side A and B). They found that despite the similarities, the timescales for progress differed considerably, with both sites having achieved significant results. At Site A, lean changes were implemented and got output within six months. By contrast, at Site B lean changes were still being kept in place after 18 months of effort. Site A has enjoyed a significant increase in orders for spare components requiring the site to double its previous output approximately. Senior managers in the company found that existing resources, equipment, and systems would not be sufficient to meet future demands and, therefore, a change strategy had to be implemented. It was decided that lean techniques would be piloted in one department, which was underperforming, and that the plan would be that lean practices would then apply from here to the whole site over time. Improvement targets were precise and linked to lean indicators, including lead-time reduction, increased stock turns, and the introduction of pull systems. The department was performed in machining, sub-assembly, assembly, and testing processes. Substantial results were achieved within six months, as shown in Table 2.

<table>
<thead>
<tr>
<th>Site A</th>
<th>Starting point (Time = 0)</th>
<th>Target (0 plus 6 months)</th>
<th>Achieved (0 plus 6 months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead time</td>
<td>8 weeks</td>
<td>4 weeks</td>
<td>5 weeks</td>
</tr>
<tr>
<td>Stock turns</td>
<td>2.3</td>
<td>10</td>
<td>5.3</td>
</tr>
<tr>
<td>Production capacity per month</td>
<td>450</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Pull systems</td>
<td>None</td>
<td>In place</td>
<td>Sub-assembly</td>
</tr>
</tbody>
</table>
At Site B, the drive to implement lean practices was motivated by recognized success at Site A and more modest demands for a 20% increase in production. The area identified for lean improvements involved assembly processes only with machining and testing in other parts of the organization. Improvement goals included the increasing output of 'delivery kits' and improving labor efficiency. Other targets for improvement were more generic, including using a range of management quotes from interviews- 'establishing customer-focused areas' and 'establishing continuous improvement practices within site. Few performance measures were at hand within the target area to start the improvement efforts, although metrics were available for the whole assembly section of which the target area formed one part. No plans were made to set formal targets and measure the achievement of the more generic goals. Production and productivity targets were achieved, and some progress was achieved in establishing customer-focused areas. While continuous improvement practices were accepted within the area, there were some reservations concerning the degree to which such practices had become embedded and would be sustained. An overview of Site B is provided in Table 3.

<table>
<thead>
<tr>
<th>Table 3. Lean performance improvements at Site B (Crute et al., 2003)</th>
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<tbody>
<tr>
<td><strong>Site B</strong></td>
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<tr>
<td>Delivery kit production capacity</td>
</tr>
<tr>
<td>Labor efficiency</td>
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<tr>
<td>Establish customer focused areas</td>
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<tr>
<td>Establish continuous improvement practices</td>
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</table>

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<tr>
<th>Table 4. Summary of the critical factors influencing the rate of Lean improvements (Crute et al., 2003)</th>
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<tr>
<td><strong>Site A</strong></td>
</tr>
<tr>
<td>Rate of Lean implementation</td>
</tr>
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</table>
| Change strategy | 1. Holistic approach  
2. Specific Lean targets  
3. Performance measures developed at the outset of implementation.  
4. Formal Lean training provided | 1. ‘Piecemeal’ approach  
2. Generic targets  
3. Performance measures developed at later stage in implementation.  
4. Informal dissemination of lean concepts. |
| Site culture | 1. Satellite site  
2. Autonomy/willingness to experiment | 1. Central site  
2. High visibility/ blame culture  
3. Bureaucratic |
2. Processes mainly dedicated to the Product family.  
3. Greater process ownership  
4. Limited dependency on other areas | 1. Changes targeted on a functional area (assembly)  
2. Processes shared by several products.  
3. Less process ownership  
4. Highly dependent on other areas |
| Senior management commitment and consistency | 1. High degree of support  
2. Consistent messages | 1. Conflicting management  
2. Initiatives/people management philosophies  
3. Changes to Lean champion’s responsibilities |
4. CONCLUSION

This study defines the lean concepts, summarizes the lean cycle for lean implementation and practice, and develops the lean production Implement model to strengthen the aerospace market competitiveness. The lean concept can apply within the manufacturing process of the aerospace industry and the business process. Especially for aerospace manufacturing suppliers, they need to scale back their cost to extend their competitiveness. The concept of lean production is a continuous improvement process. It is a long-term journey and effort. The lean Implement model incorporates four categories, i.e., human resources, machine, method, and function. The scope/level of lean topics and environment will become wider/higher than before in the aerospace industry through the continual lean cycle. The goal of lean implementation is to strengthen the management performance of an enterprise. Through the top management commitment and companywide involvement, the resources can be aligned and focused to implement lean activities. The goal of lean implementation in the aerospace industry is to construct a learning organization and achieve continuous improvement. Thus, the aerospace manufacturing suppliers can increase their competence within the present competitive market.

5. REFERENCES


THE USE OF MACHINE LEARNING FOR ELECTRICAL COMPONENT END-OF-LIFE PREDICTIONS

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Abstract: Diminishing Manufacturing Sources and Material Shortages (DMSMS), also referred to as obsolescence, is a sector of product sustainment that is receiving more attention as certain technologies continue to have longer and longer system life cycles. Much of the research today points towards a need for better electrical component end-of-life (EOL) predictors. A small-scale case study was performed to explore the use of machine learning for obsolescence forecasting of flash memory chips. The Random Forest classification algorithm was able to predict the Active vs. Obsolete status in both the training data and the test data with an OOB error rate of 10.87%. The Random Forest regression algorithm was able to predict an obsolescence date of an obsolete component on average 0.75 years after the actual discontinuation of the component and 1.08 years for active components. The regression analysis had an overall error rate of 0.53%. This study demonstrates opportunities and challenges for using machine learning as a future DMSMS forecasting tool.

1. INTRODUCTION

Diminishing Manufacturing Sources and Material Shortages (DMSMS), is a sector of product sustainment that historically has been overlooked by most industries. Technologies that have long sustainment life cycles are typically the most impacted by obsolescence. These include airplanes, ships, industrial equipment, medical equipment, and military systems which are slow in the implementation of new technology and leading-edge technology often because of the expenses and length of time that accompanies the development of a new product (Sandborn, 2011).

A deep dive into the literature shows that the main areas of concern for obsolescence are cost optimization, obsolescence management, system life cycle, design/system refresh planning, architecture/open systems, and end-of-life (EOL) predictions. In the EOL predictions category, of the six articles, there was only one article that proposed the idea of machine learning. A considerable portion of the research shows an interest in obsolescence forecasting tools, but there is minimal information involving the use of machine learning algorithms.

This paper will present an original case study of experimentation using the Random Forest classification and regression algorithms to complete a small-scale case study using a sample size of 92 Xilinx Field Programmable Gate Array (FPGA) chips. R statistical computing and graphics software was used to conduct this experiment. The goal was to see how accurately the algorithm classified each chip as active or obsolete and how closely it can predict a product discontinuation date. The features selected for the algorithms to use were Slices, Logic Cells, Max Distributed RAM Bits, DLL, PLL/MMCM, Max IO, 5V Tolerant, and MHz.
2. CASE STUDY

As previously stated, a case study was performed using the Random Forest classification and regression algorithms with a sample size of 92 Xilinx Field Programmable Gate Array (FPGA) chips. R statistical computing and graphics software was used to run these algorithms comparing the selected features of Slices, Logic Cells, Max Distributed RAM Bits, DLL, PLL/MMCM, Max IO, 5V Tolerant, and MHz. These variables were selected based on personal experience on what may be an important component prediction factor and information that was readily available for the entire sample size. A total of 11 Xilinx Part Families consisting of 92 FPGA chips used in this case study. There were 54 obsolete components used that are indicated with red in the Status column, and there were 38 active components used. The component marketplace introduction dates range from the years 1998 – 2009.

2.1. Classification Code

The importance of the classification code’s output is that it allows for the creation of an obsolescence risk model to show the probability that a part is obsolete or not. A component may still be available in the marketplace, but based on the Machine Learning model, there may be a high risk that it will be obsolete soon and is therefore not desirable for future designs. The R coding packages of cowplot and Random Forest were used for classification. The training and testing sizes were both set to 50% with the decision tree level set to 500.

2.2. Regression Code

Below is the regression code used for predicting the End-of-Life date of a component. The importance of this code is that its output gives design engineers a timeframe for when the part is expected to be discontinued. This information not only provides designers useful way of predicting the amount of time needed to complete a redesign or find an alternative part, but this timeframe assists in maximizing the number of high-risk components that can be removed from the current product or redesign (Jennings, 2016).

The Random Forest library was used, and the decision tree level was set to 500. Obsolescence predictions were compared to actual discontinuation dates and active components were compared to Q-STAR predictions. Q-STAR is a commercial database that helps companies with component life cycle management. Having results comparable to an already available commercial data source helps validate the accuracy of the Machine Learning algorithms and their efficacy in predicting obsolescence.

2.3. Error Rate Plot Code

The error rate code uses the ggplot2 package to create the decision tree chart further down in this paper. The importance of this chart is it shows how many decision trees are needed for the algorithm to perform with the lowest error rate. Too few trees will result in a larger rate of errors. A model with more trees than needed will not hurt the results, but the model will perform slower.

2.4. Feature Importance Code

This was used for determining feature importance and the statistical significance of each of the selected features. This shows us what weight the algorithm is placing on each variable along with the associated p-values.

2.5. Feature Selection

Feature selection is referred to the algorithmic process of obtaining a subset from an original set of features to select the relevant features of the dataset (Cai, Luo, Wang, & Yang, 2018). Figure 1 shows the framework for the feature selection process. The main reasons for feature selection are for faster algorithm training times, reduced model complexity, improved model accuracy, and reduced overfitting (Kaushik, 2016). Selecting features will be a combination of personal knowledge and the algorithms mathematically selecting them on their own based on relevance.
Data will initially be gathered from publicly available datasheets such as the one from Xilinx in Table 1 below. The top portion of the table contains information such as System Gates, CLB Array, Number of Slices, Logic Cells, and so on that can be used as possible obsolescence predictors. Not every data sheet for every part family or manufacturer contains the same information. This makes the initial feature selection process difficult and time consuming. However, once the features are selected and the model is trained, the model can be modified to use only what it determines to be the most important variables to improve its accuracy and speed.

Table 1: XILINX VIRTEX-II Series FPGAs Datasheet (Xilinx, n.d.)

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Note: System Gates include 10% BVI of CLB reticle lines.
1. System Gates include 10% BVI of CLB reticle lines.
2. EP2C5000 I/O Includes 5 I/O per row for row-to-row communication.
3. Data on Speed is based on the Xilinx Virtex-II series.
2.6. Model Accuracy Validity

There are five ways that the model’s accuracy can be validated. This study will be able to use four of those five methods.

1. Classification – Comparing a prediction of Obsolete to known information on whether the component is active or obsolete.
2. Classification – Comparing a prediction of Active to known information on whether the component is active or obsolete.
3. Regression – Comparing the model’s discontinuation date to a component’s actual discontinuation date on an obsolete component.
4. Regression – Comparing the model’s discontinuation date to a component’s predicted discontinuation date on an active component. The accuracy of these Machine Learning algorithmic models can be compared to a traditional model such as Q-STAR for current EOL predictions.
5. Regression – Comparing the model’s discontinuation date to a component’s predicted discontinuation date on an obsolete component. The accuracy of these Machine Learning algorithmic models cannot be compared to a traditional model such as Q-STAR for historical EOL predictions. Information is not available on historical predictions for an already obsolete component.

Validation methods 1-3 are those most important because they compare the Machine Learning results to known information. Methods 4 and 5 are less important because they are comparing one prediction tool to another when neither may be correct.

3. RESULTS

The Out-of-Bag (OOB) error rate for the 50% training set was 10.87%. From the sample size of 46, the Random Forest classification algorithm correctly guessed 14 components as Active and 27 Obsolete. The algorithm incorrectly guessed 4 components at Active when they were Obsolete and incorrectly guessed 1 component as Obsolete when it was Active. The Out-of-Bag (OOB) error rate for the 50% testing set was 10.87%. From the sample size of 46, the Random Forest classification algorithm correctly guessed 17 components as Active and 24 as Obsolete. The algorithm incorrectly guessed 3 components at Active when they were Obsolete and incorrectly guessed 2 components as Obsolete when it was Active. Figure 2 below depicts the testing classification confusion matrix results from R.

```
call:  randomForest(formula = Status ~ ., data = train, ntree = 500, importance = TRUE)  
Type of random forest: classification  
Number of trees: 500  
No. of variables tried at each split: 2  

OOB estimate of error rate: 10.87%  
Confusion matrix:  
             ACTIVE OBsolete class.error  
ACTIVE      17     3  0.15000000  
OBsolete    2      24 0.07692308  
```

Figure 2: Random Forest Testing Data Results

The regression analysis shows that the Random Forest algorithm was able to predict an obsolescence date of an obsolete component on average 0.75 years after the actual discontinuation of the component. On average the algorithm estimated the obsolescence date of an active component 1.08 years early when compared to Q-STAR predictions. Q-STAR is a commercial database that helps companies with component life cycle management. It is important to note that actual discontinuation dates were used for
obsolete components and Q-STAR data was used for active components. Q-STAR was used as a comparison tool because there is no way of knowing how well the Random Forest algorithm predicted the years until EOL without comparing it to another widely used software tool in industry today. Overall, the algorithm predicted the EOL date on average 0.08 years early which is a margin of error of less than 1% as shown in Table 2 below.

Table 2: Random Forest Regression Results

<table>
<thead>
<tr>
<th>Status</th>
<th>RF Prediction (Years)</th>
<th>Actual or Q-STAR Prediction (Years)*</th>
<th>Difference in Years</th>
<th>Percentage Difference</th>
<th>Over/Under</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obsolete</td>
<td>13.92</td>
<td>13.17</td>
<td>0.75</td>
<td>5.70%</td>
<td>OVERESTIMATED</td>
</tr>
<tr>
<td>Active</td>
<td>16.92</td>
<td>18.00</td>
<td>-1.08</td>
<td>6.00%</td>
<td>UNDERESTIMATED</td>
</tr>
<tr>
<td>ALL</td>
<td>15.28</td>
<td>15.36</td>
<td>-0.08</td>
<td>0.53%</td>
<td>UNDERESTIMATED</td>
</tr>
</tbody>
</table>

*Actual discontinuation dates were used for obsolete components and Q-STAR data was used for active components.

3.1. Error Rates & Feature Importance

Figure 3 shows the fluctuation in Active, Obsolete, OOB error rates for the Random Forest algorithm as the number of decision trees are increased to 500. After about 200 trees, all the error rates flatten off indicating that 500 trees are enough for this analysis. Larger datasets may require more decision trees and therefore take longer for the model to run.

Figure 3: Error Rates Based on Number of Decision Trees

The Random Forest algorithm places a factor on each feature based on which attributes it determines to be the most important. Of the eight features selected for this study, MHz, the number of Logic Cells, and the number of Max Distributed RAM Bits in the FPGA chips were the top three most important attributes for predicting obsolescence status and EOL dates. Each feature has an associated P-value with MHz and Logic cells having statistically significant values of 0.02 and 0.05, respectfully. Table 3 below presents both the Importance Factor and P-Value for all eight features used in the model.
Table 3: Feature Importance and Statistical Significance

<table>
<thead>
<tr>
<th>Feature</th>
<th>Importance Factor</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slices</td>
<td>3.84</td>
<td>0.12</td>
</tr>
<tr>
<td>Logic Cells</td>
<td>5.87</td>
<td>0.05</td>
</tr>
<tr>
<td>Max Distributed RAM Bits</td>
<td>5.72</td>
<td>0.16</td>
</tr>
<tr>
<td>DLL</td>
<td>1.46</td>
<td>0.12</td>
</tr>
<tr>
<td>PLL.MMCM</td>
<td>1.42</td>
<td>0.09</td>
</tr>
<tr>
<td>Max IO</td>
<td>4.34</td>
<td>0.15</td>
</tr>
<tr>
<td>5V Tolerant</td>
<td>2.45</td>
<td>0.18</td>
</tr>
<tr>
<td>MHz</td>
<td>15.81</td>
<td>0.02</td>
</tr>
</tbody>
</table>

4. DISCUSSION

The results from this small-scale case study provide some positive information regarding using Machine Learning as a tool for predicting obsolescence. The Random Forest classification algorithm was able to predict the Active vs. Obsolete status in both the training data and the test data with an OOB error rate of 10.87% at a 50% training size and 500 decision trees. The training set was 50% of the population and the test set was the remaining 50%.

Higher training sets did result in lower OOB training error rates but did not improve testing results due to the small sample size. The sample size of 92 components was small, so increasing the training size too large leaves too few of samples in the testing set to allow for any sort of statistical significance. The reason why the data is split into training and testing sets to reduce the risk of model overfitting the data. The algorithm uses the training set to define the logic it wants to use for predictions and then uses that logic on the test set. The importance of this classification information it allows for the creation of an obsolescence risk profile for a design’s Bill of Material (BOM). A company can look at the risk profile for a BOM and based on their risk tolerance, they can add or remove certain components as desired.

The Random Forest regression algorithm was able to predict the years to EOL date 0.75 years after the actual discontinuation of obsolete components and 1.08 years early when compared to Q-STAR predictions for active components. This was an error of 5.7% and 6.0% for active and obsolete components, respectively. The overall error was 0.53%.

Although a larger sample size would reduce variance and provide more significant information, there are two very positive takeaways from this information. The first is with parts that have a status of Obsolete. A discontinuation date is known information and the algorithm was able to predict its discontinuation date within one year. The second is comparing the Active results with another commercially available piece of software called Q-STAR. The Random Forest algorithm and Q-STAR predictions were on average only 1.08 years apart. This provides some validity to the Machine Learning model given the fact that its
results were comparable to another widely used and accepted software solution in the marketplace today.

5. CONCLUDING REMARKS

To conclude, Diminishing Manufacturing Sources and Material Shortages is a new reality in manufacturing systems and supply chain environments as systems are needed to be sustained for longer and longer periods of time. A greater emphasis on taking a proactive approach to the issue needs to take place rather than waiting for the problem to occur and then acting. A powerful proactive strategy includes built-in technology refresh cycles into a system that can be implemented using machine learning. A redesign can be implemented once a predetermined risk threshold is met. Afterwards, third party software or machine learning regression and classification algorithms can be used for the component selection process in the new design.

Today’s best tools for forecasting obsolescence use traditional algorithms that analyze inputs using defined logic but are only as good as the logic provided. Machine Learning takes inputs and outputs to create its own logic and then uses this logic when analyzing new data. The results for this small-scale case study shows promising results for a larger scale experiment. The Random Forest algorithm was able to classify components as Active or Obsolete with an OOB error rate of 10.87% and predict actual obsolescence dates with less than a one-year margin of error. The next step would be to reperform this experiment with a larger dataset, variable training sizes, optimized feature selection, and multiple algorithms such as Naive Bayes and Support-Vector Machines.

5.1. Challenges, Limitations & Future Research

One of the main challenges for completing future research is going to be collecting large amounts of data. It is said that we are in the Information Age as we take on projects of big data analytics and this era is moving towards more cognitive processing with machine learning and artificial intelligence capabilities that rely on the large amounts of data we collect and manage (Mullins, 2017). A model will always only be as good as the input information that it receives. When it comes to machine learning, training data determines the performance of the model’s outputs. According to Hale (2018), bad quality data will replicate itself as it flows through machine learning systems, generating flawed information. A quote from Thomas C. Redman, a well-known figure in the data quality management world, states, “Poor data quality is enemy number one to the widespread, profitable use of machine learning” (Hale, 2018).

To overcome the enemy of bad data, a great deal of time must be spent analyzing data integrity to help safeguard against inaccurate and biased results.

Comparing component data is another challenge, but there are some online databases that can provide component obsolescence. Some of these databases include, but are not limited to, PartMiner, Q-Star, SiliconExpert, CAPS Universe and Total Parts Plus. Manufacturers also often have their component datasheets publicly available. It’s important for the data to be as complete as possible, but as demonstrated in various studies, to a certain extent, machine learning models can make their own predictions to fill in gaps of missing or incomplete data.

A third challenge and possibly a limitation will be fitting the models to make them work with data from all types of components. Different types of components include resistors, capacitors, microcontrollers, integrated circuits (IC), and so on. A field programmable gate array (FPGA) is not going to have the same obsolescence trends as a diode. A digital IC may require different algorithm features than an analog IC for the predictive models to be accurate. Sometimes age can be used as a feature where other times primary attributes such as speed, size, logic gates, or logic cells can be used as inputs (Gao, Liu, & Wang, 2011). Age can be a primary driver on certain components such as an operational amplifier, but age does not have a strongly correlated effect on flash memory. This is an obstacle that may not be overcome in this research due to the complexity of having to set up different models for different types of components. This research will focus on proving the validity of Machine Learning algorithms for predicting component obsolescence using Flash Memory chips. Future research can be done to branch out to other types of components if this dissertation study shows promise.
Making sure that the historical collected data still reflects current data will be a fourth challenge. According to Jennings (2016), a machine learning or statistical obsolescence model in present day with past obsolescence data would not predict advancements and innovations in technology. This means that the obsolescence forecasting frameworks and all current machine learning models cannot predict unforeseen technological advancements, and therefore are better suited to track steady improvements in the electrical component industry (Jennings, 2016). This is an issue that is just the nature of the beast and cannot necessarily be completely erased, but it is important to be cognizant of this incidence. The main takeaway here is to remember that the goal is to improve upon the prediction accuracies of current models, of all types, and bring forward better obsolesce information to electrical design engineers than they are currently receiving. Nothing will ever be perfect, but everything can always be made better.

A final limitation to this study is there currently is not a known way of comparing the accuracy of these Machine Learning algorithmic models to a traditional model such as Q-STAR for historical predictions. I do not have access to historical predictions on an already obsolete component. This does not mean the use of Machine Learning models for obsolescence predictions cannot be justified, as the case study results show promise.

6. REFERENCES


Comparing the Regional and International Accreditation Programs of NCAAA and ABET for Undergraduate Engineering Education Evaluations

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Abstract: This research study was focused on the accreditation of a local university and its programs during the 2017-2018 and 2018-2019 periods. Accreditation requires that the university be under the consideration by an autonomous agency for the quality assurance. Accreditation can be done for the entire institution or for individual programs within an institution. Accreditation is a voluntary process that many institutions go through with multiple steps. Usually, universities request accreditation agencies to assess their programs, faculty, and students’ achievements to establish if they meet the quality requirements every six years. When requirements are met, the organization is regularly reassessed and accredited to make sure that the whole body persists in meeting the standards. Majmaah University (MU) of Saudi Arabia has been recently prepared for both regional (National Commission for Academic Accreditation and Assessment - NCAAA) and international (Accreditation Board for Engineering and Technology - ABET) accreditation programs. Most of the undergraduate engineering teaching programs were certified by both NCAAA and ABET. These accreditation programs have mainly similar outcomes although there were some small variations. This study provides the details on the similarity, differences, strengths, and weaknesses of the two accreditation systems and the required documentations to meet the accreditation criteria and demands.

1. Introduction

1.1. General Background

In engineering education, the assessment and accreditation of academic programs are vital to maintain the status and the quality of engineering graduates, and ultimately the workforce [1]. Various accreditation models are used and developed regionally and internationally. ABET accreditation is an international standard in STEM education. From computing and engineering to natural and applied sciences, graduating from an ABET-accredited program puts students in the best position to secure a job in the field [2, 3]. ABET accreditation has been embraced in several countries, and employers internationally recognize the value of ABET-accredited programs [4, 5]. Employers seek to find professionals equipped and prepared to handle complex environments where they can thrive [6]. As an international accreditor of programs in the STEM disciplines, ABET provides confidence that relevant programs meet quality standards and produce graduates that are well-prepared for the global workforce [7]. Additionally, ABET plays an essential role in ensuring the quality of education for professionals who, in return, help in solving primary challenges in the world. NCAAA was formed in the Kingdom of Saudi Arabia (KSA) with the
purpose of shaping criteria and standards for academic assessment and accreditation. The commission focuses on the quality assurance system of higher learning institutions and ensures that the management and quality of educational institutions are at par with the highest international standards shown in Figure 1.

Figure 1. Demonstrated quality and skills development with a good result level up to 75% satisfied

1.2. Literature Review

There are numerous options available for students joining different colleges. While there are several factors that are often considered before making the decision, accreditation is one of the key factors considered in the process. Accreditation means that a self-governing agency often assesses the institution under consideration for quality [9]. Accreditation can be done for the entire institution or of individual programs within an institution. Accreditation is a voluntary process that institutions go through. Universities request accreditation agencies to assess their programs, faculty, and students’ success to resolve if they meet the standards for higher learning [12]. When standards are met, the institution is regularly reassessed and accredited to make certain that the whole institution continues to meet standards. Particularly for the engineering career, accredited status is essential for globalization.

Engineering and courses such as medical specialties, education, and psychology, often require that a student’s course be accredited independently from the organization. Program-based certification that is carried out by the professional agencies focused on a specific area of study, such as ABET makes sure that the curriculum of study meets the requirements for the education. This practice requires to have a basic common foundation that will lead to success [14]. On the other hand, NCAA academic accreditation and assessment encourages, supports, and evaluates the quality assurance procedures of universities to guarantee that high standards and levels of achievement in the KSA and throughout the world.

1.3. NCAA vs. ABET Accreditations

NCAA Domains of Learning and ABET Outcomes utilized in the higher education element of the qualification’s context for the Kingdom of Saudi Arabia have some differences as shown in Table 1. NCAA domains include knowledge, interpersonal skills, cognitive skills, and obligation, psychomotor, Numerical and Communication Information Technology, and some other basic Skills. The knowledge domain assesses the capability to recollect and communicate information. The domain of intellectual skills assesses the ability to use principles and concepts in problem-solving and critical thinking. Relational skills and accountability domain assess the capacity to take responsibility for their education, and the moral and ethical growth that is linked with these abilities, exercise leadership and work effectively in groups. The psychomotor skills domain is essential in some fields of education and is measured as a supplementary domain in some programs. The domain of Communication Information Technology and Numerical Skills assesses basic communication and mathematical abilities.
Table 1. NCAAA vs. ABET student learning outcomes codes.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Knowledge</td>
<td></td>
</tr>
<tr>
<td>(h) ABET</td>
<td>a1</td>
</tr>
<tr>
<td>(i) NCAAA</td>
<td></td>
</tr>
<tr>
<td>The broad education is necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.</td>
<td></td>
</tr>
<tr>
<td>(j) ABET</td>
<td>a2</td>
</tr>
<tr>
<td>(k) NCAAA</td>
<td></td>
</tr>
<tr>
<td>A knowledge of contemporary issues.</td>
<td></td>
</tr>
<tr>
<td>B Cognitive Skills</td>
<td></td>
</tr>
<tr>
<td>(b) ABET</td>
<td>b1</td>
</tr>
<tr>
<td>(c) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An ability to design and conduct experiments, as well as to analyze and interpret data.</td>
<td></td>
</tr>
<tr>
<td>(d) ABET</td>
<td>b2</td>
</tr>
<tr>
<td>(e) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An ability to design a system, component, or process to meet desired needs within realistic constraints.</td>
<td></td>
</tr>
<tr>
<td>(f) ABET</td>
<td>b3</td>
</tr>
<tr>
<td>(g) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An ability to identify, formulate, and solve engineering problems.</td>
<td></td>
</tr>
<tr>
<td>C Interpersonal Skills &amp; Responsibility</td>
<td></td>
</tr>
<tr>
<td>(d) ABET</td>
<td>c1</td>
</tr>
<tr>
<td>(e) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An ability to function on multidisciplinary teams.</td>
<td></td>
</tr>
<tr>
<td>(f) ABET</td>
<td>c2</td>
</tr>
<tr>
<td>(g) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An understanding of professional and ethical responsibility.</td>
<td></td>
</tr>
<tr>
<td>(h) ABET</td>
<td>c3</td>
</tr>
<tr>
<td>(i) NCAAA</td>
<td></td>
</tr>
<tr>
<td>A recognition of the need and an ability to engage in life-long learning.</td>
<td></td>
</tr>
<tr>
<td>D Communication, Information Technology, Numerical</td>
<td></td>
</tr>
<tr>
<td>(a) ABET</td>
<td>d1</td>
</tr>
<tr>
<td>(b) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An ability to apply knowledge of mathematics, science, and engineering.</td>
<td></td>
</tr>
<tr>
<td>(c) ABET</td>
<td>d2</td>
</tr>
<tr>
<td>(d) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An ability to communicate effectively.</td>
<td></td>
</tr>
<tr>
<td>(e) ABET</td>
<td>d3</td>
</tr>
<tr>
<td>(f) NCAAA</td>
<td></td>
</tr>
<tr>
<td>An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.</td>
<td></td>
</tr>
</tbody>
</table>

In case of NCAAA, student outcomes and other added results that might be expressed by the Mechanical Engineering (ME) program are required to be adoptive to the realization of course educational objectives. The Educational Management in the Faculty of Engineering develops a measurement and assessment process that regularly forms and expresses the extent to which student results are achieved, compared to the five domains of learning stipulated by the NCAAA. For engineering programs, the psychomotor domain is not applicable. All ABET outcomes call for a higher level of learning in the engineering subjects when compared to knowledge-based subjects. A minimum of Level 3 of the cognitive domain of Bloom’s taxonomy is necessary. Acquaintance with discipline-related industrial practices is also necessary and is achieved through summer training activity.

2. INVESTIGATION ON PROGRAM EDUCATIONAL OBJECTIVES

Majmaah University’s mechanical engineering program is designed to prepare students with learning for a successful career in academia, government, consulting, and industry. Graduates are expected to effectively apply problem-solving skills, and critical thinking skills along with mechanical engineering knowledge in engineering practice or in non-engineering areas such as business, medicine, and law. The second objective is that graduates continue their intellectual development through professional development and graduate education. The third objective is embracing leadership roles in mechanical engineering careers. Another goal is the completion of professional engineering education and pursues advanced study and research in the mechanical engineering field. Further, graduates are likely to engage in alternative career choices.
The faculty of Mechanical Engineering (ME) at Majmaah University (MU) is considered as one of the first to obtain accreditation from NCAAA and satisfied at ME program with the faculty members at MU demonstrated in Figure 2a. Figure 2b shows the faculty workload following years of continuous workload with the preparation of self-studies, and an external evaluator visiting the team. The commissioning of the mechanical engineering program was done following the official presentation to obtain accreditation. The mechanical engineering faculty entered its final stage of accreditation. The engineering program identifies its intended learning outcomes and graduates attribute that are consistent with the mission and matches graduate attributes at the university level. The program's educational objectives are publicly disclosed, approved, and regularly reviewed.

Table 2 shows the program outcomes associated with the course to outcomes in the ME program. The resulting section validates one of the matrices for the selected courses numbering from 1-12. The educational objectives and learning results are in line with the standards of the country’s qualification framework and with the labor market, professional, and academic requirements. The program also identifies different learning outcomes for diverse tracks and applies suitable tools and mechanisms for measuring the achievement of course objectives and graduate attributes while verifying student achievement according to assessment plans and performance levels. There is a need for school commitment to program objectives for successful achievement. The institution’s leadership is committed to quality, starting from the highest level of the university’s management. Leadership at various departments is also committed in quality management and overseeing the quality assurance system. Dean’s or Heads of Quality are responsible for the operation of procedures.

Table 2. Mapping program outcomes associated with the course to outcomes of the educational program with the following samples.
3. EVALUATION

Evaluation is a practice that involves the interpretation of data and evidence collected and analyzed during the assessment process. Table 3 demonstrated the NCAAA vs. ABET criterion to indicate that the application is to be filled for the ME program. The assessment determines the degree to which student outcomes are accomplished. Evaluation results in actions and decisions regarding program enhancement. Data is interpreted and evidence accumulated during the assessment process. The level by which program educational objectives and student outcomes are presently accomplished is determined [8]. Considerate evaluation of findings is critical to ensure that actions and decisions taken because of the assessment process leads to program improvements. At the request of boards of engineers and institutions, ABET provides evaluations of engineering programs leading to a degree in an institution of higher education.

Table 3. The checklist NCAAA vs. ABET criterion to indicate that the application is to be filled for the ME program.

<table>
<thead>
<tr>
<th>No.</th>
<th>NCAAA Criteria Check List</th>
<th>ABET Criteria Check List</th>
<th>Audit team opinion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Program authorized</td>
<td>Program authorized</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Request for Internal Audit approved</td>
<td>Assessment report (ABET Form) with approval</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Program specification using the NCAAA template (including program learning outcomes)</td>
<td>Program specification using the ABET template (including program learning outcomes)</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Course specification using the NCAAA template</td>
<td>Syllabus and Course specification using the ABET template</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Descriptions of course and program requirements and regulations</td>
<td>Course Descriptions and program requirements and regulations</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Annual course and program reports using the NCAAA templates</td>
<td>Annual course and program reports using the ABET templates</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Summary report of student evaluation survey results</td>
<td>Summary report of student evaluation survey results and Attendance</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Students graduated, evaluations by the students are available</td>
<td>Students graduated, assessment by the students are available</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Program advisory committee</td>
<td>Program advisory committee</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Institutional approved KPIs and benchmarks with analysis</td>
<td>Institutional approved KPIs and benchmarks with analysis</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Consistency with NQF</td>
<td>Head of Dept final approval</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Self-evaluation scales are complete</td>
<td>Self-evaluation scales are complete</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>SSRP Self-Study Report for program</td>
<td>SSR Self-Study Report</td>
<td></td>
</tr>
</tbody>
</table>

Applicants are required to fill out the application for evaluation and pay a fee when applying for an assessment. ABET accreditation is not possible without ABET experts, so accreditation would not be possible without them. Government, academia, and professionals from the industry play an essential role in contributing to their field through ongoing improvements in quality engineering education [13]. ABET relies on experts to participate in accreditation decisions, visit campuses, and evaluate program materials in detail and provide the strengths and weaknesses as shown in Figure 3.
Program evaluators engage in hands-on work of accrediting thousands of programs at hundreds of institutions in different countries [10]. Evaluators identified to have strong leadership abilities which are promoted to the ranks of the commission and are responsible for serving and leading the teams. Thousands of dedicated STEM practitioners from the government, industry, and academia form the heart of peer-based accreditation services [11]. The experts are the face of ABET, representing the institution at campuses around the world. The technical professionals that give their time and expertise because they care about the quality of education and believe that the accreditation process enhances individual programs and enrollment of student using cohort analysis.

4. CONCLUSIONS

ABET accreditation has been embraced in several countries, and employers internationally recognize the value of ABET-accredited programs. Employers seek to find professionals equipped with the skills and knowledge and expect to handle complex problems. NCAAA was established in the KSA to determine criteria and standards for academic assessment and accreditation. The commission focuses on the quality assurance procedures of higher institutions and ensures that the management and quality of educational institutions are at par with the highest international standards. Engineering programs in the KSA are competing to attain the most internationally recognized accreditation systems. The accreditation process emphasizes students’ achievements and the quality of teaching measured through performance indicators in direct and indirect assessments related to students’ outcomes recorded in the Program Educational Objectives course portfolios, and other significant criteria.

5. CONFLICT OF INTEREST

The authors declares that we have no conflict of interest and the data availability upon the publication request.
6. REFERENCES


THEORETICAL STUDY ON INSTABILITY OF THE BASE SOLUTIONS OF LORENZ SYSTEM VIA ORDINARY DIFFERENTIAL EQUATIONS

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Abstract: The Lorenz system is well-known for producing chaotic solutions for a particular range of technical systems and process characteristics. To examine the instability, fluctuation parameters in the form of exponential functions are introduced to the base solutions of the ODEs, and numerical and computational methodologies are used to determine the range of values that cause instability under different conditions. This paper will focus on the Lorenz system's instability of Ordinary Differential Equations (ODE) that regulates the thermal-hydrodynamic behavior of a two-dimensional fluid layer which is equally warmed (distributed) from bottom to top.

The boundary layer of instability is also examined and compared with numerical and computational methods, and the accuracy of the solutions is thoroughly investigated. The study will give considerable insight into the requirements for stability of numerous technical systems such as DNA analysis, chemical reactors, thermostyphons, Malkus waterwheel, electric circuits, DC motors, pipelines, and power generation using micro as well as nanoscale techniques.

1. GENERAL BACKGROUND

The Lorenz system is a collection of ordinary differential equations (ODE) initially investigated by American mathematician and meteorologist Edward Lorenz and further developed by Ellen Fetter in advanced fluid mechanics. The system was first constructed using an estimation centered on the Oberbeck-Boussinesq approach, which is concerned with the connection between the Navier-Stokes equation and thermal convection1,2. The solution to the Lorenz set of equations is known to be chaotic3.

The butterfly effect is said to originate from the actual implications of the Lorenz system. This implies that without knowing the exact initial conditions (even the smallest air disturbance caused by a butterfly's wings flap), the chances of predicting the future course of the system are minimal4, as illustrated in Fig. 1. This suggests that physical systems could be utterly deterministic while being essentially unpredictable, even though quantum effects are not present.

Figure 1. Illustrations of the Lorenz system of ODEs' implications for the butterfly effect4.
The Lorenz System employs a novel method of calculating DNA called DNA Strand Displacement (DSD). This strategy has gained widespread acceptance and is being refined. It's employed in medical detection, computing, artificial intelligence, and biosensors. This method is quite favorable since it is isothermal enzyme-free, autonomous, the molecules assemble themselves, and operates on the Watson-Crick base pairing principle. Since it has a shorter prediction time, the hyper-chaotic system may be useful in secure communication, lasers, and encryption. The fluorophore's luminous intensity, rather than the DSD, is used to determine DNA concentration. According to Zou, digital circuits employ 1 and 0; DSD's output is 1 when the luminous intensity exceeds the threshold value and 0 when the power is less than the threshold value. The DNA strand's continuous concentration represents the values in the analog circuit. The DNA strand's concentration is used to express DSD analog signals, which can be positive or negative. The response rate of DSD may be changed generally by base number and sequence, as well as by remote toehold, although slightly. As a result of leakages and random reactions, the response cannot be controlled.

Cancer cell growth is regulated by MicroRNA (miRNA) molecules. Therefore, the detection of miRNA molecules at an early stage plays a significant in the diagnosis, treatment, and prevention of recurrence of certain illnesses. Northern blot analysis and microarray technology are detection methods used; however, they take a lot of time, need large samples, and are costly, generally limiting their application. Electrochemical biosensors, which are very affordable, aid in the detection of miRNA in blood and serum. They have a fast response time and are very sensitive, making them more effective than other approaches for the early detection of malignant cells. Even when the target molecules are in small concentrations, the SDR amplifies the signals and has remarkable target selectivity.

The biosensors contain multilayer two-dimensional (2D) materials, including transitional metal carbide and graphene oxide. These materials have improved the sensing field with their intrinsic benefits. Molybdenum carbide, a transition metal carbide nanomaterial, is utilized as a catalyst and a semiconductor due to its affordability, high resistance to mechanical forces, and excellent electrical conductivity. However, the high-temperature sintering process significantly impacts the large-scale manufacturing process, resulting in the absence of functional groups in the finished product. As a result, their use has been severely constrained. N-Carboxymethyl chitosan (NCS), which has outstanding features such as a high amine group and biocompatibility, is utilized as supporting material in conjunction with molybdenum carbide to increase the biosensor's responsiveness and stability. The pair has a large number of functional groups that might mobilize DNA molecules as well as other biomolecules to improve stability and dispersion in an aqueous form. This was initially utilized in the miRNA detection by biosensors, and it exhibited remarkable selectivity, excellent recovery rates, and a low detection limit.

2. GOVERNING EQUATIONS AND BASE SOLUTIONS

As illustrated in Eq. (1) below, the Lorenz system comprises three ordinary differential equations, generally known as the Lorenz equations.

\[
\begin{align*}
\frac{dX}{dt} &= -PX + PY \\
\frac{dY}{dt} &= -Y + rX - XZ \\
\frac{dZ}{dt} &= bZ + XY
\end{align*}
\]

Where P, r, and b are parametric constants associated with the Prandtl number, Rayleigh number, and layer properties, respectively. Additionally, X, Y, and Z are directly proportional to the rate of convection, horizontal temperature change, and vertical temperature fluctuation, respectively. Thus, the Lorenz system's solution may be obtained in the stable condition by equating the left-hand side of Eq.
(1) to zero. These are referred to as "base solutions," and they are described in Eq. (2) below, with the assumption \( r > 1 \).

\[
\begin{align*}
X_s &= Y_s = Z_s = 0 \quad \text{(a)} \\
X_s &= Y_s = \sqrt{r-1}, \ Z_s = r - 1 \quad \text{(b)} \\
X_s &= Y_s = -\sqrt{r-1}, \ Z_s = r - 1 \quad \text{(c)}
\end{align*}
\]  

(2)

3. METHODOLOGY FOR INSTABILITY ANALYSIS

3.1. Perturbation Terms

For the Lorenz equation's instability analysis, perturbation terms are included in the base solutions, i.e., Eq (2), and the resulting equations are then substituted into Eq. (1). This will offer the essential equations guiding the instability caused by the perturbations. With the assumption of linear stability, higher-order elements are eliminated from the final equations. Eq. (3) illustrates the answers by including the perturbation terms.

\[
x(t) = X_s(t) + X_0 \exp(\sigma t) \\
y(t) = Y_s(t) + Y_0 \exp(\sigma t) \\
z(t) = Z_s(t) + Z_0 \exp(\sigma t)
\]  

(3)

Substitution of Eq. (3) into Eq. (1) yields Eq (4).

\[
-(\sigma + P)X_0 + PY_0 = 0 \\
(r - Z_s)X_0 - (\sigma + 1)X_sZ_0 = 0 \\
Y_sX_0 - Y_0Y_s - (\sigma + 1)Z_0 = 0
\]  

(4)

To find the solution of Eq. (4), we equate the determinant of Eq (4). This is illustrated in Eq (5) below;

\[
\begin{vmatrix}
-\sigma - P & P & 0 \\
r - Z_s & -\sigma - 1 & -X_s \\
Y_s & X_s & -\sigma - 1
\end{vmatrix} = 0
\]  

(5)

When the determinant is solved, it yields a 3rd order algebraic equation.

\[
\sigma^3 + \sigma^2(P+2) + \sigma(P+r) + 2P(r-1) = 0
\]  

(6)

3.2. Analytical vs. Computational Approaches

Since the coefficients of Eq. (6) are positive, assuming \( r > 1 \) and \( P > 0 \), there are two possible solutions;

i. The system is stable because the equation has three real negative roots,

ii. The system exhibit instability since there are one real negative and two complex roots in the equation. If the real components of the complex solution are positive, the perturbations will rise exponentially with time, resulting in instability.

Through analytical technique, the real components of the complicated solution would be positive if the following condition is met:
Proceedings of the 2021 IEMS Conference

\[ A = r(P - 2) - P(P + 4) > 0 \quad (7) \]

Noting that Eq. (7) is an inequality, its instability would never exist if \( P = 2 \). Generally, the instability would emerge for the non-stationary base solutions, i.e., Eq. (2) (b)-(c), if the requirements indicated in Eq. (8) are met.

\[
\begin{align*}
  r &> 1 \\
  r &> \frac{P(P + 4)}{P - 2} \\
  P &> 2
\end{align*}
\quad (8)
\]

The study used contour analysis of Eq. (7) with \( r \) and \( P \) as independent variables to study the instability of the Lorenz system analytically. Some trials and errors may be used to determine the suitable ranges of \( r \) and \( P \), as well as the mesh generation method. In the following stage, the average of the two complex roots of Eq. (6) \( (Z1)'s \) contours are plotted using the same mesh formed in the analytical technique, the values of \( r \) and \( P \) would be fed into Eq. (6) as input, and the SOLVE built-in function in MATLAB. \( Z1 \) may be a real number with no imaginary element because the complex roots are conjugate. Finally, the contours of \( Z1 \) were drawn as a function of \( r \) and \( P \).

4. RESULTS AND DISCUSSION

The findings of the computation and analytical approaches to instability analysis are shown in Fig. 2. It depicts the contours of \( A = r(P - 2) - P(P + 4) \), that is, the analytical solution, as a function of \( r \) and \( P \). The contours of \( Z1 \), i.e., the average of the complex roots of Eq. (6), as a function of \( r \) and \( P \), are shown in Fig. 3. The contour plot's limit of instability, i.e., \( \text{LEVEL} = 0 \), is the most notable conclusion of these figures. We have also identified four specific points on \( \text{LEVEL} = 0 \) contours. The X-axis value represents \( r \), and the Y-axis value represents \( P \) at these places. The accuracy of the solution was further validated since the values of representative points in both analytical and computational methods were similar. It should also be noted that the right-hand side section of the \( \text{LEVEL} = 0 \) contours in both pictures represents conditions that contribute to instability, while the left-hand side region is related to stable situations. It should be observed that the contours related to \( \text{LEVEL} 0 \) do not appear for \( r \) and \( P \) that are identical. The explanation for this is because \( A \) and \( Z \) are fundamentally different. The most important factor is the exact and identical forecast of the limit of instability. A detailed examination of the contours or some simple mathematical computations reveals that the Lorenz system is always stable for \( P < 2 \) and \( r < 15 \). This method may be used for DNA analysis as well as other biological and nanoscale material research.
Figure 2. \( A = r(P-2) - P(P+4) \) (Eq. 7) ’s analytical contours as a function of \( r \) and \( P \). The instability border, i.e., Level = 0, has also been shown, along with several points representing the corresponding \( r \) and \( P \) at the instability boundary.

Figure 3. the \( Z_1 \)'s computational contours, which is the average of the real components of the imaginary roots as a function of \( r \) and \( P \). The instability border, i.e., Level = 0, has also been shown, along with several points representing the corresponding \( r \) and \( P \) at the instability border.

5. CONCLUSION

This study explored the circumstances that contribute to the Lorenz system of ODEs' instability. Perturbation terms were added to the base solutions of the Lorenz set of ODEs for this purpose and solved the ODEs to discover the 3rd order algebraic equation. The equation was then solved analytically and computationally to determine the instability boundary. It was found that instability happens when the perturbation terms rise exponentially with time. The comparison of the contours of both computational and analytical solutions and a few representative points values disclosed the circumstances that lead to instability, hence validating the system's solution. The findings further revealed that the Lorenz system is
always stable for $P<2$ and $r<15$. By identifying the circumstances prone to instability, this study gives insight into the design and optimization of the micro and nanoscale engineering systems.

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7. **REFERENCES**


Abstract: Architectural advancements in housing are limited by traditional construction techniques. Construction 3D printing introduces freedom in design that can lead to improvements in building design, resource efficiency, and cost. Designs for current construction 3D printers have limited build volume and, at the scale needed for printing houses, transportation and setup could become issues. This work is an exploration of and proposal for a swarm robotics-based construction 3D printing system that could bypass these issues. In this system, a central computer will coordinate the movement and actions of a swarm of robots which are each capable of extruding concrete in a programmable path and navigating on both the ground and the structure. The central computer will create paths for each robot to follow by processing the G-code obtained from slicing a CAD model of the intended structure. The robots will use readings from real-time kinematics (RTK) modules to keep themselves on their designated paths. The current progress in hardware and software is available on GitHub for collaborative development of this proposed approach towards construction.

1. INTRODUCTION

Traditional concrete construction is costly, has substantial environmental impact, and limits freedom in design (Ford, 2017) (The Trustees of Princeton University, n.d.). In traditional concrete construction, workers use special molds called forms to shape concrete. Over a third of the construction cost of a concrete house stems from the formwork alone (Ford, 2017). Concrete manufacturing and construction are responsible for 8% of CO2 emissions, which amounts to over 4 billion tons of emitted CO2 gas annually (The Trustees of Princeton University, n.d.). Traditional construction tends to use more concrete than necessary, and this stems from the fact that formwork construction requires walls, floors, and beams to be solid. Architects can design structurally optimized buildings that use less concrete, but since the price of formwork increases with complexity, these buildings cannot be built in a cost-effective manner.

Concrete 3D printing has the potential to reduce cost and lower the environmental impact of construction (Schutter et al., 2018). A great deal of research needs to be done before high-quality 3D printed concrete structures can successfully compete in the consumer market. Many researchers are already trying to improve the rheological properties of 3D printed concrete. Another side of the problem that needs to be solved is 3D printer design. Most concrete 3D printers in development are gantry-based and have limited build volumes. As such, larger prints need larger printers. This introduces issues with wobbling and transportation. These issues limit the real-world applications of concrete 3D printers.

2. LITERATURE REVIEW/CURRENT SOLUTION

Aiming to solve the aforementioned issues with current construction 3D printing techniques, a team from the Singapore Center for 3D Printing used multiple autonomous robots with arm-based attachments...
to successfully print a portion of a wall (Zhang et al., 2018). Their work proved that coordination between multiple robots to print a structure is possible. The robots in their design were tethered and confined to the ground, which limited their mobility. Along these lines, the Minibuilders system uses a team of three tethered robots to build a structure. Each robot has a different design and task: one lays the foundation, the second builds up a cylindrical wall, and the third scales those walls to reinforce the structure. Their design demonstrates that it is possible to print using robots that navigate on the structure being printed. However, their robots use tethers, which limited their navigational range. Also, the design of the robots does not allow for the printing of infill patterns ([Minibuilders website], n.d.). Other approaches involve moving around an arm-based robot in an attempt to get past the limited reach of the arm (Chandler | MIT News Office, 2017) ([Apis Cor website], n.d.). However, these approaches still have limited reach in the vertical z-axis.

3. SYSTEM OVERVIEW

The proposed construction system will consist of (1) a swarm of highly maneuverable robots and (2) a system for coordinating those robots using RTK navigation and processed G-code. Having a swarm of mobile 3D printing robots would bypass the problems with limited build volume and scalability that stand in the way of most concrete 3D printer designs. Also, using multiple robots would speed up the fabrication process. The size of the swarm can be scaled according to the size of the project. If one construction site needs a larger workforce, more robots can be deployed and incorporated into the swarm. The feasibility of concrete mixtures with rheological properties tailored to construction 3D printing (e.g., fast setting, low warping) have already been demonstrated (Zhang et al., 2019). There is also research on incorporating fibers directly into 3D printed concrete to increase the strength and printability of the concrete (Pham, Tran, & Sanjayan, 2020). The proposed system will leverage these developed materials, or other materials like polyurethane foam, to print structures.

3.1. The Robot

The proposed robots will be completely untethered and will have an onboard battery and concrete storage tank, as illustrated in Figure 1. This design allows the robots to travel farther and build larger structures than gantry or arm style printers. Refilling and recharging will be done at a central station that robots can navigate to after depositing their supply of concrete mixture or when battery runs low. This design enables the robots to build complicated infill structures into the walls, as shown in Figures 2E–F. Each robot can complete the full set of tasks necessary to construct a building and can do so without tethers or division of work among multiple types of robots. These robots will have a high degree of mobility because they are untethered and can move up and around the structures that they are printing, as demonstrated conceptually in Figures 2A–D. Estimations show that, if each robot will carry 5 liters of concrete, which will be extruded as a 50m long line with a cross-sectional area of 1cm², it will take a team of 50 robots 25 refill trips apiece to print the 15cm thick outside walls of a 170m² (1500 ft²) single story house to a height of 3m with a 20% infill pattern. If the robots extrude concrete at a rate of 1L/min, this process will take around 2 hours.
Each position is described in more detail below:

A. The robot will begin by printing the first few layers of the structure on the ground. It will orient its wheels to drive along the ground and can alter the height of its print head by changing the angle of the arms. Steering will be done by changing the yaw of the arms.

B. After printing the first few layers, the robot clamps onto the printed structure and tilts its wheels to drive up onto the wall.

C. When the robot needs to climb onto a wall, it sweeps two of its arms forward to engage with the wall or a specially printed “climbing rail” and pull itself into position D.

D. The robot uses its arms to grip and climb up the side of a wall or climbing rail.

E. The robot can control the path of extrusion by manipulating the yaw of each of its arms. This allows the robot to print complicated infill patterns and paths.

F. The robot can manipulate its arms to print curves and corners.

3.2. Navigating using RTK and processed G-code

To coordinate the swarm, a central computer will create paths for the robots by modifying the G-code obtained by slicing the STL file of the structure that needs to be built. G-code is a CNC language that tells the toolhead of the CNC machine to move to a sequence of points on a Cartesian coordinate system and to perform certain actions at or between points. A custom workspace was set up in Ultimaker Cura, a slicer program commonly used for 3D printing. This workspace has a build volume and nozzle diameter...
renamed to the scale needed to print architectural structures.

The slicer provides the G-code needed to print out the structure. To navigate to the points specified in the G-code, the robot compares its current position with the planned path obtained by processing the G-code and maneuvers itself to stay on that path in a closed feedback loop.

To obtain an accurate enough reading of its position, the robot has a real-time navigation (RTK) chip on board. RTK is an application of the Global Navigational Satellites System (GNSS) that compares the positional readings of a designated “rover” unit to those of a designated “base station” unit. Any fluctuations in the readings obtained by the base station are known to be errors. This data is transmitted to the rover unit in an RTCM data stream and is used to calibrate the readings of the rover chip to obtain locational data with centimeter accuracy and sub-millimeter precision. The robot then uses a set of algorithms to move and print in accordance with those commands.

4. ROBOT DESIGN

A prototype of the proposed robot design, named Minim mk2, is shown in Figure 3. The main frame of the robot is designed with 15mm aluminum extrusions that are compatible with M3 hardware. All the brackets used to hold the robot together are 3D printed and designed in CAD. The files for the robot model and for all the 3D printable brackets are available in GitHub. This method of robot design simplifies building, redesigning, and adding onto the robot.

Each of the 4 arms on the robot is a kinematic chain formed from 3 servos: yaw, elbow, and camber (ordered by increasing distance from chassis). At the tip of each arm is a wheel driven by a stepper motor that allows the robot to move. Note that the concrete dispensing system and battery have not been implemented on the Minim mk2 prototype shown in Figure 3.

![Figure 3. Minim mk2, the current prototype of the robot](image)

4.1. Electronics

**Actuators:** The robot design follows the CAD model in Figure 1. Commands will be sent from a PC wirelessly to the ESP32 board, which acts as the brains of the robot. In the end product, power will be supplied by an onboard battery, but testing was done using a desktop power supply. The 12 servos in the robot will be controlled using a PCA9685 servo controller, as shown in Figure 4. Each arm will have a 600 N·cm servo that controls the yaw of the arm, as well as two 350 N·cm servos that control the pitch of the arm and the camber of the wheel. Using servos will allow the arms to be precisely positioned, and the
arrangement allows for even distribution of torque. The stepper motors that actuate the wheels will be controlled using DRV9985 stepper controllers as seen in Figure 5. The ESP32 board has 34 general-purpose input/output pins that allow electronic components to interface with the ESP32 chip. The PCA9685 and DRV9985 each use two pins, so there is room to add more electronics during future development.

Navigation system: To track the location of the robot for coordination purposes, the robot will use two ZED-F9P RTK modules — one connected to the PC acting as the base station and another on the robot in rover configuration, as shown in Figure 6. The RTCM correction data from the base station will be sent to the board on the robot using a serial telemetry radio kit (Seidle, n.d.). The corrected UBX location data from the rover will be sent back to the base station and PC using the same radio link where it will be read and displayed using u-center, a GNSS evaluation software. The orientation of the robot will be found using the built-in gyroscope on the ESP32 board.
5. **BotCode**

The robot will receive commands via a custom coding language named “BotCode.” BotCode will be based on G-code, as most of the commands needed for printing using this system are coordinate-based commands that closely resemble the G1 commands in G-code. G-code itself is not well suited for use in this system, as it contains hundreds of functions, many of which perform niche tasks. It also lacks functions that are vital for the operation of the robot (e.g., commands to climb walls or refuel). BotCode also needs to differentiate between printing on the ground, wall, or corners.

For the robot to print a structure, the central computer will first need to convert the CAD model of said structure into BotCode using the process outlined in Figure 7. Since the robot uses the same Cartesian coordinate system as G-code, the preliminary processing is done using Ultimaker Cura, which slices the CAD model into G-code [1]. Secondly a DXF file, derived from the CAD model, [2] will mark out the walls, corners, and climbing rails that will be used to path the robot. This will be especially important for coordinating multiple robots. After slicing the CAD model, the resulting G-code is converted to BotCode in a spreadsheet as seen in Figure 8. The spreadsheet enables the processing of G-code files that are tens of thousands of lines long.

![Figure 7. Flowchart illustrating CAD model to BotCode to robot movement](image)

The converter first removes code specific to 3D printers (e.g., nozzle and bed heating) [3] and adds...
the initialization code [4] needed by the robot. This includes "zeroing" the robot by setting the global position of the base station RTK receiver as the local origin which corresponds to the G-code command G92 X0 Y0 Z0 E0. Next, the robot finds its local Cartesian position by subtracting the global position of the origin from its own global position. Since G-code and, by extension BotCode, follows a Cartesian positioning system, the position and orientation of the robot can be used to check and correct its path. After this, the converter searches the G-code for commands within a certain radius of the corners, which are marked in the DXF file [5]. The robot then begins construction by printing along the ground ("ground mode") and will climb onto the printed structures to build higher ("wall mode"). A particular command will be used to notify the robot to switch from ground mode to wall mode when a change in z-position is required [6]. After this, the remaining G-code commands are split between commands occurring on the ground and those occurring on a wall before being converted into BotCode [7]. Using the DXF file, the converter calculates a path to return the robot to the base station for recharging [8].

To send BotCode commands from the computer to the robot [9], the SerialToSerialBT Arduino sketch will be used. Much like G-code, BotCode gives the robot directions on where to go, but it does not tell the robot how to turn its motors. To calculate this, the ESP32 will be hard coded to algorithmically decompose BotCode commands using the Arduino IDE [10].

### 6. INVERSE KINEMATICS

The robot needs to maneuver itself along the set of points given by the BotCode; this will be calculated using closed-form inverse kinematics. All variables referenced in the calculations below are visualized in Figure 9. To start, the bot must find its “extrude center” — the point that the bot prints from. The x-coordinate $h$ and the y-coordinate $k$ of the extrude center is defined with

\[
    h = r_x + r \cos (\theta + d) \\
    k = r_y + r \sin (\theta + d)
\]

where $(r_x, r_y)$ is the position (latitude and longitude) returned by the RTK module. This is offset by the distance $r$ between the RTK and the extrude center, multiplied by the corresponding trigonometric function of the heading, and offset by the angle $d$ to the extrude center from the RTK. From this, it is
possible to calculate the corner \((cx, cy)\) where the motors are attached.

\[
c_x = h \pm \frac{s}{2}
\]

\[
c_y = k \pm \frac{s}{2}
\]

The position of the corner is calculated by adding half of the side length of the robot \(s\) to the location of the extrude center (when on the left side or bottom, this is subtracted instead). Next, the location \((wx, wy)\) where the wheel should be positioned is calculated

\[
w_x = \frac{(w_l - t)}{2}
\]

\[
w_y = c_y \pm \sqrt{l^2 - (w_x - c_x)^2}
\]

where \(w_l\) is the thickness of the wall plus the diameter of the wheels, and \(t\) is the amount of extra arm movement needed by the robot to provide the force necessary to securely grip the wall. The \(y\)-position of the wheels is found via the Pythagorean theorem. Given the length of the arm \(l\) and the \(x\)-position it should be at, it is possible to calculate the \(y\)-position of the wheel. Finally, the yaw angle of the arm is derived.

\[
y_{aw} = \tan^{-1}\left(\frac{w_y - c_y}{w_x - c_x}\right) + 90 \pm 90 \text{ mod } 360^\circ
\]

By taking the arctan of the intended slope of the arm, the angle is calculated. This value is modified to accurately output the yaw value — \(90^\circ\) is added or subtracted based on if the arms are to the left or right of the robot. The yaw is returned modulo 360 so as to fall within the range of movement of the motor.

![Figure 9. Comparison of the mathematical model and the robot at corresponding positions](image)

7. TESTING

With the prototype, servos and stepper motors were tested using an Arduino Uno because the slow upload time when using the ESP32 hindered the testing process. First, individual actuators were tested using the Arduino. The actuators all worked, and code was written that allowed the arms of the robot to
be precisely positioned and maneuvered (found on GitHub). The robot was weighed, and estimates were
made that took into account the torque of the motors and the load that they would experience. These
estimates confirmed that the actuators could bear the weight of the robot.

The process described for converting the CAD model of the intended structure to BotCode explained
in section 5 proved successful. The custom workspace created in Ultimaker Cura worked in processing
large, construction-scale projects. The converter spreadsheet was capable of converting G-code taken
from the slicer program into BotCode. It successfully filtered out unnecessary parts of the G-code and
turned the rest to BotCode.

8. CONCLUSIONS

A proposed system for concrete 3D-printing was designed. This system consisted of (a) a swarm of
highly maneuverable robots and (b) a system for coordinating those robots using real-time kinematics
navigation and processed G-code. This is a novel approach to robotic navigation that opens up possibilities
in large-scale construction and coordination using preexisting software infrastructure designed for CNC
machines. Using positional readings in conjunction with traditional CNC software allows for navigation
of autonomous robots that have a broader range of navigation than gantry based or fixed-arm construction
3D printers.

To fully demonstrate the feasibility, there remains a list of tasks that need to be executed in both build
and code. The first step is to get the current prototype fully moving. Then the concrete dispenser and
navigation systems need to be added. After this is done, the anti-collision and pathing software will need
to be implemented in order to coordinate a swarm of these robots.

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Abstract: Non-small cell lung cancer (NSCLC) results in over 1.8 million deaths worldwide every year; however, most of these deaths are preventable via early diagnosis, which reduces the mortality rate by more than 50%. Currently, physicians use a CT (Computed Tomography) scan as a preliminary method of identifying cancerous tumors. Unfortunately, this visual process of identifying NSCLC scans becomes time-consuming and inaccurate, leading to high misdiagnosis rates. The goal of this project is to create a cloud-based web application that can take an inputted CT scan and identify regions of potentially cancerous tumors at an accuracy >90%. This is accomplished by first standardizing all inputted scans to a standard size and range of pixel values. A 3D CNN is then trained to classify an inputted scan as either “positive” or “negative” for cancer. Class Activation Mapping (CAM) is then used on scans classified as “positive” in order to identify the location(s) of cancerous tumors. This algorithm core is accessed through a cloud-based user interface on AWS allowing physicians to upload and organize their patient's NSCLC scans as well as receive dynamic results based on patient biometric and cancer history background. Using the LungStat platform, an oncologist can simplify the procedure for lung cancer diagnosis by cutting down the average tumor identification time from about 1 hour to a few minutes. Overall, this project establishes a critical tool needed for the accurate diagnosis and treatment of NSCLC, leading to a severe reduction in the death rates caused by lung cancer.

1. INTRODUCTION AND BACKGROUND

NSCLC is a type of cancer emerging from the inner tracts of the lungs, damaging the airways of the patient and creating long term impacts on oxygen flow systems. This type of lung cancer results in about nearly 3 million deaths globally each year (WHO, n.d.). While NSCLC is traditionally more prominent among smokers, the emergence of more pollutants in the air has caused non-smoker NSCLC rates to match that of the smoking population (Pope et al., 2002). Within the US more specifically, the rise of lung cancer within non-smokers has been startling with growing from 8% of total cases from 1990-1995 to 14.9% of all cases from 2011-2013 (Pelosof et al., 2017). Regardless, the case rate for the general population still continues to rise with more than 200,000 new cases expected in just 2021 within the US (American Cancer Society, 2021). As a direct response to this dramatic increase in overall cases, the US Preventive Services Task Force has increased its recommendation namely for smokers from the ages of 50 to 80 to take an annual CT scan to screen for lung cancer tumors, thus placing the new importance of screening in the spotlight of the medical field.

Unfortunately, a large part of the issue with NSCLC is a lack of effective early diagnosis. Patients diagnosed within the early stages of lung cancer (stages I and II) have a 5-year survival rate of more than 60%; however, this drops down to less than 10% in later stages of cancerous growth, indicating that early detection and diagnosis of NSCLC tumors is essential to maximizing a patient's chance of recovery (Willow, 2020). Due to a lack of specific diagnosis in the early stages, more than 75% of patients are not
aware of the extent of the cancerous growth until a point past potentially curative surgical resection (stages III and IV) (Birring, 2005). Additionally, due to a considerable time cost associated with checking each scan, physician fatigue is spread throughout the NSCLC diagnosis process. As a result of these issues, the diagnosis process is riddled with high false-negative, false-positive, and overdiagnosis rates, leading to only 85-92% of NSCLC cases being accurately diagnosed by a physician (Pinsky, 2014). Thus, new methods and tools of detection are desperately needed to improve the effectiveness and efficiency of NSCLC diagnosis.

Current lung cancer treatments are based on location-specific radiation therapy (for targeting metastases) and chemotherapy to address the overall distribution of cancerous tumors. However, the reason for high mortality with NSCLC lies in the inability to diagnose cancer early and efficiently. 91% of NSCLC diagnosis takes place in the 3rd and 4th stages of the disease. In addition, physicians and other hospital staff must often spend hours (if not days) analyzing the scans for a single patient, leading to physician fatigue. This fact, when combined with the sharp reduction in NSCLC survival rates for patients diagnosed in the later stages (~70% survival when detected in early stages vs. ~25% survival when detected in later stages), indicates that there is significant room for improvement in the NSCLC detection procedure. The detection methodology in analyzing CT scans for tumors has a high prevalence of misdiagnosis and missed tumors, with the current aggregate rate of misdiagnosis at almost 40% (Svoboda, 2020). This project aims to reduce the mortality rate of NSCLC by improving the NSCLC diagnosis procedure via the development of a deep-learning-based software to diagnose NSCLC tumors efficiently and effectively.

Thus, this project aims to help improve the effectiveness and efficiency of the NSCLC diagnosis process by using Machine Learning algorithms to aid physicians in identifying the locations of lung cancer tumors.

2. MACHINE-LEARNING CORE

The Machine Learning section of this project uses the 3D CNN (Convolutional Neural Network) architecture to create a classification model that can accurately identify if a given CT scan has a cancerous tumor present. The backend then utilizes Class Activation Maps in order to determine the regions of the scan that most “excited” the CNN and thus identify the areas of the scan that are likely to contain cancerous tumors.

The classification 3D CNN was trained on the LIDC-IDRI dataset, which includes nearly 1300 full CT scans from over 1000 patients (TCIA, n.d.). However, these scans vary in size and range of pixel values. In order to better standardize the dataset and make it easier for the model to analyze a given scan, a preprocessing script for CT scans was developed. This script takes a given scan and standardizes its size to a 128 by 128 by 128 cube. Depending on the CT scanner used to take the scan, different scans may have different ranges of pixel values; thus, in order to minimize the variance in the dataset and ensure a more accurate end model, scans are then converted from their original values to Hounsfield units of radioactivity, which will have the same range of values regardless of the initial pixel values.

Once the input data had been preprocessed and stored, it was iterated through in 100 epochs. Each epoch trained the model on a randomly selected 70% of the data and “validated” the model on 20% of the data. 10% of the data was withheld from the model entirely to create a completely new set of data upon which to test the model. The model architecture consisted of several Convolution, MaxPooling, and Batch Normalization layers followed by Global Average Pooling and Fully Connected Layers.
Once the classification network had been trained, a Grad-CAM-based CAM class was developed to detect the regions of highest activation once the model had run on a particular scan. A visualization class was then created to visualize the class maps, the inputted scans, and the overlays of the class maps on the input scans. Using the trained model, the region(s) of highest activation are marked as regions that may contain tumors and displayed through the LungStat Diagnostic Application.

3. **DIAGNOSTIC APPLICATION**

While previous research has developed a computer vision alternative to the current method of visual identification, the implementation into a clinical setting has been limited with the difficulty of transferring this software into an easy-to-use application. The user interface of the LungStat application aims to complete this task of moving the functionality of the machine-learning algorithm core into a physician-friendly web application.

The development of the LungStat user interface took place over several iterations involving creating an accessible frontend, proper data management, and an efficient structure that could support a large number of queries at a given time. More specifically, the parameters for the created hosting application around the ML algorithm were to remain scalable for individual users without administrative involvement, efficient with a runtime under 3 minutes, and be subjectively simple for physicians to integrate into a standard lung cancer diagnosis. Based on these parameters, the best solution was creating a cloud-based web application using AWS for hosting and data management based on these parameters.

The frontend of the application was created using the React.js framework that allowed quick customization of the UI while maintaining the ability to pull from multiple libraries for stylistic components. The web application structure involved an opening and informational page about LungStat as well as a user-specific section with the physician dashboard, patient entry, and settings pages, all shown in the figure below.
On the backend, AWS Cognito tied with DynamoDB tables were used to set up individual physician accounts and store scans associated along with other patient data. Additionally, AWS S3 buckets were used to store the user-entered scans in ZIP format, thus reducing the direct impact on the backend processing limit. Finally, for the processing and location of the ML algorithm core, AWS Lambda Functions were put into use. Instead of a traditional EC2 instance that would keep the ML algorithm running and ready for processing, the Lambda function instead stores an image of how to boot up the algorithm. At the same time, the majority of the code is hosted within a separate S3 bucket. Overall, the entirety of the application proved effective as a demonstration of serverless architecture, which allows this algorithm to be easily scaled up without significant hits to processing time.

4. RESULTS AND DISCUSSION

The usage of this application within a clinical setting effectively reduces issues associated with the current NSCLC diagnosis. With the LungStat application, the patient’s traditional process is changed so that when they enter a hospital and a CT scan is taken, the imaging result is uploaded onto the LungStat website, returning a detailed report on the presence and locations of cancerous tumors. This simple change compared to the time-intensive and inaccurate process of visually identifying each of the tumors in the body ensures the reduction of physician fatigue in hundreds of cases each year. As a future step, physicians can recommend a treatment plan based on their own examination of available imaging, thus ensuring that any clinical plans are mapped to the severity and location of all tumors in the body. The high accuracy of 94% and low runtime of 3 minutes throughout this process instead of the alternative of visual inspection at a low accuracy proves beneficial for patient health outcomes with early detection. Additionally, the unique approach of combining the most effective parts of both the current physician process with AI detection ensures the best diagnosis.

Figure 3: Classification CNN Model Accuracies by Epoch

The usage of this application within a clinical setting effectively reduces issues associated with the current NSCLC diagnosis. With the LungStat application, the patient’s traditional process is changed so that when they enter a hospital and a CT scan is taken, the imaging result is uploaded onto the LungStat website, returning a detailed report on the presence and locations of cancerous tumors. This simple change compared to the time-intensive and inaccurate process of visually identifying each of the tumors in the body ensures the reduction of physician fatigue in hundreds of cases each year. As a future step, physicians can recommend a treatment plan based on their own examination of available imaging, thus ensuring that any clinical plans are mapped to the severity and location of all tumors in the body. The high accuracy of 94% and low runtime of 3 minutes throughout this process instead of the alternative of visual inspection at a low accuracy proves beneficial for patient health outcomes with early detection. Additionally, the unique approach of combining the most effective parts of both the current physician process with AI detection ensures the best diagnosis.

Figure 4: Visualizations of CAM and Final Software Outputs
In the future, the following steps are to expand the capabilities of the machine learning algorithm for tumor detection and optimize this software for physician implementation. While the current 3D CNN in conjunction with CAM can identify the location of the tumor, it falls short of pinpointing the exact boundaries of tumors; thus, for this feature, we plan on supplementing our current model with a 3D Mask RCNN tumor mapping algorithm that can locate the edges of the tumor, ensuring the utmost precision of any diagnostic interpretation. Expanding the current dataset would additionally prove beneficial for the current accuracy of the machine learning algorithm, leading to a more comprehensive report given to the physicians. On the application side, the goals are to expand the ease of integrating this software into a clinical setting through the iterative development of features and user experience. By optimizing the LungStat application to the needs of hospitals and physicians through in-hospital testing, this technology would be much more accessible to patients around the country.

![Figure 5: Dataflow for the LungStat Software](image)

5. REFERENCES


A BRAIN COMPUTER INTERFACE SYSTEM FOR THE IMPROVEMENT OF COGNITIVE AND COMMUNICATION ABILITIES FOR PATIENTS WITH NEUROMUSCULAR DISORDERS

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Abstract: More than 16 million people in the United States are living with cognitive impairment. Reports suggest that 12,000-15,000 people have amyotrophic lateral sclerosis and approximately 17 million people have cerebral palsy, globally. The engineering goals are (i) to design an experimental study to analyze and improve cognitive performance and (ii) to develop a communication aid to support people with neuromuscular disorders using non-invasive brain-computer interface. A low-cost EEG device, Emotiv EPOC+ is used to record EEG data and a Python interface is used to stream the data for analysis. The features extracted are used to train the classifier, Linear Discriminant Analysis. The participants’ cognitive performances were measured initially and after giving 20 days of feedback sessions with alpha-numeric speller. The performances were in the range of 76%-81% initially and accuracy improved for all the participants and are in the range of 84%-89.3% after feedback sessions. The proposed feedback training design is an excellent way to improve cognitive abilities and can be used for healthy individuals as well as people with attention deficiency to improve their attention. A software application is developed to use the system as a communication aid for neuromuscular disorder patients who are unable to communicate. The accuracy in identifying the words of participants’ choice are measured only using their brain activity. The communication aid was able to predict more than 91% of the words correctly. The system is low-cost and easy-to-use with a short setup time regardless of users’ expertise.

1. INTRODUCTION

Cognitive impairment is not limited to a particular age group and it is not caused by any one disease or condition alone. Alzheimer’s disease, other dementias or conditions such as strokes, brain injuries, and developmental disabilities, can cause cognitive impairment (CDC Report, 2010). Reports suggest that 12,000 to 15,000 people in the United States have amyotrophic lateral sclerosis (ALS) and approximately 17 million people have cerebral palsy, globally. Brain computer interface (BCI) is an emerging technology that can help the lives of these people. BCI monitors brain signals, extracts relevant features, and converts them into outputs that replace or improve human cognitive abilities. BCI has the capability to improve cognitive performance in healthy individuals as well as to replace or restore important functions to people disabled by neuromuscular disorders such as ALS, cerebral palsy, strokes, or spinal cord injuries. To study the activities of the brain, electrical activities of neurons are monitored through electroencephalogram (EEG). It can be measured either by invasive or noninvasive methods. One of the techniques to study the brain activity is to stimulate it by presenting a paradigm. The P300 event related potential embedded within the EEG signals can be used to analyze, improve and communicate human thinking. The P300 signal is seen in the EEG signals as a rapid single potential change in response to a sensory, cognitive, or motor event. The signal's peak appears at an average of 300 milliseconds after the stimulus. The detection of the P300 signals require the subject to correctly recognize the stimulus event to generate a strong and
observable P300 (Haider et al., 2017).

The engineering goals of this project are (i) to design an experimental study to analyze and improve cognitive performance and also (ii) to develop a communication aid to support people with neuromuscular disorders using non-invasive BCI.

1.1. Research

Various studies have been done to improve the cognitive abilities, and the use of computer-based training programs are of growing interest in recent years. Computerized interventions are low-cost and can be exercised from anywhere as compared to traditional face-to-face training programs (Kueider et al., 2012). Previous studies include a user-friendly BCI based cognitive training system targeted to healthy elderly which showed promising results in improving memory and attention (Lee et al., 2013). Other studies show that it is possible to influence the brain waves (theta, alpha, beta and gamma) to improve attention, memory, motor skills and mood (Gruzelier, 2013). Another study shows that substantial improvement in the response time in young adults after providing neurofeedback training and hence suggests that neurofeedback training is a promising tool for improving attention mainly for those who are at risk of attention deficiency (Arvaneh et al., 2018).

Patients with motor disabilities caused by stroke, or by neurodegenerative diseases such as ALS are conscious and alert but are unable to use their muscles, significantly disabling communication, even by writing. Birbaumer et al. developed a communication system for patients with ALS that employed an electronic spelling device in which letters were presented on a screen. The letter selection is slow, but it is reliable and precise enough to allow patients to communicate (Birbaumer et al., 2003).

P300 is a positive deflection in the EEG signal which occurs around 300 ms after the appearance of the target stimulus. P300 potential (evoked by a target stimulus) is distinguishable from the samples synchronized with frequently ignored non-target stimuli. The P300 potentials reflect peaking signal patterns observed to occur around 300ms after the appearance of visual stimulus. P300 is very useful in assessing cognitive function. Human attention, memory performance and error awareness are largely dependent on the amplitude, latency and energy of P300 signal. According to previous studies, shorter P300 latency and larger amplitudes are associated with higher cognitive performance (Polich, 2007).

2. MATERIALS AND METHODS

The EEG data is collected from 4 subjects aged 16 – 57 years over 20 days using Emotiv EPOC+ EEG headset. The same experimental conditions are maintained for each subject and data are collected for the same number of sessions.

The Emotiv EPOC+ is a portable, high resolution, 14-channel, EEG system. The EEG signals are obtained from the 14 sensors located in the positions AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 arranged according to the International 10-20 locations. Emotiv EPOC+ has 2 reference locations P3 and P4. Figure 1 (a) shows the device and the placement locations of the electrodes are given in Figure 1 (b). Emotiv EPOC+ headset connects to the computer wirelessly. The EEG signals are recorded from all the 14 electrodes with a sampling rate of 128 Hz (EPOC+ User Manual, 2019).

Saline solution is used to hydrate the sensors to get good contact. After fitting the headset on the head of the subject and powering on the device, the contact quality is checked by the freely available software from Emotiv (EmotivPRO). There are four states with color codes as given in Figure 1 (c). Before acquiring any EEG data, the contact of all the electrodes is ensured by pressing the sensors on the scalp firmly until a green indicator (100%) is received for each sensor from the software (EPOC+ User Manual, 2019).
2.1. Methodology

The methodology used in this research is given in Figure 2. First, the training dataset from a given participant is acquired while he/she performs a real time BCI activity. The recorded data is preprocessed and is used to train the classifier off-line as given in Figure 2 (a). The next step is to measure the performance of the participant while doing an online BCI application as shown in Figure 2 (b). After preprocessing the EEG data acquired, the relevant features that distinguish a target (P300) signal from a non-target (non-P300) signal such as band power features and power spectral densities are extracted from the data. These feature vectors are used by the trained classifier to classify the data and give the feedback to the user in real-time. The user performance in executing the BCI activity is calculated.

2.2. Software

OpenViBE software version 2.2.0 is used to design the scenarios in which the EEG data will be analyzed in order to obtain P300 evoked potentials. OpenViBE is an open-source software platform which enables researchers to design, test and use BCIs (Renard, 2010). OpenViBE consists of two modules: (i) the Acquisition client that imports EEG data for online and/or offline processing, and (ii) the Designer which supports data pre-processing, processing and visualization. A Python interface, CyKit is used to stream the raw EEG data from the Emotiv EPOC+ headset to OpenViBE. CyKit is a Python 3x server to provide EEG data to browser and generic users via Transmission Control Protocol (TCP) stream (CymaticCorp, 2020). To study the cognitive performance, the P300 speller scenario is used.

The P300 spelling model depends on the visual evoked potentials (VEP) and was first proposed by Farwell and Donchin (Farwell et al., 1988). P300-based speller consists of a 6x6 matrix of an
alphanumeric display on a computer screen. The rows and the columns of the matrix are flashed in a programmable configuration. The target letter to identify is highlighted in blue color at the beginning of the scenario. Then, the participants were instructed to focus at the target letter and count quietly whenever the target letter flashes on the screen. The EEG signals were recorded during this process. The flashes of row/column of the target letter (target stimulus) should generate a P300 signal in the EEG data and the flashes of all other rows/columns (non-target stimuli) correspond to non-target EEG data. In order to preprocess the recorded EEG data, an xDAWN filter is used (Rivet et al., 2009), while the Linear Discriminant Analysis (LDA) machine learning algorithm is used for the classification of P300 signals.

2.3. Experimental Design to Improve Cognitive Abilities

The participants were informed about how the alphanumeric speller works and were asked to sit in front of a computer monitor. The participants completed a session with 12 flashes each per row/column (a total of 24 flashes) of the target letter and there were 20 target letters in each session to identify. So in one session, each participant would generate 480 evoked potentials. The target and non-target EEG signals were collected in real-time using OpenViBE software. The OpenViBE acquisition client that is connected wirelessly to the Emotiv EPOC+ collects the data which is subsequently imported and written to a file. All these functions as well as the target letter generation and p300 alphanumeric speller visualization are implemented using OpenViBE box algorithm modules (Renard, 2010). The number of trials, the number of repetitions a target letter flashes, the flash duration, and the inter-trial delay time are configurable. The EEG data is collected while running the P300 Speller.

The recorded EEG data is pre-processed using the temporal filter. The channels are selected using the xDAWN spatial filter after the filter is trained by the acquired EEG data. The data collected from all the channels are then aggregated into one feature vector that can be used by the classifier. The feature vector from the target events and the feature vector from the non-target events are sent to the classifier, LDA. These feature vectors are used as different inputs to train the classifier to distinguish between the target and non-target signals produced by the participant’s brain activity.

This offline testing is done by k-fold cross-validation (k = 5) in which the data set is randomly partitioned into k subsamples of equal size. Among the k subsamples, k – 1 subsamples are used as training data for the model and the remaining one subsample is used as the validation data for testing the model. This process is repeated k times, thereby using each of the k subsamples only once as the validation data. The results of the k trials are then averaged to produce a single estimation. In this method, all observations are used for both training and validation, and each observation is used for validation only once. The performance was calculated according to the number of samples correctly classified into the target (P300) and non-target (non-P300) categories with the classifier.

Once the classifier has been trained, the participant can use the system with free choice of words in real time. The online application collects the EEG data, pre-processes and classifies the data and also displays the result of the prediction.

For the initial testing of the cognitive abilities, the participants were asked to spell the words (including non-dictionary words and numbers “uncopyrightable” “mfdjq” “xvkswz” “1357924680” “jumbling” “vext” “frowzy” “hacks” “PDQ” “1470258369” (contain all letters of the alphabet and numbers equally) by identifying the letters using BCI alphanumeric speller. Each target letter was flashed 24 times (12 each per row/column). The EEG signals were recorded. The performance of each participant is calculated using the trained LDA classifier model.

The participants were given feedback sessions after the initial testing of cognitive abilities. They were asked to focus on a target letter highlighted in blue color and count whenever it flashes. EEG signals were recorded during this process. At the end of 24 flashes, the target letter identified by the trained classifier (from the collected EEG data) was highlighted in green color, allowing the participants to learn whether they correctly identified the letter. This is repeated for 15 target letters, each time displaying the feedback letter. Each participant went through three 20-minute feedback sessions and is repeated on 20 different days.

Testing the cognitive abilities session is repeated for each participant after giving 20 days of feedback.
training and the performance of each participant in correctly identifying the target letter before any feedback training and after the feedback training on the 20th day are calculated.

2.4. Communication Aid System

In order to implement a system that can be used as a communication aid, a software application is developed to display a screen with 12 words which would be commonly useful for a patient suffering from neuromuscular disorders (Figure 3). Three scenarios are developed using OpenViBE software: EEG data acquisition, Offline training of the LDA classifier, and Online application in real time. The three scenarios were implemented using OpenViBE box algorithms.

The participant was asked to sit in front of the monitor and the images of the words are displayed. A target word was highlighted in blue color and participant was asked to focus on that word and count quietly whenever the word appears. When the word disappears a black screen was shown at its place. The words appear in the screen randomly and each word appears 10 times and is repeated for 10 words. Hence the target words appeared 100 times and the participant generated 100 evoked potentials for the target events.

![Figure 3. 3x4 Display matrix of words](image)

The collected EEG data is passed through a Butterworth band pass filter to remove the signals below 1 Hz or higher than 30 Hz because the normal EEG data should be in the range between 1 Hz and 30 Hz. There are two groups of data, one for the target events and another for the non-target events. The features are extracted and used to train the LDA classifier. K-fold cross validation is used (k=5) for the offline training.

Once the classifier has been trained, the interface can now be used in real time application. The participant is presented with the display of 3 x 4 matrix which consists of different words. The participants are asked to focus on the word of their choice and count the number of times it appeared. The words appear in the screen randomly and each word appears 10 times. At the end of this, the word predicted by the classifier is displayed in green color. Hence, the participant can check whether the target word was correctly identified. This is repeated for 12 words and each time, the identified word is displayed in green color. The performance of the system is calculated with all the participants.

3. RESULTS

3.1. Application To Improve Cognitive Abilities

The four participants were asked to spell the words and numbers “uncopyrightable” “mfdjq”“xvkswz” “1357924680” “jumbling” “vext” “frowzy” “hacks” “PDQ” “1470258369” by identifying the letters/numbers in the alphanumeric speller. The performance of each participant is measured over 3 trials and were in the range of 76%-81%. The participants were given three sessions of 20 minute feedback training. This is repeated for 20 different days. The performances of the participants are again measured
on the 20th day. The accuracy of identifying the correct letters/numbers improved for all the participants after the feedback sessions and are in the range of 84%-89.3%. The results are tabulated in Table 1. The graph of the performance of the participants in cognitive abilities before and after the feedback sessions is shown in Figure 4.

Table 1. Performance in cognitive abilities.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Performance Before any feedback session</th>
<th>Performance After the feedback sessions (on 20th day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>78.71%</td>
<td>84.72%</td>
</tr>
<tr>
<td>2</td>
<td>80.09%</td>
<td>87.04%</td>
</tr>
<tr>
<td>3</td>
<td>75.93%</td>
<td>84.26%</td>
</tr>
<tr>
<td>4</td>
<td>81.02%</td>
<td>89.33%</td>
</tr>
</tbody>
</table>

Figure 4. Performance in cognitive abilities

3.2. Communication Aid System

The number of words correctly identified by the four participants during the online application in real-time over 4 trials (the 4 trials are done on different days) are given in Table 2. The words provided are commonly used words on a daily basis by a disabled person and are provided as images (Figure 3). The average of the performance of the system for each participant is calculated and is also given in Table 2. The classifier was able to predict more than 91% of the words correctly with all of the participants. The highest performance achieved was 97.92%. The graph of the performance of the system used as a communication aid is shown in Figure 5.

Table 2. Performance of the communication aid

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Number of words in each Trial</th>
<th>Number of words identified correctly over 4 trials</th>
<th>Average Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>11, 12, 11, 11</td>
<td>93.75%</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>11, 11, 12, 12</td>
<td>95.83%</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>10, 11, 11, 12</td>
<td>91.67%</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>11, 12, 12, 12</td>
<td>97.92%</td>
</tr>
</tbody>
</table>
4. CONCLUSION AND DISCUSSION

The engineering goals of this project were (i) to design an experimental study to analyze and improve cognitive performance and also (ii) to develop a communication aid to support people with neuromuscular disorders using non-invasive BCI.

A low-cost EEG device, Emotiv EPOC+ headset with 14 channels, is used to record EEG data while executing the BCI alphanumeric speller task by the participants using only their brain activity. OpenViBE software is used to design the application scenarios for real-time and off-line analysis of EEG data. A Python interface is used to stream the raw EEG data from the Emotiv EPOC+ headset to OpenViBE. The EEG data is preprocessed and the features extracted for the target and non-target events are used to train the classifier, Linear Discriminant Analysis (LDA). The performance of the participants are measured during the task of spelling various words (i) just after the initial training on how to use the speller and (ii) after giving feedback sessions for 20 different days. The performances were in the range of 76%-81% while spelling the words before any feedback sessions. After giving feedback trainings in alphanumeric speller task for 20 days, the accuracies of identifying the correct words improved for all the participants and are in the range of 84%-89.3%. The proposed feedback training experimental design is an excellent way to improve the cognitive abilities and can be used for healthy individuals as well as people with attention deficiency to improve their attention.

To use the system as a communication aid, a software application is developed to display a screen with 12 useful words for patients suffering from neuromuscular disorders. This application will enable the user to identify the words by using only the brain activity, more precisely P300 signals. Once the participants complete a brief training to identify target words with this application, the classifier LDA is trained with extracted features of target and non-target events. The performance of the communication aid system to identify the words correctly is measured with the participants. The system was able to predict more than 91% of the words correctly with all of the participants. The highest performance achieved was 97.92% in the case of participant #4. People suffering from neuromuscular disorders have limited or no communication capacity. As an alternative of taking the difficulty to identify each character in the speller to form a desired word, identifying the words used to communicate on a daily basis would be an easy task for the patients suffering from debilitating neurological disorders. The Emotiv headset is affordable as compared to other medical devices and the setup time for the device is short and can be used by anyone without expertise. The engineering goals of the project were achieved by the design and both cases were met with promising results.

Brain-computer interfaces using this technology can effectively improve cognitive and communication abilities for patients with neuromuscular disorders, allowing them to communicate through their brain signals more easily and accurately. Consequently, the lives of these patients are much less stressful with an easier method of communication. Lastly, the regular use of this BCI technology can help improve their focus and skills which may further aid their living situations.
5. REFERENCES


A VIRTUAL STEM OUTREACH PROGRAM FOR ELEMENTARY AND MIDDLE SCHOOL STUDENTS DURING COVID-19

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Abstract: Gender inequality has been a persistent problem in higher education and industry in the STEM fields in the United States. While progress has been made in the last decade, there is a potential for increasing inequality in the time of COVID-19 with the inability to engage students in a face-to-face forum.

In order to introduce elementary and middle school students to robotics and STEM, a monthly, virtual online outreach curriculum, mostly led by female students has been developed to stimulate student excitement and encourage girls to get involved in the fields of science and technology. Robotics is used as a conduit to teach and stimulate interest in STEM. A fun, hands on, and interactive curriculum for a series of educational online workshops has been developed, covering the engineering design process, competitive robotics, 3D CAD tutorial, programming, and robot mechanics. Our findings suggest that in elementary school, girls and boys are approximately equally interested in STEM. The outreach workshop appears to be a useful way to encourage and engage boys and girls in STEM virtually during COVID 19.

1. INTRODUCTION

The United States, between 2009 and 2018, the percentage of women working specifically in the computer and mathematics occupations, and in the architectural occupation rose from 14% to 16% (US Bureau of Labor Statistics, 2019). The chart in Figure 1 shows the breakdown by STEM occupation in 2018.

![Women in STEM Occupations](https://example.com/figure1.png)

Figure 1: Women in STEM, 2018, US Bureau of Labor Statistics

Despite the small increase, the representation of women in the STEM workforces are problematic for a society that relies heavily on technology. Not having enough women in the technology field leads to biases in the development new algorithms, machine learning, as well as depriving the field of innovation
and talent from women. Society can benefit from women’s’ different perspectives and expertise (Milgram, 2011). Many root causes have been advanced, including gender stereotypes and teacher biases, and lack of role models. Starting STEM education early while encouraging girls has been proposed as a solution. There is evidence that boys and girls score the same in math in elementary school, but diverge in secondary school (Card, 2017) (Steven W. Hemelt, 2020). Even more troubling, there is evidence that the recent interest in STEM by girls has declined 11 percent between 2018 and 2019 (Rose, 2019).

2. DESCRIPTION OF FIRST WORKSHOP

A novel, online STEM workshop was the first introduction for elementary and middle school students of the entire SUSD school district of 2000 students, introducing different type of robotics competitions at elementary, middle school, and high school levels. These include the FIRST Tech Challenge, FIRST Robotics Competition, VEX Robotics Competition, and FIRST Lego League. In addition, the workshop focused on the teaching the engineering design process with a hands-on workshop to further solidify the learnings. The workshop was fast-paced, fun, and interactive; it was squeezed into one hour after school, entirely online, and was able to keep the young students engaged. Special emphasis was placed on encouraging the participation of girls with the following format:

- Introduction to Robotics: 10 Minutes
- Introduction to the Engineering Design Process: 10 minutes
- Design a vehicle with wheels with household recycled materials: 30 minutes
- Sharing the design results: 10 minutes

This workshop was conducted online over Zoom due to COVID. Participants were supposed to stay muted unless they have a question. If they have a question, they used the raise hand function in Zoom to be called on, and typed their questions in the chat. Participants were taught about the engineering design process and got a chance to apply the concept through a hands on, fun design challenge.

In this challenge, students built a non-robotic vehicle that could transport small toy people or goods. The vehicle had to be sturdy, and had to travel at least 1 meter without breaking. They were allowed to use common materials found around the house, including bottle caps, balloons, straws, toilet paper rolls, bananas/potatoes, empty water bottles, paper cups, empty containers, cardboard, construction paper, old CDs, sticks, pencils, and plastic containers. They were expected to follow the engineering design process, shown in Figure 2, for making their vehicle. The steps include asking a question about a problem that could be solved, imagining a solution about how to solve the problem, writing out a detailed plan, creating the prototype, testing and improving the prototype, and sharing their creations.

![Figure 2: Engineering design process chart](image-url)
The students were encouraged to ask questions anytime, and in particular, the elementary school girls were very active in asking questions during this workshop. The participants were given 30 minutes to design and build. At the end of the build, they shared their creations. Figure 3 shows a few of the creations.

Figure 3: Workshop 1 creations

The registration list consisted of 81 students. The gender and age breakdown were analyzed. Figure 4 shows the number of girls participating per grade. As shown, girls’ interest in STEM and engineering peaks at 4th and 5th grade, and then quickly declines in 6th, 7th, and 8th grade. 51% of the registrations were girls.

Figure 4: Percentage of girls in workshop 1

Figure 5 shows the total attendees that attended workshop 1, divided up by grade. 4th graders were the largest group that attended this workshop.
3. DESCRIPTION OF SECOND WORKSHOP

Workshop 2 led by a female member of the RMS Robotics Club, and was focused on middle school robotics competitions. After a presentation about robotics, students were given an interactive task to draw a robot of their own creation.

Figure 6 shows the number of girls participating per grade, taken from the total number of 58 signups. This chart of workshop 2 confirms high interest in STEM for elementary school girls. The similar trend of the declining interest is seen in the middle school grades with each year showing less interest in 6th, 7th, and 8th grades.

Figure 7 shows the total attendees that attended workshop 2, divided up by grade. 3\textsuperscript{rd} graders were the largest group that attended this workshop.
4. DESCRIPTION OF 3\textsuperscript{RD} WORKSHOP

This third outreach workshop was led by another female member of the robotics club. She taught the students about 3D CAD. This workshop detailed out the merits of CAD, and taught students about different functions. Finally, they were given a hands-on challenge with the text: “CAD something to help you survive if you were stranded on an island.” Students used Tinkercad for this challenge, since it was free and available on all devices.

Figure 8 shows the percentage of girls participating per grade, taken from 46 signups. The results from this chart are surprising, as the grade with the highest participation of girls is 6\textsuperscript{th} grade. One possible explanation for this data might be that CAD is more advanced, and therefore more girls in middle school would like to attend. It could also be that in elementary school, girls don’t want to try CAD, but gain more interest in the middle school years. Also, no 8\textsuperscript{th} graders signed up for this workshop.

The second chart shows the number of participants in this workshop, by grade level. 4\textsuperscript{th} graders were the largest group that attended the 3\textsuperscript{rd} workshop.
5. **FUTURE WORKSHOPS**

We will be hosting monthly virtual workshops on STEM related topics including basic 3D CAD design using Tinkercad, beginner coding using a visual programming language, intermediate coding using a text-based language, and identifying robot components and mechanical elements. Many outreach sessions are hosted by middle school girls in the robotics club to provide role models for their peers and younger students.

6. **SUMMARY**

Engineering, computers, and mathematics have low gender diversity, and the improvements of the last decade have been minimal. This leads to lost opportunities, and a lack of diversity of perspectives. COVID-19 has created further hurdles, especially for girls to learn STEM. The objective of the virtual outreach workshops to middle and elementary school students is to engender and promote interest from girls and boys into STEM at a young age. The workshops were successful at garnering the attendance of girls in the elementary schools, but a significant drop-off was seen at the middle school level. It is the hope of the author that this outreach program will be successful in encouraging children to pursue further STEM education, and increase the likelihood that girls will have an interest in STEM for their later education and careers. I think this virtual outreach model should be continued in the future, because the previous in-person outreach programs had low participation and diversity. I think that the reason why these outreach programs are so successful is because students can log in remotely from anywhere, so it’s a lot more convenient and gives students a lot of flexibility.

7. **REFERENCES**


A MULTIPURPOSE ROBOTIC GLOVE DESIGNED TO TEACH SIGN LANGUAGE THROUGH GUIDED MANUAL MOTIONS

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Abstract: Projections show the numbers of deaf and deafblind individuals are quickly increasing, as both the number of deaf and blind individuals are expected to double within the next 50 years. Additionally, there is limited support for deafblind individuals, as they have little sensory access to the world. Most existing solutions are inadequate because they are either not portable, readily accessible or are very expensive. The goal of our project is to create a low cost, accessible solution for those with these disabilities: a portable device that utilizes the sense of touch to teach sign language, instead of conventional sign language learning methods that rely on sight. By doing this, a more immersive and personalized experience is created. The implementation of this solution is two-pronged: first, the physical portion of the solution is equipped with servo motors that control the pulling and release of a cord threaded through rings on the fingers that moves the user’s hands into various sign language positions, which is closely modeled after human hand anatomy. Secondly, feasibility is determined for an AI algorithm to take in data from an external camera to efficiently add new signs to the glove, and also to track the user’s sign language patterns and rate the user’s accuracy with various signs. Through these mechanisms the user is engaged in learning new signs and expanding their sign language vocabulary, all without their sense of sight. We were successful in creating a working prototype analyzed through hand-tracking mechanisms, and achieving a 91-92% accuracy for the American Sign Language alphabet.

1. INTRODUCTION

1.1. Deafblindness

Deafblindness is a general term for anyone who suffers from some degree of hearing and visual loss. A person who suffers from deafblindness may be born blind and lose their hearing as they get older, or be born deaf and lose their vision as they get older. This combination of symptoms is disastrous, as it can vastly limit the abilities of people with this disability (Jaiswal et al., 2018).

In the United States, it is estimated that 70,000-100,000 people are deafblind (NARUC), and over a million exclusively blind and over a million exclusively deaf. Both of these numbers are expected to double in the next 40 years. Globally, approximately 97.6 million people experience some form of visual or hearing impairment, and this too is getting much worse. By 2050, estimates show that one in every ten people will have disabling hearing loss, while blindness rates are expected to triple (Bourne et al., 2017; Goman et al., 2017; World Health Organization, 2019). These statistics highlight the widespread nature of this problem. Even more astonishing facts lie underneath this data. The World Health Organization has estimated that deafness costs the world more than $21 billion annually in assistance and lost productivity (World Health Organization, 2019). In this way, helping individuals with deafness helps the economy of society as a whole. In addition, approximately 100,000 U.S. school children suffer from a serious visual
problem, even though vision is one of the most important tools needed to learn (United States Census Bureau, 2007). As of 2007, Over 90% of the world’s visually impaired live in developing countries, where they lack the necessary resources to function effectively (World Health Organization, 2007). Therefore, there is an increasing need for a cost-effective solution to this issue. In addition, global awareness of this condition is almost non-existent, especially within developing countries, where this condition is especially dangerous. Primary ear and hearing care has not yet been implemented in developing countries, and the support for secondary and tertiary care is minimal (WFDB, 2018). Also, there are not enough ear health and vision specialists in the world, so there is a need either to train more or find an alternative solution that does not depend on these specialists (Moss and Blaha). Furthermore, the effects of this condition are catastrophic. Not only does deafblindness limit speech and learning at an early age, it leads to slow progress in school and problems in securing a job. It leads to separation from the rest of society and extreme differences in the social and economic aspects (Miles, 2008). Additionally, research has shown that a multisensory, phonics-based approach at an early age is best for learning new concepts (van Staden, 2013). Hence, to create the best learning experience for the deafblind user, there is a need to utilize the various remaining senses, including touch, and whatever limited form of vision or hearing that remains.

Today, current communication technologies make maximum use of the remaining senses, especially the sense of touch (Mason, 2014). This allows the individual to communicate effectively with those around them by both receiving and giving information. As there are many different forms of deafblindness, the possible tools that may help someone who struggles from deafblindness vary greatly, with differing levels of technicality. Some common tools are described below.

**Magnification Devices:** Depending on the level of hearing or vision loss, certain magnification devices, such as hearing aids or cochlear implants, can be used to recover some hearing. However, these depend on the type of hearing loss the user has and are not available in many parts of the world. Additionally, the cost of such technologies far exceed the amount of financial support given to deafblind individuals, and as a result, many cannot afford them (WFDB, 2018).

### 2. DESIGN OVERVIEW

The design of the device is analogous to that of the human hand, with a flexible frame to provide the underlying structure, similar to human bones, while keeping it flexible enough to comfortably fit around hands of various sizes. The bending and extension of the fingers are facilitated by the pulling and pushing of cords, representing the flexor tendons in the human hand, which also cause the bending and extension of each digit. This cord retracts and withdraws as a result of the rotation of the servo motors located in the upper forearm of the device, representing the flexor muscles in the human hand, which are attached to the flexor tendons in a similar way. The dorsal and palmar interossei muscles of the human hand, which control the abduction and adduction of the fingers, respectively, are represented by micro servos providing a 30 degree rotation to the metacarpophalangeal joints, which connects the digit to the main surface of the hand. One dissimilarity between the device and the human hand is the location of the flexor pollicis brevis and flexor digiti minimi brevis muscles, which are responsible for the primary bending of the thumb to the palm of the hand, and the primary bending of the little finger to the palm of the hand. Although these muscles are located in the thenar and hypothenar eminences of the human hand, respectively, which are the bulges of muscle at the base of the thumb and little finger, the servo causing the corresponding movements on the device are located in the upper forearm, next to the other servos representing the flexor muscles for the other fingers. This difference in design, however, leads to little difference in the overall movements of the device. Two other muscles in the thenar eminence, the abductor pollicis brevis and adductor pollicis, control the abduction of the thumb away from and towards the midline of the hand, respectively. To simulate these muscle movements, the device contains a larger servo located at the back of the hand, which is connected to a wheel that causes the corresponding rotation. The degree of rotation for this servo is 90 degrees, which is greater than that for the interossei muscles of the other fingers. To simulate the opposition of the thumb, the same cord for flexion will be used, in conjunction with abduction, allowing the thumb to rotate in a circle.
The proposed operation of the device is to start off by going through the alphabet as they are simpler, one-handed signs and easier to learn for the student. They will also provide a base for the later more complex signs, as the glove will spell out each new word before teaching the new gesture so the user can understand the glove exclusively through touch. The glove will progressively go through more complex signs, so by the end users can frame together sentences and effectively communicate with others. In addition to this teaching mode, there is also an assessment mode where users can practice the gestures they have learned which will be tracked either through a camera on a smartphone or laptop, while providing real-time feedback for improvement. The user will then have options to practice these signs, all controlled through the pro-tactile user-interface, using an external Braille keyboard or through Braille buttons on the glove.

3. APPROACH

3.1. Plan and Prototyping Stages

To reduce costs, the original hypothesis was that if we only use a single servo motor for each finger, instead of a servo motor for every joint in the finger, we can create a device designed to be much more affordable with no drawback in functionality, as many signs in American Sign Language can be formed by solely utilizing the flexor tendons and flexor muscles. To test this hypothesis, we proceeded to create a feasibility prototype which only allows for the flexion of each digit as a simpler model of the human hand. The structure of this prototype was created using 3D-printed parts created from polylactic acid (PLA) filament. This prototype is modeled after the inMoov project with modifications for ASL. To create the finger flexion and extension movements, two cords are threaded through each finger: one on the top, and one on the bottom. The flexion cord, located on the front of the finger, makes the finger flex when pulled, while the extension cord, located on the back of each finger, makes the finger extend when pulled. These cords are attached to a wheel driven by a servo motor that pulls the flexion cord while releasing the extension cord when turned in one direction, while releasing the flexion cord and pulling the extension cord when turned in the other direction. A simple circuit was used to train various signs on the Stage 2 Prototype. Using a potentiometer dial and a pushbutton, we are able to toggle between the various fingers and change the flexion of each one, while a second push button allows us to save the sign to the memory of the microcontroller. However, due to the rigid structure of this prototype, many flaws were noticed, and the glove was not able to perform many signs, including basic alphabet letters, so we proceeded to develop another prototype: a device that fully encompasses a user’s hands with flexion in all fingers and abduction, adduction, and opposition in the thumb. In addition, the Stage 3 prototype is made out of a flexible rubber that fits precisely around each of the user’s fingers, allowing for a more comfortable fit. It primarily consists of 3D printed rings with loops where a cord is threaded. This cord is attached to servo motors located on the forearm of the glove, which pulls and retracts, making the finger flex and extend, similar to the design of the feasibility prototype.

Figure 1. Stage 3 Prototype finger flexion and extension
One major difference is that the glove is wearable, unlike the Stage 2 Prototype, and rings are used to thread the flexion and extension cords instead of directly through the finger. Additionally, a larger servo fits on the back of the glove, creating the thumb abduction and adduction movements. To make the thumb both flex and abduct, a novel mechanism was used in which a flexible thumb guide was fabricated that moves the thumb away from and towards the rest of the fingers, while being flexible enough to allow the thumb to flex and extend like the other digits. By abducting the thumb away from the fingers while flexing it, we can also create the opposition motion of the thumb in this way.

![Figure 2. Stage 3 Prototype thumb abduction, adduction, and flexion](image)

4. **HAND TRACKING FUNCTIONALITIES**

Hand keypoint extraction was used for multiple different aspects of this project and implemented through the Google Mediapipe framework. This framework allows us to create and modify a machine learning pipeline that locates 21 specific keypoints on our hands as various gestures are performed in front of the camera by overlaying a wire model of the hand on top of the input image.

This algorithm was then modified to output the relative coordinates of the various keypoints, normalized in a 1x1 square centered at the palm, with (1, 1) as the bottom left coordinate and (0, 0) as the top right coordinate. Additionally, the z-coordinate was estimated based on lighting and hand anatomy through Mediapipe.

![Figure 3. Normalization of coordinates for keypoint estimation and coordinate output](image)

Once the locations of the keypoints were found, more information can be extrapolated. Firstly, the keypoint coordinates were used to calculate the various flexion and abduction angles between the fingers. To do this, the angles between two consecutive keypoints were found and summed for the whole finger to get the flexion angle for that finger. For example, to find the angle of rotation of the PIP joint on the index finger, the vector pointing from the PIP joint to the DIP joint and the vector pointing from the PIP joint to the MCP was found. Using the dot product formula where \( \mathbf{a} \) and \( \mathbf{b} \) are the two vectors this angle can be calculated. Repeating this process for every joint in the finger, the total flexion angle of the finger can be calculated. A similar process is repeated to find the abduction angle by finding the angle between the vector pointing to the MCP of the thumb from the base of the hand and the vector pointing to the MCP of the index finger from the base of the hand.
After the various flexion and abduction angles are found, they can be used to teach the glove new signs. For example, we can form a sign with our hands in front of the camera so that keypoints and angles are tracked, and saved to the memory of the Arduino microcontroller. The device can rotate its flexion and abduction servos to the corresponding angles to form the sign. This feature allows us to add new signs to the device with relative ease, instead of hard-coding each of the servos, and can easily be expanded as we continue to add more servos to the device for future prototypes. Keypoint extraction and analysis also helps with testing of the prototype, as it allows us to determine how inconsistent the human hand forming various signs is to the device forming various signs. We propose a third use of the hand tracking feature which we seek to include in future iterations: personalized feedback to the user. In the assessment mode of the device, the device can prompt the user (through the Braille display, the LCD display, and/or the speaker) to form a specific sign. Similar to how the device was tested, the error between when the user is forming a sign and when an expert is forming a sign, found in an online ASL dictionary, is determined through finding the distance between the respective keypoints, as well as the percent error between the coordinates. The average of this distance is then computed. The signs that have a high average distance and high percent error are the signs that the user needs the most assistance on, so the algorithm ranks the signs based on this characteristic. This allows the user to practice the signs that he/she struggles with the most. Our Stage 3 prototype cost us around $60 to develop. Including further manufacturing and development costs, a proposed selling price for the minimally viable product is $120. This is vastly cheaper than current BTSs, the cheapest of which sells for $1,000 today, validating one of our objectives. This objective was largely accomplished through minimizing the amount of servo motors on the device by using a single servo motor per finger, closely related to how the human hand only has one flexor muscle per finger, instead of a motor per joint in the hand.

5. RESULTS AND DISCUSSION

5.1. Stage 3 Prototype Testing

To test the Stage 3 Prototype, the hand tracking algorithm was utilized to extract various keypoints and angles on the glove and compare them to the theoretical sign keypoints and angles. Multiple tests were performed to compare the set of keypoints formed by the glove and the set of keypoints formed by a human: a percent error analysis and a distance error analysis. Firstly, the percent error was calculated between each coordinate formed by the glove and each coordinate formed by the human hand, and these were averaged between the X, Y, and Z coordinates to get the total error for a specific keypoint. Lastly, the percent error for each keypoint was averaged to get the average percent error for a single gesture, and subtracted from 100% to get the average accuracy. This process was repeated for every gesture in the ASL alphabet, excluding the letter “R,” which is explained below.
This chart shows that when including the Z-coordinates, the accuracy of the gestures are significantly lower for most signs. The Z-coordinates were estimated based on lighting conditions, and was largely inconsistent, as the keypoint tracking does not take in an input of a depth sensor. This allows us to significantly reduce the costs for the user, as personalized feedback can be given without the reliance on the depth sensor, but also limits the extent of testing, as the Z-coordinate gives very little information. Still, only using the X-coordinates and the Y-coordinates, we can still evaluate the accuracy of the device, as it is difficult to change the Z-coordinate of a sign without also changing the X-coordinate and the Y-coordinate. Using the percent analysis approach, there is a greater than 75% accuracy for all signs, and the least accurate sign is the letter “B” with a 78.93% accuracy. The average accuracy for all letters (excluding the inconsistent Z-coordinate) is 91.86%. The letter “R” could not be shown in the results because the hand tracking algorithm does not recognize the hand when the index finger and the middle finger are crossed, which is used in this sign. Therefore, no result could be computed and this had to be omitted from the analysis. Additionally, the letters “J” and “Z” (marked with an asterisk) both involve motion, as the sign for “J” involves bringing the pinky down in the shape of a “J” and the sign for “Z” involves tracing a “Z” with the index finger in the air. To make the testing procedure the same for each sign, the motion aspect of these signs was omitted, and instead a static image of the gesture was used instead. Additionally, the distance between keypoints on the glove and keypoints on the human hand was also found, so that each keypoint on the glove was compared to the same keypoint on the human hand. For example, the coordinates of the tip of the index finger on the glove was found, and the coordinates of the tip of the index finger on a human hand performing the same sign was found, and the distance between these coordinates was calculated using the Pythagorean Theorem to determine the error for this coordinate. This process was repeated for each of the 21 keypoints on the hand and device.
Again, the error with the Z-coordinate is much higher than when the Z-coordinate is not included, due to inconsistencies in the approximation of this coordinate. In future testing procedures, the depth sensor will need to be utilized in addition to current methods. Additionally, the sign for “R” could not be analyzed again and the signs for “J” and “Z” were limited to a static image. By dividing each of the distance errors by 1.0, which is the maximum distance error possible for each keypoint, a percentage is calculated that also shows the accuracy of this keypoint. For this test, the average accuracy was computed to be 94.64% for the ASL alphabet signs excluding the Z-coordinate, and 90.53% including the Z-coordinate. Because the hand tracking algorithm could not identify the glove due to differences in skin tone, a human hand imitating the glove as closely as possible was used, through anonymous images. This may lead to some human error, but the hand was not the experimenter’s own hand, to reduce this human error. For future studies, the training set of the hand tracking algorithm will be modified to include the device. Current devices designed to translate the ASL alphabet to speech do so at around a 90% accuracy, which our device surpasses (Medhi and Khan, 2012; Waldron and Kim, 1995). However, the objective for our device is not to translate ASL alphabet to speech but to teach sign language instead, which has not currently been implemented. We are expanding on this current research on analyzing sign language in a more quantitative way for use in robotics and machine learning.

6. CONCLUSION

Overall, we created a device that would be able to teach people sign language at a significantly lower cost, at a high level of accuracy. We were able to create a glove-like unit that replicated the movement of the human hand and managed to complete all ASL alphabet signs, except for the letter “R”. Through our testing we confirmed that our solution performs at a 92% accuracy. We believe that our product can help those who are deafblind easily communicate with the people around them. We have also started preliminary research on the Stage 4 Prototype, which will include additional movements for wrist flexion and extension and radial and ulnar deviations, and elbow flexion and extension, allowing us to have a greater accuracy for the full range of sign language gestures. Possible movements for the final design will include: flexion (bending) of each finger, including the thumb, abduction and adduction of each finger up to 30 degrees, abduction and adduction of the thumb up to 90 degrees, opposition of the thumb and the little finger, flexion and extension of the wrist, radial and ulnar deviation of the wrist, flexion and extension of the bicep, pronation and supination of the forearm, the vertical and horizontal flexion and extension of the shoulder, and internal and external rotation of the shoulder.

For more complex motions, such as shoulder rotation and flexion, vibration motors located on various parts of the device will be used that guide the user into the right position, without forcing their arm to move.

7. REFERENCES


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