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Message from the Symposium Chair

Dr. J.R. Gamage
University of Moratuwa,
Sri Lanka

Dear Colleagues, Researchers, and Industry Professionals,

Welcome to the Engineering Research Unit Symposium (ERUS) 2023. It is an honour to host this gathering of academia, industry personnel, and other stakeholders to showcase research and innovation presented by like-minded researchers in the field of engineering. I am glad that this year's symposium went parallel to the University Research Week allowing inter-faculty collaborations.

This symposium is not just an exhibition of academic achievements but also serves as a mode of connecting academia with industry. Furthermore, it intends to inspire the younger generation to join the world of engineering by encouraging STEM education, which was realized through the participation of the school children in the event. Our aim is to foster a collaborative environment where ideas can be exchanged, and partnerships can be formed, to drive forward the frontiers of engineering.

The main objective of ERUS 2023 is to provide opportunities to disseminate the knowledge. We believe that sharing research outcomes widely and effectively is crucial for the growth of the field. Through a series of insightful poster sessions and oral presentations, participants had the chance to present their work to a diverse audience, gaining valuable feedback and recognition. Moreover, this symposium is an excellent opportunity for participants to develop and refine their presentation skills. Whether you are a seasoned researcher or a budding engineer, the ability to communicate your ideas clearly and persuasively is paramount. ERUS 2023 offers a supportive environment to hone these skills, ensuring that your research can make the greatest impact.

Networking is another cornerstone of ERUS 2023. The symposium brings together a vibrant community of scholars, industry experts, and innovators. This was a great opportunity to connect with peers, forge new collaborations, and explore potential career opportunities. The relationships built here can lead to progressive advancements and long-term partnerships. I would like to thank our main sponsor, Rise Motors and Heyleys Fentons for their generous support in making the event a success.

I sincerely like to acknowledge all the researchers who contributed and presented their research for ERUS2023. There were 61 submissions out of which 28 were selected for the poster session leaving 22 good quality extended abstracts to be published online. I would like to extend my sincere gratitude to all the reviewers for their untiring efforts in reviewing the papers. Further, I am pleased to inform you that the ERU symposium is getting published with an ISSN for the first time. I further like to appreciate the support of the ERUS2023 organising committee and all the participants for making the symposium a success.

Thank you.

Sincerely,
Dr J.R. Gamage
Symposium Chair
ERUS 2023

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Investigating the Design Process of Traditional Costume Penetrating a Niche Market

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Keywords – Design Process, Traditional costume, Niche market, Consumers, culture

I. INTRODUCTION

The design process defines each market segment in the apparel sector. Traditional costumes of Sri Lanka gained a long historical and cultural demand among Sri Lankan consumers. The most demanding costumes are "*Nilame*" costumes (male costume) and "*Ohoriya*" (female costume). This research identifies that traditional costume has become an emerging and demanding market segment today. The market segment is evident in Sri Lanka's suburbs in Colombo, Kandy, Galle, Rathnapura, and Kurunegala. The researcher predicts that the market meets niche market parameters.

A. Significance of the study

Inadvertent scholarship in the research of the design process of traditional costumes in the niche market has created a vacuum in the academia of costume studies. The new scholarship of this study will advance systematic research in traditional costume studies. Further, the absence of a systematic design process in the traditional costume may lead to inefficient procedures, increased costs, prolonged completion times, and an inability to reach the intended market effectively. The traditional costume industry in Sri Lanka currently experiences a deficit of high-end traditional costume artisans specializing in exclusive couture.

Traditional costume design represents the cultural wisdom of the past [1]. It's a cultural treasure, but its preservation is at risk as young talent leaves the industry due to low profits and wages. This study's outcomes eradicate and bring new hope to the young generation who lack enthusiasm and are disappointed to work in this sector due to prolonged poor profits and low labor rates in the traditional costume design industry. This study benefitted for stakeholders of artisans, academics, fashion designers, and policymakers.

B. Aim of the study

This study seeks to develop a conceptual framework that comprehensively outlines the features of the traditional costume design process, aiming to cater to the preferences and needs of modern-day consumers in terms of both functionality and aesthetics.

C. Objectives of the study

1. To identify characteristics of the traditional costumes within the local niche market.

2. To formulate a conceptual framework outlining the key aspects of the traditional costumes.

3. To validate the conceptual framework by finding the impact of key aspects of the design process of traditional costumes concerning modern-day consumer purchasing decisions.

II. LITERATURE REVIEW

Munasinghe [2] suggests that researching diverse market levels and design methods can reveal valuable insights for the fashion supply chain, benefiting stakeholders and enhancing the industry's financial health and sustainability.
The traditional costume market experiences complex and dynamic demand [3]. Purchases are often linked to special events like festivals and weddings, driven primarily by social circles [4]. Sociocultural, religious, political, and economic factors significantly shape traditional costume choices [5]. Modern consumer needs have also transformed the purpose of traditional costumes [6]. A significant gap exists between traditional costume design and theoretical research [7]. Traditional costumes have evolved recently, offering improved quality and diverse designs, including nontraditional options [4]. These costumes hold a strong connection to past generations and serve sociocultural needs.

A. Niche market strategy

Niche marketing targets a specific, well-defined market segment with unique needs, often preferred by small firms. Benefits include increased profits, diverse consumer behaviors, and adaptability. Key factors for success are understanding customers, matching market needs, effective communication, fit, style, market size, brand image, and reasonable pricing [8], [9]. Textile and apparel firms often use pull marketing to differentiate in niche markets [10].

B. Sri Lankan Traditional costume

The Kandyan costume's historical elements are visually well-documented. It originated during the Kandyan era, the last

kingdom of Sri Lankan rule from 1469 to 1815. This period witnessed rapid influences from South Indian, Western (Portuguese, Dutch, British), and Siamese cultures, impacting costume pieces, designs, accessories, and more [11].

C. Nilame costume and Ohoriya

During the English era, high-ranking officials like *Adikar and Disawe* wore *nilame* costume during the Kandyan Kingdom, later known as *Mul anduma*. This costume included long pants, a *tuppotti*[1] with a belt, a *mante*[2], gem-studded gold rings, carved ornaments, bangles, gold necklaces, and a flower-tree-decorated cap. The value of their clothing was associated with the quality of raw materials used [12]. *Mul Anduma* symbolizes national identity and pride. Its extravagant design, characterized by knotted and pleated layers, signifies power, wealth, and high social standing, particularly at the abdomen, where knots are called *'mohotti geta* '[13]. Ananda K. Coomaraswamy [14] asserts that *ohoriya* has Tamil origin. The national costume for Sinhalese women in the Kandyan region is *ohoriya*. It features a ruffled waistband and a loose, flat piece draped over the shoulders. Modern Ceylon brides often blend Eastern and Western styles in their costumes, incorporating shiny pearls, sequins, and tulle fabric into Kandyan sarees. The "fall" is a distinct part of the saree that hangs over the upper body and back shoulder, made from a different fabric than the main saree. This is often referred to as a "made-up" *ohoriya*, preserving the traditional *ohoriya* designs with various fabrics.[15]

III. Materials and Methods

In pursuit of an overarching research objective, this study has delineated three specific research objectives to guide investigative endeavors. Data collection will adhere to the sequential mixed-method methodology to ensure a comprehensive and robust approach [16]. This research will be executed in two phases.

A. Phase one: study one

Phase one involves qualitative research through semi-structured interviews with traditional costume artisans, industry experts, weavers, and costume tailors. This aims to delve into the traditional costume characteristics and the design process. Objectives one and two will be achieved within this phase. This qualitative exploration will serve as the foundation for constructing a conceptual framework that underscores the pivotal aspects of the traditional costume design process. The collected qualitative data will be subjected to an inductive analysis using thematic analysis. Defining and enhancing key aspects and themes will contribute to establishing a theoretical framework for the traditional costume designing process within the niche market.

B. Phase two: study two

The subsequent phase will employ a quantitative methodology by consumer survey with a multiple-choice questionnaire to rigorously assess the validity of the conceptual framework established in the first phase [17]. Objective three will be achieved within this phase. The framework will be segmented into measurable constructs through operationalization. Subsequently, pre-validated scales will evaluate the constructs' relevance and applicability to modern-day consumer purchasing decisions by consumer survey. The validated framework will be disseminated to artisans through a designated social media (Facebook/Instagram) page and group for usability assessment.

IV. Conclusion

This research addresses the disparity in focus between global and Sri Lankan traditional costume niche markets. It introduces an innovative approach to understanding and improving the traditional costume design process within Sri Lanka's niche market. Developing a conceptual framework will offer theoretical insights and recommendations, enabling artisans to address design process challenges and leverage opportunities in contemporary consumer behavior.

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[1] "tuppotti" A cloth of some fifteen or twenty cubits in length, folded round the waist and legs [18]

[2] "mante" (tippet) is a collar part which fastened to the shirt [18]

Development Of an Odorless Rapid Composting Machine For Domestic Use

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Keywords—Composting machine; Energy efficiency; Low odor; domestic usage; Sustainable waste management

I. INTRODUCTION

In the current world, the escalating waste problem has reached an alarming level. With the rapid growth of the population, the amount of waste generated has also increased, leading to significant challenges in its organic decomposition. Like many other regions, Sri Lanka is also facing many challenges due to inadequate waste management practices. One of the areas that help to solve this problem effectively is the development of waste recycling technology. Municipal solid waste takes a long time to decompose naturally and often produces unpleasant odors. Therefore, it is essential to develop an appropriate technology to accelerate their decomposition to manage the problem at the grassroots level. This research aims to provide a technical solution to these pressing issues in waste management and recycling.

The scope of this research is to improve an ordinary kitchen garbage composting machine by introducing controlling variables such as temperature and humidity, heating capacity, aeration, and optimization of the local climate within the composting chamber to develop a conducive environment for microbial activities. This would enhance the microbial growth rate and increase the quality of compost while reducing the residence time of garbage. Other than this the research aims to reduce the odor during the recycling.

II. LITERATURE REVIEW

Composting techniques can artificially accelerate and enhance the effectiveness of the process. They include open-air composting, direct composting, vermicomposting, etc. [1]. The materials used, moisture level, temperature, and the aeration of the pile are affecting factors to the success of the composting process [2]. Composting additives can also be used to improve the quality of the compost. Additionally, the sections will cover the possibilities for composting machinery in Sri Lanka and the different heating methods that can be used in the composting process, such as band-type heaters or blanket-type heaters [3]. The structure of the machine, including the mixing mechanism, instrumentations, and quality control of the compost. Odor is a common issue in composting, both in large-scale and small-scale operations. Several technologies can be used to treat odors in composting operations. These technologies can be categorized as biological, physical, and chemical [4]. To identify the quality of the compost have to check moisture content, visual screening, organic matter, C-N ratio, pH, etc. [5].

III. MATERIALS AND METHODS

A. Materials

Drum and mixer - Mild steel, Odor filtration system - Active carbon, sheet metal and steel pipe

B. Methods

The setup includes a circular drum with a volume of 0.334m^3. The final product can be retrieved from the lower door after the process is completed by adding garbage through the upper door.

Fig. 1. The drum with garbage

Electric heating blankets are used as the heating source to control the temperature inside the drum. The heating blanket is a surface heating system with an Ordinary electric heater and thermostat, silicone and resin insulation, and fiberglass fabric sheathing [3].

Fig. 2. Container with heater pads

Active carbon was inserted into the filtration system. Active carbon absorb odor from exhaust air. 100g of active carbon enough for 24 months.

Fig. 3. Active carbon filtration arrangement

Cooling fan was maintained a maximum air supply flow rate of 50 m^3/h.

Fig. 4. Air supply system assembled to the machine

The mixing mechanism utilizes a double ribbon mixture. The optimal rotational speed for this mixture is 25 revolutions per minute.

Fig. 5. Double ribbon mixture

IV. Results and Discussion

A. Results

1) Effect of temperature

The required temperature range of the garbage is between 50°C and 65°C to maximize the bacterial growth rate. Testing was conducted with and without load and supplying air until the desired inside temperature of garbage was achieved.

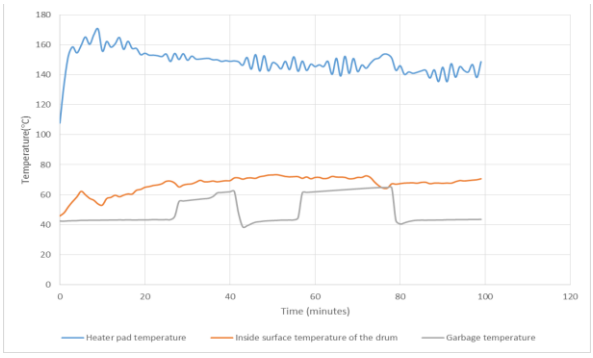

Fig. 6. Temperature variation of garbage at 120 °C supply temperature

2) Effect of additives

The study found that compost fertilizer produces high-quality compost. Additionally, it was observed that the quantity of additives affects both degradation time and quality. The optimum ratio was identified 10:1 of garbage to compost fertilizer.

Fig. 7. Nature of additives added garbage

3) Quality test results

pH = 4.5, Moisture content = 45%, Bulk density = 1428 kg/m^3 ,Organic matter = 99%, Total Nitrate = 0.009 mg/l, Total Organic Nitrogen= 0.008-0.1w/w%, Total phosphate = 0.54 mg/l

B. Discussion

The final product can be taken after 3 days of machine process. While the continues heating operation, and the mixing operation 4 hours per day, and should be supplied air 8 hours per day to control the moisture of the garbage.

V. Conclusion

The implementation of an active carbon filtration system was utilized as an effective strategy to mitigate unpleasant odors. To ensure the efficient operation of the composter, a minimum of 7kg of garbage was required. For optimal performance, it was recommended to incorporate 10:1 ratio of garbage to compost fertilizer, factoring in considerations such as availability and cost. Attaining the desired internal temperature within the waste unit was accomplished by setting the heater pads to a rated temperature of 120°C. Moreover, recirculation of air could help in maintaining a uniform moisture level, resulting in the production of compost with a relatively high quality, meeting the required moisture level, and reduced electricity consumption. Through the operation of the machine. The operation of the machine continuously for three days and then removing the compost from the machine to an open place has improved the compost quality with reduced odor generation. This machine can be used as the best solution for winter to manage food waste.

Acknowledgment

We express our gratitude to all who helped, including the Department of Mechanical Engineering at the University of Moratuwa and the project supervisors, Prof. J.G.A.S. Jayasekara and Eng. Lal Weerasinghe, for their invaluable guidance and assistance.

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Design of Refuse Collection Mechanisms for an Intelligent Beach Cleaning Robot

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Keywords - Beach cleaning robot, refuse collection, raking, sieving shaker, motion study analysis.

I. INTRODUCTION

Ensuring the protection of natural habitats from growing coastal pollution includes the important task of cleaning plastics from beaches. The buildup of plastics and debris not only endangers marine life but also amplifies the problems, underscoring the need for effective intervention measures.

While manual beach cleaning efforts are admirable, they are time-consuming and can lead to health issues for workers, including musculoskeletal diseases. Moreover, relying solely on manual labor proves inadequate given the large scale of the problem. Thus, there is an urgent need for advanced technological solutions capable of assisting and enhancing human efforts. This paper advocates for the deployment of intelligent beach cleaning robots as a promising approach towards a more sustainable and efficient strategy for mitigating coastal pollution.

II. LITERATURE REVIEW

The development of design and implementation of refuse collection mechanisms has garnered significant attention in recent years as they have emerged as a critical area of research. These robotic systems are tasked with the formidable challenge of efficiently managing refuse in coastal areas, necessitating robust and adaptive collection mechanisms.

The robot “Binman” introduces a filtration component comprised of a conveyor equipped with rows of steel tines [1] which exhibit spring-like characteristics with a degree of torsion, enabling the capture of waste with a sand director guide. But utilization of continuously rotating conveyor belt makes it to have ineffective energy usage and unavoidable battery consumption. The robot “Hirottaro” discusses a system utilizing a brush mechanism which emulates the functionality of a floor cleaning human with a broom and dustpan [2] by a linkage mechanism. However, this robot exhibits substantial size and entails significant expenses. In later contributions, a modular robot uses an anterior claw appendage [3] which was conceived and affixed to the robot, facilitating the retrieval of cans from ground level. Nonetheless, this gripper design configuration demands a significant power supply. Moreover, a radio-controlled bot is designed with a filtration segment of sieve [4] which contains a wire mesh to transfer all the ploughed sand on it, and another one incorporated a picking up mechanism [5] which makes it focused for can collection but ineffective for other wastes.

But what we emphasize is the need for a robust collection system that can adapt to varying types and sizes of debris commonly found on beaches. This paper demonstrates the efficacy of dual modes of refuse collection mechanisms (in which only one mode can be selected at a time): raking mechanism and sieving shaker mechanism. Building upon previous work, this research introduces a cost-effective approach that leverages intelligent systems to enhance refuse collection capabilities.

III. MATERIALS AND METHODS

The proposed prototype combines two modes of refuse collection mechanisms to be affixed onto a tracked mobile robot platform. It includes a raking mechanism tailored for the retrieval of larger-sized debris and a sieving shaker mechanism designed for sand filtration. The aforementioned mechanisms were designed using SolidWorks software.

A. Raking Mechanism

This configuration, as shown in Fig. 1, incorporates a rake-like implement with a revolute joint arm with 1 DOF, facilitating the elevation of debris into a designated storage bin. The rake itself measures 32 cm by 25 cm, with a height of 20.4 cm from ground level. Each branch of the rake features a 30:31 dual curve bending and maintains a 1.6 cm spacing within the array. For producing the components for this mechanism, 3D printing is employed. This mode of refuse collection is complemented by object detection, ensuring swift and efficient servicing of the robot, thereby

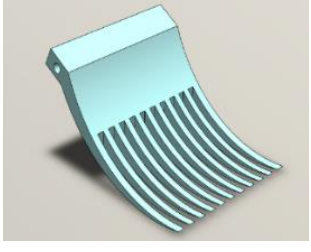

Fig. 1. Raking Mechanism

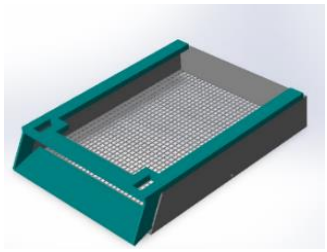

Fig. 2. Sieving Mechanism

minimizing operational downtime during cleaning procedures.

B. Sieving Shaker Mechanism

As shown in Fig. 2, this mechanism includes a sand director measuring 32 cm by 4 cm, responsible for elevating debris to the sieve area. A vibrating mesh is deployed for the purpose of sifting through sand, while effectively retaining solid waste. The mesh possesses dimensions of 32 cm by 40 cm and maintains a height of 6 cm. Given the necessity for robustness in the components, the fabrication of parts for this mechanism was accomplished using sheet metal. This mode primarily targets the capture of larger debris categories, including plastics, glass, wrappers, and driftwood, while allowing smaller sand particles to pass through. The collected refuse is subsequently transported to a designated storage compartment for subsequent disposal.

C. Other related functionalities

Fig. 3 illustrates the combined robot utilizing the above two mechanisms. During the operation of the raking mechanism, informed by object identification via YOLO (You Only Look Once) model and guided by the VFH (Vector Field Histogram) algorithm which generates a grid-based map with plastics and obstacles, the robot autonomously determines an optimal path to approach and collect plastics. And upon activation of the sieving shaker mode, the robot utilizes sensor inputs to navigate along a predetermined path, considering obstacles en route and adeptly maneuvering around them. This mode allows for effective filtration of sand while ensuring the efficient movement of the robot. These operations will be implemented with an RGB camera and a Laser Range Finder.

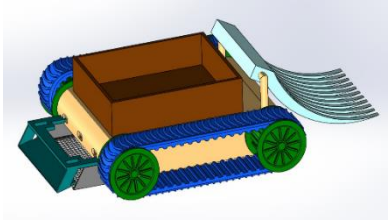

Fig. 3. Combined Design of Robot Prototype

IV. RESULTS AND DISCUSSION

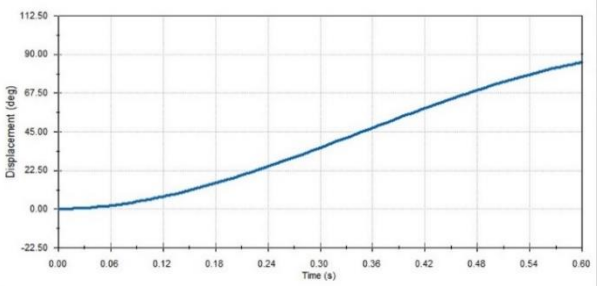

Fig. 4. Displacement(degrees) vs Time(s) graph for Raking Mechanism

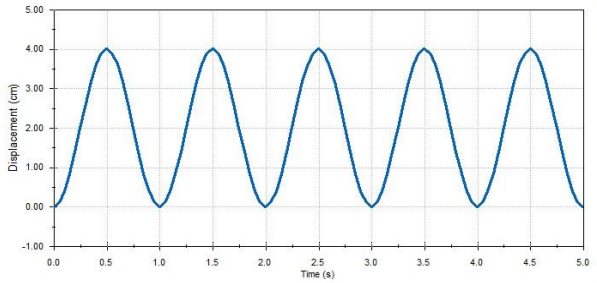

Fig. 5. Displacement(cm) vs Time(s) graph for Sieving Mechanism

The motion study analysis of the dual modes of garbage collections was performed using SolidWorks software.

Upon detecting the presence of garbage, the robot will initiate movement towards it. Subsequently, the raking arm will acquire debris from the ground by rotating the revolute joint through an angle ranging from 90 to 150 degrees, facilitated by servo motors. Fig. 4 depicts the angular displacement of the rake with time at a speed of 10 rpm for a rotation through 90 degrees.

The vibration mechanism of sieve mesh operates at a predefined frequency of 1Hz (60 rpm) and maintains a vibration range of 4 cm. The oscillation of vibration of the sieve is shown in Fig. 5 above. The sand director frame is securely affixed to the sieve mesh frame via an interconnector comprising two joints - one rigid and one free.

V. CONCLUSION

The 3D model of the mechanisms was designed according to the predetermined plan and subsequently subjected to simulation using specific parameters. Our singular prototype selection driven by identified research gaps, is grounded in a thorough literature review. Filling the void of models with integrated essential mechanisms, the prototype prioritizes cost-effectiveness, positioning it as an innovative force. Further improvements will be implemented through a detailed analysis of their optimal values.

Furthermore, we aim at creating a solution for effectively identifying and/or separating seashells from beach debris. Seashells, being primarily composed of substances like $CaCO_3$ and Chitin, based on their unique functional groups, chemical bonds, and molecular arrangements, we can analyze and prepare the FTIR (Fourier Transform Infrared) and Raman spectra of seashells. Following the use of a suitable algorithm, we can compare the real-time spectrum data with the created database to discern seashells from other wastes.

Moreover, thus far our robot relies on human intervention to select its operational mode. So, we intend to develop a proactive behavior with an algorithm that empowers the robot to autonomously initiate and execute tasks without explicit human guidance.

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Investigating Pomegranate Rind Dye for Wearable Health Monitoring: A Colorimetric Approach to Analyzing Sweat, Glucose, and Insulin

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Keywords - Colorimetric Sensing, Wearable Technology, Natural Dyes, Sweat Sensing, Smart Textiles

I. INTRODUCTION

This study investigates the potential of pomegranate rind dye, a natural source of pH-sensitive anthocyanins, in the field of health monitoring through the colorimetric detection of sweat analytes, markers of physiological states [1], [2]. Addressing the limitations of cost and complexity inherent in traditional sweat analysis methods prevalent in healthcare and sports science [2], [3], our approach utilizes colorimetric analysis. This technique, simpler and more cost-effective, relies on visual color changes in response to specific analytes for quantitative data acquisition [1]. Emphasizing sustainability and economic feasibility, our research highlights the potential of natural dyes, particularly pomegranate rind, in creating eco-friendly, cost-efficient textile-based indicators for health monitoring applications, including fertility and menstrual cycle tracking.

II. LITERATURE REVIEW

Reflecting a novel approach, this research examines the colorimetric sensing capabilities of pomegranate rind dye, owing to its rich anthocyanin content and focuses on the development of passive sensors using fabric infused with pomegranate rind dye, a groundbreaking concept in wearable technology. Such sensors are envisioned to detect sweat analytes, providing insights into individual well-being. This study not only aligns with the environmental shift towards sustainable materials but also addresses a critical research gap. It explores the potential of natural dyes, particularly pomegranate rind, in creating eco-friendly, reliable wearable bio-indicators with additional antimicrobial properties [1]. While previous studies have highlighted challenges in the consistent extraction and stability of natural dyes [1], [2], this research aims to overcome these hurdles, thereby contributing significantly to the paradigm shift towards sustainable, non-invasive, and personalized healthcare modalities.

III. MATERIALS & METHODS

The materials used in this study included Pomegranate Rind *(Punica Granatum)* peels, 100% cotton fabrics, and distilled water. The authenticity and purity of pomegranate peels was validated via a spectrophotometric assay for anthocyanin content. This approach was selected for its feasibility in a university lab setting. The process involved grinding dried pomegranate peels to enhance anthocyanin extraction efficiency, followed by extraction using acidified

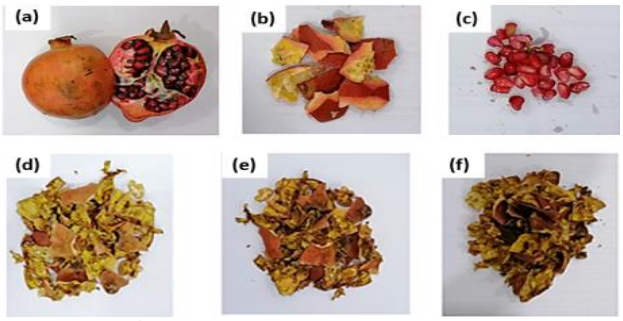

Fig. 1. Stages of Pomegranate Rind Preparation: (a) Whole Fruit, (b) Rind, (c) Seed, (d) 1-Week Dried, (e) 2-Weeks Dried, (f) 3-Weeks Dried

methanol. The extract was left overnight for thorough anthocyanin extraction, then filtered to isolate the anthocyanin-rich solution. We quantified anthocyanins by measuring absorbance at 520 nm using a spectrophotometer, comparing it against a calibration curve. This method, repeated for multiple samples, confirmed the peels' suitability for dyeing and their application in health monitoring textiles.

For preparation, the peels were thoroughly washed to eliminate contaminants, then shade-dried for 3-4 weeks to remove moisture, which is crucial for preventing microbial growth and maximizing dye concentration. The dried peels were ground into powder for uniform dye extraction. The dye was extracted by dissolving this powder in distilled water and heating, with temperature control to optimize anthocyanin extraction. The resulting vibrant dye was applied to cotton fabrics, chosen for their compatibility with natural dyes, using a double immersion technique to ensure color depth and uniformity for accurate sweat analyte analysis.

To augment the dyed fabrics' functionality, we employed microencapsulation, preparing sodium alginate mixed with pomegranate dye and forming microcapsules in a calcium chloride solution. This was done to control dye release and enhance fabric functionality in health monitoring. We carefully controlled the microcapsules' size, maintaining a 1-2 mm diameter to optimize surface area for sweat analysis. The microcapsules were evenly applied to the fabrics, properties for health monitoring. Post-treatment, fabrics were cured at 60°C to improve color fastness and stability against environmental factors. The colorimetric response of the dyed

fabrics to sweat analytes was assessed using spectrophotometric methods ensuring consistent dye release and maintaining functionality. To ensure repeatability and consistency, we tested 30 samples for each method (dyeing, microencapsulation, combined) and analyzed the results statistically. Additionally, Scanning Electron Microscopy (SEM) was used to examine the dye distribution and microcapsule integrity on the fabrics.

IV. RESULTS & DISCUSSION

A. *Colorimetric Analysis and Color Changes in the Pomegranate Extract*

The colorimetric response of the extract to chemical stimuli is as shown in Fig 2. The extract's color transitioned from pale yellow to reddish yellow upon the addition of Sodium Hydroxide (NaOH), consistent with the known pH sensitivity of anthocyanins. Conversely, Hydrochloric Acid (HCl) decolorized the extract, highlighting anthocyanin's reactivity to acid. The extract also displayed varied color responses to Aluminum Potassium Sulphate, Sugar solution, and Insulin solution, turning green to ash/black, bright yellow, and vivid yellow, respectively, and adopted a vivid yellow hue with an Insulin solution, indicating complex interactions between the anthocyanins, metal ions, and various molecules, demonstrating the extract's capacity as a versatile colorimetric instrument for physiological assessments.

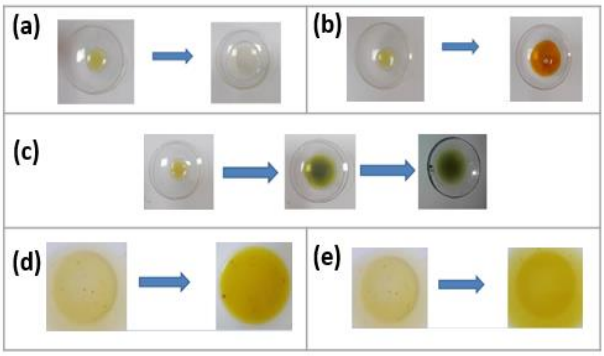

Fig. 2. Colorimetric Responses of Pomegranate Dye: (a) 20% NaOH, (b) 20% HCl, (c) 10% $AlK(SO_4)_2$, (d) 10% Sugar Solution, (e) 10% Insulin Solution.

B. *Comparison of Color Strength*

The spectrophotometric analysis of the pomegranate rind dyed samples; dyed, encapsulated, and both dyed and encapsulated, as depicted in Fig.3, reveals insightful differences in their color / colorimetric properties. The analysis focused on three main aspects: lightness (DL), chroma (Da, Db), and hue (DH).

The dyed samples, both with and without encapsulation, exhibited a darker tone as indicated by their negative DL values, with the purely dyed sample showing a slightly darker appearance than its dyed and encapsulated counterpart. This darker tone in the dyed samples is associated with a higher chroma, suggesting a richer color saturation. In contrast, the Pomegranate Rind Encapsulated samples displayed a lighter shade, evidenced by their less negative DL value. This lighter coloration is crucial for health monitoring textiles where color change is a key indicator of analyte presence. The lighter shade provides a more distinct contrast, making it easier to observe and quantify color shifts that indicate changes in sweat analyte concentrations, which could be less perceptible against a darker background.

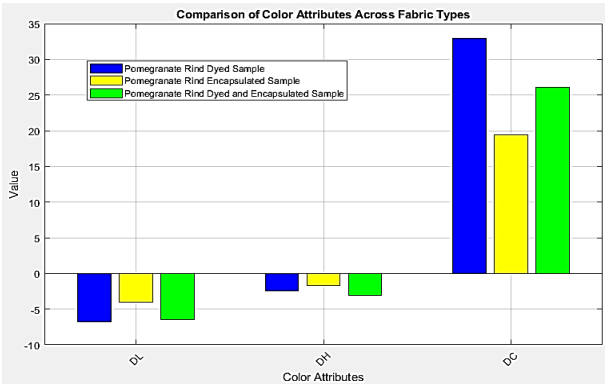

Fig. 3. Comparison of Color Strength of treated vs untreated samples

Moreover, encapsulation improves color fastness, protecting the dye from environmental factors and ensuring the stability and longevity of the color. This aspect is critical in health monitoring applications, where the durability of the colorimetric response is as important as its accuracy. While the dyeing process alone imparts a more intense color, the encapsulation process, yielding a lighter shade, is more advantageous for health monitoring. It balances visibility, crucial for detecting colorimetric changes, and durability, ensuring the longevity of the fabric's functional properties. The hue analysis across all samples indicated a shift towards bluer tones, with the purely dyed sample showing a more pronounced shift. This shift in hue, alongside the observed differences in lightness and chroma, demonstrates the significant impact of the dyeing and encapsulation processes on the color properties of the fabrics. Thus, the findings highlight the versatility of pomegranate rind extract as a natural dye, offering diverse coloration possibilities for various applications, particularly in the field of responsive health monitoring textiles.

V. CONCLUSION

This study explores the potential of encapsulated pomegranate rind dyes as effective colorimetric indicators for health monitoring. These dyes exhibit notable sensitivity to a range of chemical stimuli, making them suitable for detecting specific health markers. The encapsulation process enhances their distribution and stability, crucial for consistent and reliable colorimetric responses. While challenges such as data analysis latency, contamination risks, and limitations in current microfluidic systems remain, continued research is essential to address these issues. Advancements in these areas will further solidify the role of pomegranate rind dyes as valuable tools in personalized healthcare diagnostics.

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Development of a New Bio-based Adhesive for Cardboard Using Latex of Pterocarpus Indicus

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Keywords - bio-based adhesive, latex, Pterocarpus indicus, adhesive strength

I. INTRODUCTION

Bio-based adhesives are derived from renewable resources such as plant-based materials, animal by-products, and microbial sources. Latex-based bio adhesives, specifically those made from natural latex derived from plant sources, have garnered significant research interest. While natural rubber remains the most commonly used bio source for latex adhesives, this study explores the potential of Pterocarpus indicus wild (PIW) latex as an alternative and discusses modifications that can be made to enhance its adhesive properties. Additionally, this research examines the effect of additives such as Polyvinyl Alcohol (PVA) on the adhesive properties of natural latex while evaluating their capacity for adhesive performance. The major challenges faced by existing bio-based adhesives, including low bonding strength and water resistance are acknowledged. Consequently, this study offers guidance on advancing new plant sources for bio-based adhesives, addressing the limitations of current adhesive products.

Adhesives are social substances and can be defined as a mixture in a liquid or semi-liquid state, capable of joining permanently to surfaces, by an adhesive process [1]. Bio-based adhesives are a type of adhesive that is made from natural and renewable resources, such as plant-based materials [2]. These adhesives are becoming increasingly popular due to their sustainability and environmentally friendly nature, as they have a reduced carbon footprint and are biodegradable.

The disadvantages of the current bio sealants can restrict their use in some circumstances. Their lower strength and longevity compared to conventional adhesives are significant drawbacks. Some bio-based adhesives are also moisture-sensitive and may lose their adhesion when exposed to moisture or high humidity [3]. Due to the higher expense of obtaining and processing natural materials, bio-based adhesive production has another disadvantage. Additionally, bio-based adhesives' scalability and broad use may be constrained by the lack of readily available natural materials. Additionally restricting their use in some applications, some bio-based adhesives have a lower shelf life than conventional adhesives.

Making bio-based adhesives calls for specific understanding and proficiency in chemistry and materials science. The final product, though, is a long-lasting and environmentally friendly adhesive that can be applied to many different things, including packaging, textiles, and construction [4].

II. METHODOLOGY

A. Materials

Fresh latex was extracted by tapping the bark of PIW tree. Chemicals needed to modify latex samples were supplied by the polymer laboratory, department of material science and Engineering. They are 25% (w/w) Ammonia solution, Poly vinyl alcohol (PVA), Calcium carbonate, Acetone, Acetic acid, ethanol, Carboxymethyl Cellulose (CMC), and Glycerol.

B. Methods

PIW latex was applied on 2 cardboard materials that were used for packaging. Cardboard was adhered to by external force and roughly tested for primary adhesive properties. Approximately, 5 ml sample of PIW latex was taken and 0.1 ml of 25% (w/w) of ammonia solution was added using a syringe. The latex sample was kept for 1 day and tested for adhesive strength using cardboard. First, 15 g of CMC was taken and dissolved in 250 ml of boiling water by continuously stirring. Afterwards, 250 ml of cold water was added and stirred again. After 30 minutes CMC was completely mixed. This mixture was put into a container and left closed for 24 hours. 20 g of PVA was dissolved in a 500 ml of boiling water while stirring. After 30 minutes PVA was fully mixed. CMC solution, PIW latex and PVA solution were mixed at different ratios. 2 batches were made.
Batch 1 – CMC solution and Preserved PIW latex were mixed in a ratio of 1:2.
Batch 2 – CMC solution, Preserved PIW latex and PVA solution were mixed in ratio of 1:1:1.

C. Testing

- *Bond permanency test*

Each adhesive sample was tested by the following procedure, after each modification. The testing procedure was based on Sri Lanka Standard – Specification for General Purpose Paper Adhesives (SLS 660:1984).

- *Peel resistance test*

Peel resistance is the average load per unit width of the bond line required to produce progressive separation of two

bonded, flexible adherents. It is performed on a tensile testing machine using specially made specimens.

III. Results and Discussion

PIW latex was developed as an adhesive CMC. CMC is a water-soluble polymer derived from cellulose, which is a natural component of plant cell walls. It is widely used in various industries, including food, pharmaceuticals, and personal care products, as well as in adhesives [5]. CMC is not typically used as a solvent for adhesives. Instead, CMC is used as an additive or thickener in adhesive formulations to improve their properties. In adhesives, CMC is used as a thickener to increase the viscosity of the adhesive, which helps to control its flow and improve its adhesion properties. CMC can also enhance the adhesive's open time (the time during which the adhesive remains workable before setting) and increase its bond strength. However, CMC itself is not used as a solvent for adhesives. Solvents in adhesives are typically liquids that can dissolve or disperse the adhesive's components, helping to reduce its viscosity and make it easier to apply. Common solvents used in adhesives include water, ethanol, acetone, and toluene. In this approach CMC is dissolved in water and later PIW latex was added to increase the adhesive properties. Additionally, PVA is used as an adhesive enhancer.

PVA is an adhesive that enhances bonding strength through multiple mechanisms. PVA molecules interact with surfaces through hydrogen bonding and van der Waals forces, creating strong adhesive bonds. Its excellent penetration and wetting properties enable it to seep into pores and crevices, forming a mechanical interlocking effect. The suitable viscosity allows PVA to spread and conform to surfaces, increasing contact and bonding area. As it dries, PVA undergoes cross-linking and polymerization, reinforcing the adhesive layer and creating a stable bond. Its elasticity accommodates material movements without compromising the bond's integrity. Moreover, PVA is non-toxic and gentle on substrates, leading to durable, non-damaging bonds.

Shear tests are done for 3 sets of specimens which were made of batch 1, batch 2 and Chemifix. The specimens were made of craft paper 200 gsm. 3 tests were done for each adhesive type and the average shearing force is calculated.

TABLE 1: MAXIMUM SHEAR FORCE VALUES FOR ADHESIVE SAMPLES

Adhesive Type	Average Shear Force (N)
Batch 1	154.12
Batch 2	175.46
Chemifix	189.76

The above observation shows that PIW latex-based adhesive has nearly better adhesive strength compared to existing products like Chemifix. This observation justifies the effect of PVA which was added in batch 2. PVA increases the adhesive strength.

Peel resistance test was done for batch 1, batch 2 and Chemifix adhesive samples and the following graphs were obtained. According to the test results, below average peel resistance values were obtained. When calculating average value, initial peeling forces were neglected, and force values of continuous peeling were taken.

TABLE 2: MAXIMUM SHEAR FORCE VALUES FOR ADHESIVE SAMPLES

Adhesive Type	Average Peel Strength (N)
Batch 1	8.42
Batch 2	11.01
Chemifix	11.87

This observation shows that PIW latex alone has good adhesive properties, which are represented by batch 1. Batch 2 was made by adding PVA to the adhesive mixture and it clearly indicated the effect of PVA on adhesive strength. PVA molecules form intermolecular interactions with the surfaces of the materials being bonded. These interactions, such as hydrogen bonding and van der Waals forces, create strong adhesive bonds between the PVA and the substrate. The formation of these interactions increases the surface area of contact between the adhesive and the material, leading to higher bond strength [5].

IV. CONCLUSION

The successful development of a new bio-based adhesive is contingent upon several factors, including the availability of suitable bio sources, the preservation time of the extracted biomaterials used in adhesive production, and the fundamental adhesive properties. Considering the obtained results, it has been found that the adhesive derived from Pterocarpus indicus latex exhibits the highest potential for commercialization. Using CMC as a thickener and PVA as an adhesion increment has given good test results for PIW latex-based adhesive. Nonetheless, certain enhancements are required to optimize its properties, such as reducing the curing time, improving storage stability, and extending the preservation duration. Furthermore, modifications can be made based on the chemical origin of the latex sample. Notably, the bonding strength of the newly modified adhesive demonstrates a noteworthy advancement when compared to existing adhesive products.

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Intelligent Wheelchair Controller System for Human-Robot Interactions

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Keywords—Robot controlling, layered architectures, Human-robot Interactions.

I. INTRODUCTION

Robot controllers are crucial when executing high-level algorithms. Sometimes designing these controllers from scratch will be the best solution for building robots. However, the process will consume much time to build all the electronics and other mechanical hardware from scratch. Therefore, for rapid prototyping continuing from the available hardware will help a lot to save time. Additionally, low-level controllers are crucial when it comes to autonomous robot manipulations [1]. The outcomes produced via these embedded systems [2] will directly pass to the actuators to operate robots. Therefore, the accuracy of these controllers will also cost the overall accuracy of the entire system [3].

There are many types of controlling mechanisms to control wheelchairs. The pieces of evidence from the literature give many examples[4-7]. Out of these controlling techniques, controlling via a joystick [8] is the default controlling mechanism for almost all wheelchairs. When designing novel controlling mechanisms, the way of perceiving environmental details and delivering control signals that are produced with the algorithms is very important and crucial.

When exploring the literature, it shows that layered architecture is preferred for implementing controller mechanisms[9,10]. However, the possibility of integrating hardware systems on top of available designs are challenging task to achieve. Even though the literature shows many developments for controlling mechanisms, scaling these hardware units to align with the present knowledge expansions on the algorithms is far below the expected level.

Therefore, this work proposed a novel layered hardware unit to replace existing joystick-based controllers and integrated software modules with the help of the proposed layered architecture. Moreover, the work suggests injecting the data by replacing the already available joystick controller of the wheelchairs. In the rest of the article, section II will introduce proposed architectures, and section III will showcase the results based on the observations and follow up with the discussion. Section IV will conclude the paper with future directions.

II. WHEELCHAIR CONTROLLER DESIGN

The proposed controller has a layered architecture that can be scalable as per the expansion of the Wheelchair capabilities. The following two sub-sections provide a detailed overview of the proposed mechanism. Following Fig. 1 illustrates the complete hardware and software architecture.

A. Hardware-Layered Architecture

The development of the main embedded system will be discussed in this section. In the process of developing an Intelligent Wheelchair System including a Robotic arm, it needs a set of controller units and a core central unit which will bring the interconnection among these controllers. Under this work, it is discussed about the sub-controller unit which is responsible for handling the kinematics of the wheelchair. The key aspect considered is the development of a scalable hardware unit while utilizing the available hardware system as much as possible. With this route, it proposed to reduce the cost while enhancing the usability of commercially existing wheelchairs.

Since electric wheelchair systems are composed of many sub-units it needs considerable computational power to handle all the respective tasks. Therefore, for this purpose separate single-board computer(Jeston Nano*) is used while the bottom-level functions will be handled by another distinct Arduino ATMEGA328p** based hardware unit. At the bottom layer wheelchair controller receives controlling signals as analog voltages via the integrated digital-to-analog(DAC) converter circuits. Then the intelligent systems can be controlled with the supplied voltages and also activate other security considerations which are added to the system when releasing the commercial product. Further, five separate DACs are used to control each unique channel separately.

B. Software- Layered Architecture

One of the main intentions of this work is to design a hardware layer in such a way that it will readily adapt to a novel software model presented with the continuous expansion of the knowledge generated by the research. To achieve the intention, a separate layered software architecture was designed and evaluate the feasibility of the proposed mechanism. As the central hub ROS environment was selected and joined the central controller unit with the low-level motor controller unit. Significantly the novel algorithms proposed for the controlling techniques of the wheelchair are added to the processing layer (Fig. 1). which again provides more scalability to the available functionalities.

III. RESULTS & DISCUSSION

The developed hardware design was tested with the electric wheelchair to identify the accuracy of the controller. Fig. 2 shows a complete sequence of turning the wheelchair by a user. The sub-figures depict how wheelchair control over a given specific angle at a time. As shown in Fig. 2, position and orientation vary since the user controls the speeds of the wheels separately. It is observed that the chosen turning angle has a maximum positive error of up to 21° from the required angle that again depend on various other factors including

* https://developer.nvidia.com/embedded/jetson-nano-developer-kit
** https://www.microchip.com/en-us/product/atmega328p

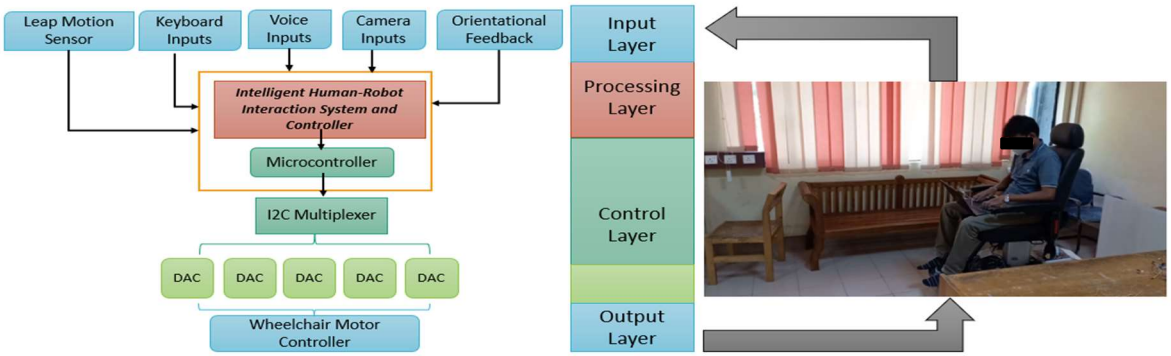

Fig. 1. Overall block diagram of the proposed layered software hardware architecture.

Fig. 2. The sequence of diagrams illustrates how a user can smoothly control the wheelchair with the developed layered hardware and software module. The sequence begins from the leftmost image which depicts the user moving in a straight course and changing his trajectory by turning the Wheelchair by 90°. The generated trajectory is a curved path since the user selects both move forward and turn functions simultaneously.

overall weight, nature of the surface, and initial orientation of the caster wheels. Further, the controller received feedback from the integrated initial measurement unit(IMU) sensor for maintaining the exact orientation. Positional variations are purely controlled with the user's inputs and can control all the movements of the wheelchair via four specific keyboard inputs which can further expand to other input mechanisms.

The results will be highly affected by the surface properties. For example, there will be a small error in the final orientation of the wheelchair which depends on the frictional coefficient of the floor. However, the error compensating mechanism of the module can bring the final rotational accuracy up to a maximum of positive 10° error which could be further examined with the floors having different frictional coefficients in the future.

While keeping all the safety features of the wheelchair system as it is, and with the identified acknowledgment sequence, the controller successfully communicates with the inbuild motor controllers via serial communication established with the proposed architecture. This illustrates that the work can be utilized to control Joystick-based state-of-the-art wheelchairs. Moreover, the understanding of the layered structures obtained from the proposed work can also be used in other autonomous robot controllers as well.

IV. Conclusion

The proposed human-robot controller produced positive results with the experiments carried out to confirm the controllability of the intelligent wheelchair system. Further software architecture proposed with the work enhances the scalability of the project as well. In the future development, all the key components of the overall controller including high-level functionalities of the Intelligent Wheelchair System with the work described by this article can be deployed to establish a fully equipped control system. Additionally, more parameters can be identified to minimize the errors discussed in the discussion section. Therefore, the effort proposed in this work is designing a layered hardware and software architecture for human-robot interaction made in intelligent wheel-chair systems.

Acknowledgment

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Experimental Bending Performance Characterization of sHAMs Used Underwater Growing Robot

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Keywords—Soft growing robot, sHAMs, Steering, Exploratory, Robot body diameter

I. INTRODUCTION

Soft-growing robots represent an emerging field characterized by their ability to extend at the tip while the base remains stationary. These robots offer a unique advantage in navigating through confined spaces inaccessible to humans. Specifically, in underwater exploration tasks, their flexible bodies render them particularly efficient. Moreover, these robots exhibit the capability to steer even while growing. There exist several steering methods including sHAMs (soft Hydraulic Artificial Muscles), sPAMs (soft Pneumatic Artificial Muscles), tendon-driven techniques, and predefined bending mechanisms, applicable both in air and underwater [1],[2].

This paper specifically delves into the study of sHAMs (soft Hydraulic Artificial Muscles) and their inherent characteristics. Various critical factors influence the bending behavior of sHAMs, including pressure, the diameter ratio between the robot body and the sHAM, the length of the robot body, and the number of sHAMs employed. In this study, we concentrate on varying the diameter ratio between the body and sHAM, while keeping other parameters constant. To achieve this, we fabricated robot bodies with varying diameters while maintaining a constant diameter for the sHAM. By systematically analyzing the results obtained from this experimental setup, we aim to provide insights into how the bending angle varies in relation to the diameter ratio.

II. LITERATURE REVIEW

In previous studies, the prevalent approach for altering bend angles involved adjusting internal pressure, applicable both in air and underwater environments [3]. However, this method only allowed for a limited range of achievable angles. Also, head changing is a comparably costly process. And still, there are no concerns about the diameter ratio adjusting for bending angle adjustment. Notably, there exists a gap in research concerning the influence of diameter ratios on bending angles.

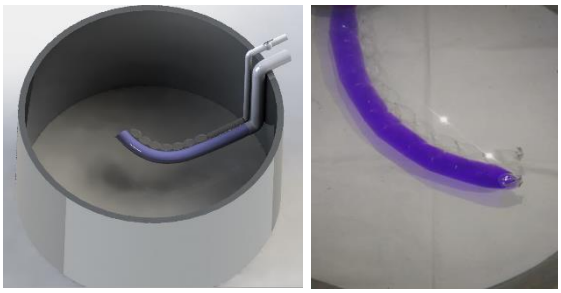
III. MATERIALS AND METHODS

The selected material for constructing the robot body and sHAMs is LDPE (Low-density polyethylene), chosen for its lightweight and flexibility.

A diameter (d) of 2.426 cm was chosen for sHAM, while diameters (D) of 2.426, 3.234, 4.851, and 6.468 cm were selected for the robot bodies, considering the limitations of the tank size. The length of both the body and sHAM was standardized to 30 cm.

The primary focus of this experiment lies in the analysis of bending characteristics. Initially, the robot body will be grown by providing a constant flow rate of water. Subsequently, the sHAMs will be actuated by supplying water at fixed intervals under a fixed head to maintain consistent internal pressure.

A camera setup will capture a top-down view, enabling measurement of the angles. This experiment will be conducted five times for each body diameter type. The resulting data will be graphed and analyzed to establish a relationship between diameter ratio and angle.



(a) *(b)*

Fig 1. Experiment on sHAMs. (a) Experimental setup, (b) A bent sHAM.

IV. RESULTS AND DISCUSSION

The experiment yielded a dataset comprising observed values of bending angles corresponding to various diameter

ratios of the robot body and sHAM. These values were meticulously recorded and analyzed for their correlation.

In addition to the dataset, a graphical representation was generated to visually illustrate the relationship between diameter ratio and bending angle. The graph provides a clear visualization of the observed trend.

TABLE I. DIAMETER RATIOS AND BENDING ANGLE

sHAM Diameter (cm)	*Body Diameter (cm)*	*Diameter Ratio d/D*	*Bending Angle (o)*
2.426	2.426	1	121.29
			126.63
			124.11
			134.53
2.426	3.234	0.75	74.43
			83.2
			83.61
			80.28
2.426	4.851	0.5	37.44
			37.51
			40.58
			32.6
2.426	6.468	0.375	13.78
			12.56
			18.71
			20.35

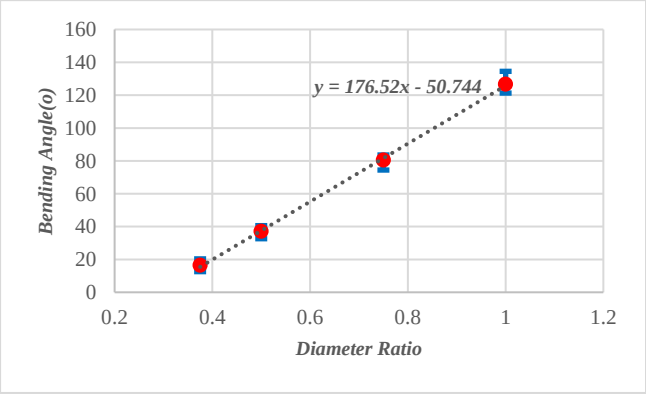


Fig 2. Diameter Ratios vs. Bending Angle

Considering the above graphical representation, it can be said that the bending angle of the robot body and the diameter ratio of the sHAM and robot body have a linear representation. The relationship can be represented by this equation.

$$y = 176.52x - 50.744 \quad (1)$$

This finding highlights the critical role of diameter ratios in achieving controlled bending behavior, a crucial aspect in the design and optimization of soft-growing robots. The observed consistency across multiple trials underscores the reliability of the experimental setup.

V. CONCLUSION

In conclusion, the experimental investigation focused on the relationship between diameter ratio and bending angle in soft Hydraulic Artificial Muscles (sHAMs) has yielded significant insights. The results demonstrate a clear linear correlation between these parameters, indicating that as the diameter ratio increases, so does the bending angle. This finding underscores the importance of considering diameter ratios in designing and developing soft-growing robots, particularly in applications requiring precise control over bending behavior.

The outcomes of this research not only contribute to the understanding of sHAM behavior but also offer practical implications for the design and optimization of soft-growing robots. Engineers and researchers can fine-tune the bending characteristics by strategically manipulating the diameter ratio to suit specific operational requirements.

In future studies, exploring additional factors that may influence bending behavior, such as material properties, pressure variations, and environmental conditions may be beneficial. Additionally, investigating the applicability of these findings in real-world scenarios and further refining the design parameters of soft-growing robots would be valuable avenues for continued research.

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A Single-Feed 3-in-1 Cinnamon Processing Machine

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Keywords—Mechanized cinnamon processing, cinnamon peeling, single feed operation.

I. INTRODUCTION

Cinnamon holds global recognition as a necessary spice and a vital food ingredient. Apart from being highly regarded as a spice, it shines in areas such as medicine, as a powerful agent against cancers, heart diseases, and diabetes [1], [2]. Various cinnamon breeds exist worldwide. True Cinnamon, native to Sri Lanka and commonly known as Ceylon Cinnamon, is renowned for its superior taste, aroma, and quality. It contains significantly less coumarin, a potentially harmful substance when compared to alternatives such as Cassia cinnamon [3], [4]. Cinnamon trees yield various extractants, including cinnamon oil from leaves. The most sought-after extract is obtained from the inner bark, which is the primary focus of this project. The cinnamon industry exhibits remarkable resilience and growth, continuing strong export performance during the pandemic. While it faces fierce competition from Chinese Cassia in terms of quantity, Ceylon cinnamon remains unrivalled in quality.

Cinnamon extraction is a labour-intensive process cantered around harvesting the prized inner bark of cinnamon stems. Skilled workers are pivotal for ensuring product quality and process efficiency. High labor costs and the need for specialized skills in cinnamon processing pose significant challenges, leading to demotivation among planters and exacerbating the labor shortage issue.

In addressing above gaps, this research aims to design and develop an automated machine for cinnamon processing that includes the functions: scraping, rubbing, and peeling in a single feed, as a solution for the high demand of skilled laborers, with high efficiency and acceptable quality output.

II. LITERATURE REVIEW

The background study for this research started with a thorough analysis of the cinnamon peeling process followed by previous mechanization attempts related to this industry, and other related industries.

A. Traditional Cinnamon Harvesting Process

The process begins with harvesting cinnamon sticks, removing knots and leaves, and soaking the stems to facilitate later stages (see Fig.1). These later stages involve scraping to delicately remove the outer layer, rubbing with a brass rod to ease inner bark removal, and meticulous peeling with a stainless-steel knife tool. These initial steps form the basis for further processing tailored to specific cinnamon product outputs.

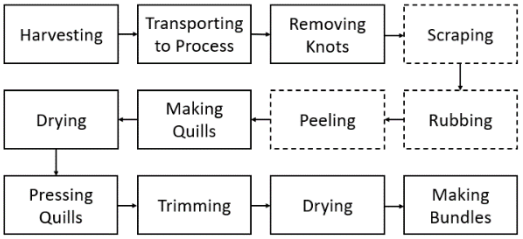

Fig.1. Steps of Traditional Cinnamon Processing

B. Previous Mechanization Attempts

This phase involved studying the previous attempts to mechanize the process. The identified design limitations are as follows:

- Mostly dedicated to accomplishing one singular task of harvesting process (scraping, rubbing, or peeling).
- Cinnamon stems do not have uniform shapes and different cross sections. These approaches mostly fail to address these factors.
- Not being developed up to an industrial performance level.
- Insufficient efficiency.
- Still requires skilled labor for a certain extent.

C. Mechanization Attempts of Similar Industries

In cassava peeling, sugar cane peeling, and timber debarking industries, similar forms of mechanization approaches could be seen. These studies gave insights into the concept development stage presented in this paper.

III. MATERIALS AND METHODS.

The following sections outline the research methodology.

- Literature Review and Field Visits:
  A comprehensive literature review was carried out to study the industry, previous attempts, and similar industries. A field visit was arranged to the National Cinnamon Research and Training Centre to explore and get hands-on experience in manual processing methods.

- Design Conceptualization:
  Various mechanisms and approaches were developed using for key processing stages.
- Morphological Analysis:
  . Morphological analysis is used to select mechanisms for conceptual design and in the subsequent process of choosing the final concept.
- Prototype Testing:
  Three individual sub-assemblies will undergo refinement to achieve their specific functionalities within the machine. The overall performance of the machine will be evaluated by measuring the purity of the chips it produces.

A full-scale functional prototype was built using stainless steel, box bars, nylon, and guitar strings. NEMA 23 stepper motors ensured precise operation.

IV. Results and Discussion

The developed mechanisms are shown in Fig.**2**, Fig.**3** and Fig.6. These were designed as modules to be assembled into a tall structure as shown in Fig.7 which is the CAD model of the complete assembly. The fully assembled mechanism is designed to process three steps, scraping, rubbing, and peeling in a single pass which is the novel concept presented in this research as the 'Single feed 3-in-1 mechanism'.

Scraping results were generally positive, with minimal inner bark damage, improved processing time with a sufficient quality output. Handling of non-uniform stems, however, has caused occasional inner bark damage. Further, issues with knots and stem diameters below 30 mm and above 45 mm were observed. The peeling mechanism displayed moderate control but caused some inner bark damage and had challenges related to resistance torque due to burrs, jerky motion, and issues with wire tangling. Effective peeling was limited to diameters between 30 mm and 45 mm. Fig.4 and Fig.5 shows the sample output of the mechanisms developed.

In traditional cinnamon processing, quill-shaped products of varying grades are the norm. However, the machine produces chips, which may contain unwanted elements such as outer bark and stem pieces. Since it is difficult to compare the machine-produced output with the quills produced in the manual method, the output quality is evaluated by measuring the weight of inner bark chips within 1 kg output.

Fig.2. Scraping Mechanism

Fig.3. Peeling Mechanism

Fig.4. Scraping Results

Fig.5. Peeling Results

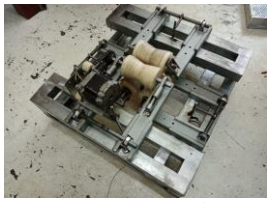

Fig.6. Rubbing/Transferring Mechanism

Fig.**7**. 3D Model of the Complete Assembly

Manufacturing and assembly complexities posed challenges, affecting component fitting and causing changes in shapes and dimensions. Burr on components impacted plate movements, and high spring tensions contributed to inner bark damage.

V. Conclusion

In conclusion, this project aimed to develop a single machine for scraping, rubbing, and peeling operations in cinnamon processing. The manual methods of three sub-processes were studied thoroughly through literature and field visits. It helped to identify issues and drawbacks in those processes. Thereafter, individual mechanisms were developed for scraping, rubbing/transferring, and peeling. These mechanisms were modeled using CAD package. Morphological analyses were carried out to select the most suitable mechanisms. Similarly, the most suitable design was selected. The prototype is developed in three segments, and it will be used to validate the concept. The objectives 1 and 2 have been achieved and further research is directed towards achieving Objective 3, which with the prototype testing stage.

The developed mechanism can only handle one cinnamon stick at a time. As further research, this design can be extended to handle multiple sticks (a bulk of cinnamon) at the same time, to increase productivity, and to accommodate a wider range of cinnamon stem diameters.

Acknowledgment

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A Coconut Deshelling Machine for Improved Safety and Productivity

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Keywords - coconut, deshelling, deshelling machine, desiccated coconut

I. INTRODUCTION

Coconut is the third largest cash crop grown in Sri Lanka. There are a variety of coconut-based products available, and deshelling is an essential step in the manufacturing processes of all those products. However, the deshelling process faces several safety concerns which are yet to be addressed. It was found through field visits that on average, 4 accidents per month are reported by the laborers who work in deshelling machines. These injuries are caused by slippage of coconut when it is held onto the cross cutter of the deshelling machine. Another concern was that the coconut kernel was damaged slightly by the cross-cutter, the cutting wheel of the current machine. This damage is significant when a large-scale coconut processing plant with over 200,000 nuts daily capacity is considered. The scarcity of skilled laborers to operate the deshelling machines is another challenge. Training new laborers is both a time-consuming and costly process.

Therefore, this research aims to develop a new mechanism for coconut deshelling to be used in an industrial setup. The mechanism intends to enhance the safety of the operation while reducing the damage to the kernel and to reduce human intervention in the process. The scope of this project is limited to deshelling a coconut starting from dehusked coconut and the intended output is kernel with brown skin while dehusking and paring will be out of the scope.

II. LITERATURE REVIEW

A. Previous proposals of coconut deshelling methods

Fig. 1 represents a motor-driven coconut deshelling machine developed to deshell split and partially dried coconuts older than 12 months or more. The coconuts were first dried inside a hot air electric oven up to 25-66% moisture level (dry basis) and the output was deshelled by an impact force created by the collision of coconuts with each other inside a rotating drum. The study claims that the machine can deshell a batch of 400 split coconuts in 4 min when the machine rotates at an optimum speed of 10 rpm. This means it works with one-fourth of the time compared to manual deshelling. It also claims that the coconuts must be dried up to 35% to achieve the maximum efficiency of 82% [1].

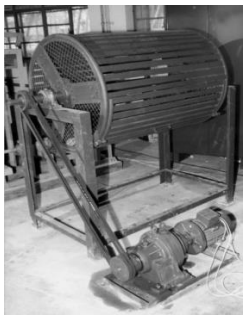

Fig. 1: View of the coconut deshelling machine [1]

Fig. 2 depicts a proposed machine to deshell coconuts by first segmenting the coconut shell into six rings using a "Dremel" cutting tool, then letting those partially cut coconuts to collide with each other inside a rotating drum. The study claims that skilled labour requirement is reduced since an operator is only needed to feed the coconuts, to switch the machine on and off and to monitor the process. Even though it ensures a reduction of human intervention in the deshelling process, the average time estimated for deshelling, which is 35 s is much higher than the manual deshelling time taken by a skilled labourer [2].

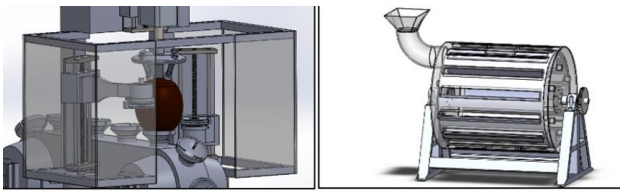

Fig. 2: Finalized design of cutting section (left) and rotary drum (right) [2]

Fig. 3 shows a coconut deshelling machine powered by a motor which is much similar to the existing machine in the industry (see Fig. 4). Coconut has to be fed manually and held against a rotating cross cutter which can break the coconut shell by applying a crushing force. In this research deshelling capacity and efficiency are evaluated based on the number of well deshelled fruits with respect to the time taken, and average deshelling efficiency and capacity are calculated as 90% and 195 nuts per hour respectively [3].

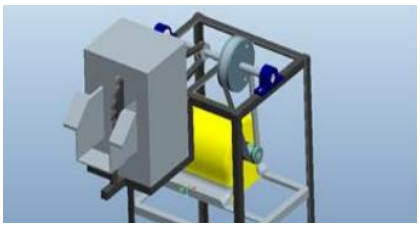

Fig. 3: 3D model of the proposed machine [3]

B. *Existing deshelling machine in the industry*

The Loluwagoda factory of Silvermill Group was visited by us, and it was found that the existing machine had two cross cutters instead of one. This was done to reduce the risk of coconuts slipping and causing injuries to the operators' fingers. The machine can deshell about 200 coconuts per hour. The company claims that this is the best possible machine available for deshelling considering the deshelling rate and the cost, but the safety concerns mentioned in introduction section are still the same with this machine as well.

Fig. 4: Existing deshelling machine

III. MATERIALS AND METHODS

An industrial visit to Loluwagoda factory was conducted to collect data and information about coconut-related product manufacturing process, especially focusing on the deshelling step. Several interviews were conducted with industry professionals within the day of the field visit. To find information about deshelling technologies and their advantages and limitations, a literature review was conducted by studying articles published in peer-reviewed journals, international conferences, and other coconut-related research bodies such as coconut research institution in Lunuwila, Sri Lanka.

IV. RESULTS AND DISCUSSION

The three coconut deshelling methods discussed before have their own merits and demerits. TABLE I shows a comparison of those methods. TABLE I further shows that even though the first two methods solve two major concerns (safe operation and no need of skilled labor), they can still break the kernel. This is problematic for the next phase in the manufacturing process, which is paring (removing brown skin of the kernel), because both manual and semi-automatic paring methods need kernel as a whole. Therefore, it is understood that a novel approach is required to mechanize the deshelling process with improved safety while ensuring unharmed coconut kernel.

TABLE I. ADVANTAGES AND DISADVANTAGES OF DESHELLING METHODS

Deshelling Method	Advantages	Disadvantages
Fig. 1	High deshelling rate	Prone to kernel damages
	Safe operation	Suitable for copra only
	No need of skilled labor	
	Low manufacturing and operating costs	
Fig. 2	Safe operation	Low deshelling rate
	No need of skilled labor	Prone to kernel damage
	Suitable for coconuts of any age	
Fig. 3	High deshelling rate	Prone to kernel damages
	Low manufacturing and operating costs	Operation is unsafe
		Need of skilled labor

V. CONCLUSION

The coconut industry is a vital sector in Sri Lankan economy, and deshelling is a key process in the production process. In this research, we conducted a comprehensive background study on the existing deshelling mechanisms and compared their pros and cons to understand the bottlenecks in the process. Our findings reveal that the existing machines do not provide an all-in-one solution for the major concerns identified earlier in this paper. Therefore, it is required to develop an improved deshelling machine that can overcome these limitations and enhance the quality of coconut products.

VI. FUTURE WORK

As the next phase, several concepts will be generated combining the technologies found in the literature. The best possible combination for deshelling will be selected through scientific methods such as morphological analyses and decision matrices. Then, a 3D model of the machine will be generated to evaluate the functionality and to optimize the design. After finalizing the design, a prototype will be built to validate the concept.

ACKNOWLEDGMENT

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Digitalized Platform to Better Utilize Empty Space of Return Runs of Truck

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Keywords - return runs of trucks, real time information, digitalization approach

I. INTRODUCTION

Sri Lanka depends heavily on road for freight transportation where around 97% of domestic freight is transported by roads using trucks [1]. It was further related that half of the above trucks returning empty [1]. Such empty truck return runs go unnoticed in Sri Lanka. In other developed countries, digitalization such as digital tracking and tracing is used to minimize empty return runs of trucks by making them noticed by the parties in the supply chain. No such digital tracking and tracing is available in Sri Lanka to provide real time information on the truck operations. Therefore, the empty return runs remain unnoticed. Because of its being unnoticed, these empty space in the return runs of trucks are not used optimally. Lack of optimal use of these available space in the return runs of trucks incurs high cost of operation and lowers the net profit of truck operators. High cost and lower profit to truck operators leads to increase in charging high transportation cost from the shippers (local farmers). High transportation cost affects all the parties in the supply chain including the customers, suppliers, transport operators and the country. Therefore, the objective of this study is to propose a digitalization approach of tracking and tracing the trucks that could give real time information on truck operations in Sri Lanka. This digitalization approach can help suppliers, transport operators and regulators to better utilize the empty space available in the return runs of trucks. This approach would pave the way for better customer satisfaction as it could reduce the freight transport costs.

II. LITERATURE REVIEW

Live information sharing models generated many business opportunities in today's world [2]. Models such as "uber" was one of the leading live information shared models existing in the world and users had positive comments and feedback towards the service offered. Uber provided multiple options for users to transit from one location to another. Estimated cost of traveling, duration of the trip and number of kilometers to travel were some of the information shared through the live information system [3]. Tracking vehicles using an installed GPS devise inside the vehicle and mapping the live location via the use of internet was identified as one of the easiest and inexpensive methods. The importance of connecting GPS with Android enabled smart phones for the convenience of users was identified [4]. Use of GPS data to improve transport solutions for domestic shippers was discussed as a strategic step taken by transporting companies to decide when and where they had to engage in other transport assignments to improve the load factors on their trucks [5]. GPS based fleet management system technology provided synergy to transport companies and achieved many management goals such as monitoring and tracking commodity distribution, energy saving, safety, and quality [6]. Nowadays, finance and technology are combined with the use of the internet triggered digital payment technologies and such technological innovation in the payment industry is the foundation for financial inclusion to transform from traditional payments methods to digital paying methods in the modern-day digital environment.

III. MATERIALS AND METHODS

The transport operators who are willing to utilize the empty space of return runs of trucks were also agreed on sharing real time information on space and location through a digitalized approach at the time of discussion. The discussions were organized with the truck operators and the benefits of sharing live information on return runs were elaborated. The methods of sharing live information based on calculations on available space and live locations of the trucks were investigated. The feasibility of attracting the shipments on their return runs was investigated. Computer programmers were contacted to design an algorithm on behalf of uber to estimate the empty space available in the trucks upon getting shipment entries from the shippers as the return run progresses. Informal discussion with the shippers on the feasibility of using a digitalized platform for their daily transportation operations was conducted. Either paying cash at shipper's location or submitting credit card or debit card details as existing for other uber services such as "uber eats" were discussed as acceptable methods of payments.

IV. RESULTS AND DISCUSSION

The first step of this overall project would be creating two interface/portals/apps as one for the transport operator and another for the shipper same as in the taxi operation for driver and passenger. Secondly, to register fleet of vehicles/trucks own by transport operator's using transport operator's interface/portal/app. A smart phone enabled with GPS and downloaded app should be equipped in each truck/vehicle. Users would be able to enter the current

location of the shipment to be picked up, dimensions of the shipment (length, width, and height in centimeters), estimated weight of the shipment, destination of the shipment, contact details of the shipper and contact details of the consignee using the shipper's app. Shipper would have a place to upload the photo of the shipment too. In addition, several categories of trucks would also consist which could be desired by the shippers.

Computer algorithm would be required to calculate the available empty space in the trucks. For that, the details on the truck capacity should be pre-entered at the time of registering the truck/vehicle using transport operator's app. Based on the entries from the shippers using shipper's app, the available empty space would be thus calculated by subtracting the volume of the shipments received from the volume of the truck for loading. Based on the available empty space in the truck for cargo loading, invoice would be generated and sent to the respective shipper. This invoice would consist of the details on the shipment and the charges. The payment portal would be available for the users to make their payments. Once payment is made, the shipper would get a phone call from the conductor of the nearby truck for further verification. Therefore, this approach helps empty space of the return runs of truck being well utilized.

However, collecting cargo from all the shippers would become a challenge for the truck operators due to the locations of shippers. Therefore, it was suggested that cargo centers could be pre-determined for each route to load and unload cargo to save time. To increase the efficiency of service, cargo centers might be helpful to avoid travelling to byroads to collect shipments and deliver shipments. Service can be operated giving full focus to run on the main roads to increase the efficiency.

V. Conclusion

As discussed in the above sections, the concept of providing digitalized platform to provide real time information on the empty spaces will help better utilization of the empty spaces of the return runs of trucks in Sri Lanka. This concept will be beneficial for both transport operators and local shippers to fulfil their requirements. The shippers would be able to transport their shipments at a lower cost whereas the truck operators would get additional income as their empty spaces in their return runs were to be utilized. Cost of transportation in return journeys is a topic which was never addressed in Sri Lanka previously. Therefore, to make trucking industry more cost effective, the available empty space of trucks in return trip can use as an opportunity for domestic shippers who are willing to send goods to Colombo. This attempt to use empty space available in trucks in the return trip would be therefore a win – win situation for both domestic shippers and transport operators.

The main limitation of this study is that this concept does not propose any mechanism to crosscheck the accuracy of the information on volume of the shipment provided by the shippers. Such inaccurate information could disturb the efficient utilization of the empty space in return runs of the trucks. Future research can recommend any technological component to get the real time data on the volume of the shipment.

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Interactive Learning Facility for PLCs, and Simulations Using Factory IO

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Keywords— Factory IO, PLCs, User interface, Learning, Simulations

I. INTRODUCTION

To improve efficiency, productivity, and worker safety, industries are implementing automation facilities into their processes to take advantage of the rapid development of technologies [1]. Programmable Logic Controllers (PLCs) are one of the major parts of automatic systems in the industry [2]. Learning PLCs and their functions is one major component in learning industrial automation, and hence laboratories pay much attention to instruct students about PLCs and their functions.

On the other hand, there is much research being done on intelligent learning platforms such as ALESK, and BYJU's learning, where they implement student knowledge assessment methods and adaptive teaching methods [3].

This is one part of an ongoing project working on developing an intelligent learning platform for students to learn PLCs, its decentralized connections and simulations using factory IO. With an attempt to identify the hardware components needed to build a 'Palletizer', this work tries,

- to develop a simulation in Factory IO for students to learn about PLCs, ladder programming and input/output devices,
- to develop a web platform for students to refer to lab materials, data sheets and tutorials.

As outcomes of this work, a simulation and the ladder logic program of a palletizer was built, and the components needed to build a physical palletizer and their specifications were identified. Moreover, a web interface was designed for students to learn about the lab practical.

II. LITERATURE REVIEW

Using different methods to teach PLCs and Industrial Automation to students is a widely researched topic. Authors of [4] have developed a learning media for programmable Logic Controllers for a sorting machine application and have done a feasibility study to conclude that their PLC learning media is suitable to be used in PLC practicum course. Authors of [5] discuss the advantages/disadvantages of using physical, virtual, or remote/online platforms for laboratory experiments.

In 2019, authors of [6] tried using Factory IO as a virtual engineering laboratory environment to introduce students of PLCs. The student responses of that implementation suggest that Factory IO was a useful, and enjoyable software to be used in virtual laboratory environments. The authors of [7] have also developed a virtual simulation system with different examples and tools to practice and learn PLCs. Moreover, an interactive learning facility was developed to teach profibus communication in PLC-based automated systems by authors of [1]. Their results show that the use of web applications to supply guided materials has been beneficial for students.

However, there stays the opportunity of improving the learning experience of PLCs through web platforms. This work tries to build an interactive learning platform to teach students simulations using Factory IO through a web platform and tries to improve the learning experience of the web platform.

III. METHODOLOGY

In achieving the goals, design of the simulation of a given scenario (Palletizer) and development of web application were done simultaneously.

A. Simulation using Factory IO

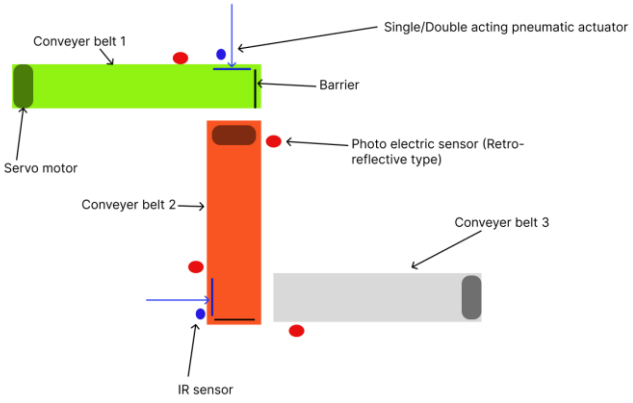

Fig 1: Top view of the 'Palletizer' with components identified

The scenario developed was the 'Palletizer' system, shown in Figure 1. The system collects packages from conveyor belt 1 and 2 making four packages at the end of conveyor belt 3, ready for packing. The simulation for the scenario is built in Factory IO and the ladder logic was developed using TIA portal (V17) and S7 PLCSIM (V17). The RLL was developed on TIA portal and connected with the simulation of Factory IO through S7 PLCSIM.

B. Web platform

The web application is built with Firebase, firebase as a web application development platform that offers services such as cloud functions, real-time database, authentication, and hosting. Moreover, Firebase hosting is utilized to host the applications and use google cloud functions to integrate machine learning algorithms in future developments. Figure 2 shows the overall system architecture of the web interface.

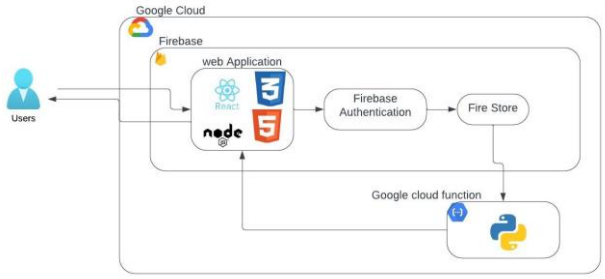

Fig 2: Architecture of the web interface

The main goals of web application are to:

1) guide students in simulating the given scenario in factory IO,
2) help students finding the technical details of S7 1200 PLC and different sensors and actuators,
3) guide students building ladder program for the given scenario in TIA portal,
4) present a Q&A for students to evaluate themselves.

Aligning with the design flow which has been defined according to the UX-based workflow, the designing of web interface is adhered to following steps; requirement gathering, interface design, prototyping.

IV. RESULTS AND DISCUSSION

Hardware components needed for the lab setup were identified using the results of the simulation. Figure 3 shows an instant of the simulation of the given scenario in operation. Table 1 shows the hardware specifications of those components. Moreover, this simulation of the 'Palletizer' is added to the web page, as a reference simulation for students to learn.

Fig 3: Simulation of 'Palletizer' in Factory IO

TABLE I. SPECIFICATIONS OF HARDWARE COMPONENTS

Component	Specification
DC geared Motors (3)	*10-15 W output power 12 V*
Pneumatic actuators (2)	*Single acting, Reciprocating, stroke-8-12cm*
Photoelectric Sensors (4)	*Diffuse type*

The procedure for simulating the scenario and ladder program is linked to the web application.

The homepage of the web interface is shown in Figure 4. To achieve earlier goals, three sections; 'tutorial', 'datasheets' and 'lab practical' are included to the web interface. As future work, UX (User experience) assessment based on user testing must be followed as the last step of design flow.

Fig 4: User interface of the web interface

V. CONCLUSION

As conclusion this work simulates a 'Palletizer' scenario on Factory IO and identify the hardware components needed for a physical laboratory set up. Moreover, develops a web platform for students to learn about the laboratory practical and evaluate themselves.

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Human Centered Study of Strawberry Picking Behavior for Intelligent Harvesting Robot

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Keywords—RRT*, fuzzy logic, motion planning

I. INTRODUCTION

Strawberries, highly valued both commercially and for consumption, are predominantly cultivated in controlled environments like greenhouses. Despite these advantages, human labor remains a significant factor in strawberry production costs, especially during harvesting. To address this, there is a growing interest in developing strawberry harvesting robots. However, detecting strawberries poses challenges due to leaf shading, overlapping, and plant structure interference. Enhancing the visual object detection system is crucial for accurate and real-time detection. Given the vulnerability of strawberries to damage due to low mechanical strength during harvesting, we propose a stem-based harvesting method and plan to develop an efficient motion planning approach for the robot manipulator [1][2]. The goal is to enable the intelligent robot to navigate autonomously, picking strawberries with improved efficiency and minimal damage, thus transforming strawberry harvesting processes.

II. LITERATURE REVIEW

Various motion planning methods are explored for optimizing the efficacy of strawberry picking.

A. *Traditional Algorithms*

Artificial potential field algorithms necessitate the entire workspace for sampling and may stop path searching due to inflection points. A* algorithm speed diminishes with increasing degrees of freedom (DOF) and obstacle complexity. The Improved Rapidly exploring Random Tree (RRT*) algorithm addresses these issues in high-dimensional spaces but incurs high computational time and generates zigzag paths, which pose challenges for motion of the manipulator. [3],[4]

B. *Fuzzy logic*

Fuzzy logic enables a smooth path and swift decision-making [3]. However, path optimization depends on rule quality, potentially leading to inefficiencies. Careful rule refinement is crucial for effective fuzzy logic-based path planning.

C. *Hybrid motion planning*

To overcome the drawbacks of traditional algorithms and stand-alone fuzzy logic in motion planning, researchers commonly employ a hybrid approach. By combining both methods, they aim to leverage the respective advantages of each and enhance overall efficiency [3].

Based on the literature review, we selected RRT* as the traditional algorithm to integrate fuzzy logic for our hybrid motion planning method. Initially, our investigation sought insights into human hand behavior during strawberry picking.

III. METHODOLOGY

A. *Experiment design*

A total of 35 strawberry-picking experiments were conducted, involving seven distinct individuals. Each participant executed five distinct approaches, each based on varying hand orientations. Figure 1 illustrates the five distinct approaches used by each individual during the experiments.

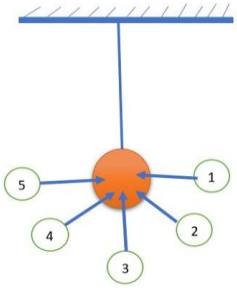

Figure 1 – Five distinct approaches.

The experiments were carried out with restrictions: participants used only their right hand, and the distance between the sample model and the human remained constant throughout the experiment to maintain consistency and control for and reliable analysis of the collected data.

B. *Data collection of joint angles*

This study focuses on analyzing the right shoulder, right elbow, right wrist, and right-hand joints. We established the Kinect Version 2 Camera with Vitruvius Library to collect joint angles data by modifying existing code for the selected right-hand joints, as illustrated in Figure 2.

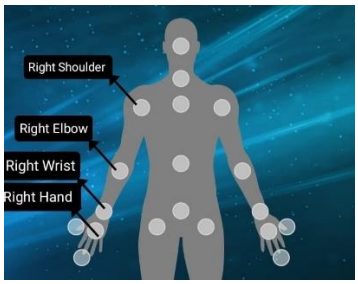

Figure 2 – Chosen joints of right hand.

IV. Analysis and Results

This study involves recording 15 joint angles reading per second for each joint and finding mode values on each second, revealing the most frequent angles.

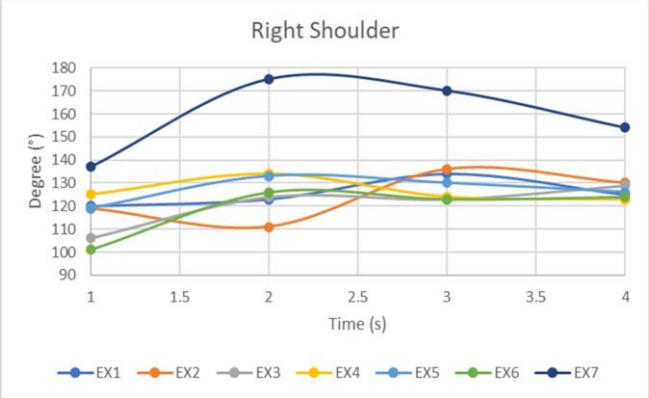

Figure 3 – Hand Orientation 1_Right Shoulder

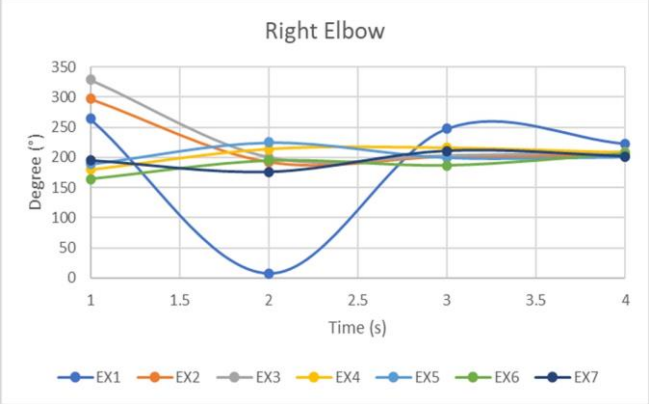

Figure 4 – Hand Orientation 1_Right Elbow

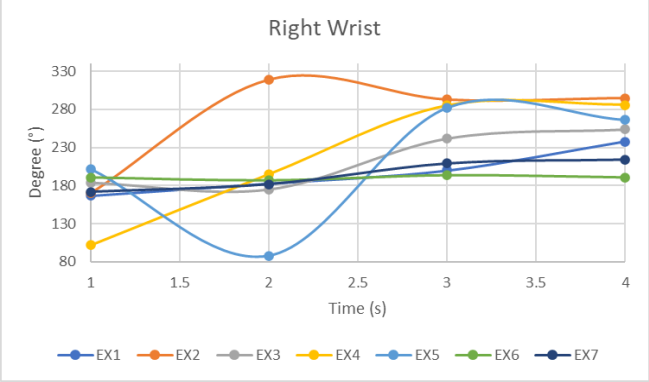

Figure 5 – Hand Orientation 1_Right Wrist

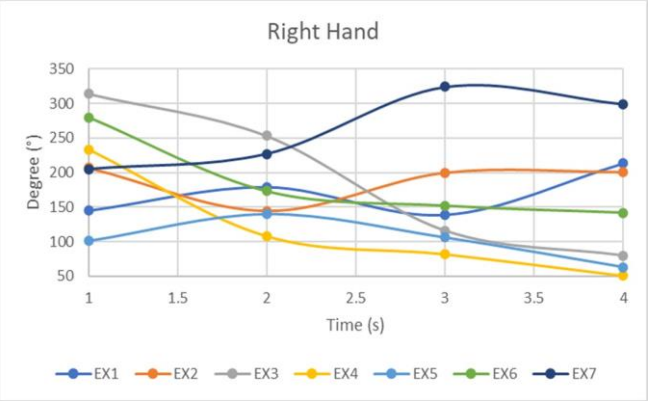

Figure 6 – Hand Orientation 1_Right Hand

Above figures 3-6 illustrate angle variations over time for each joint in hand orientation 1. Right Elbow and Right Shoulder joints are mostly same joint angle variation for approach of all individuals in hand orientation 1.

Similarly joint patterns were identified in the analysis of the other four right hand orientations.

Hand Orientation	Joint Patterns
1	Right Elbow, Right Shoulder
2	Right Elbow
3	Right Elbow
4	Right Elbow, Right Wrist
5	Right Elbow

Table 1 – Joint patterns for distinct hand orientation.

V. Conclusion

According to the human centered study, the Right Elbow joint angle be as a key indicator of common human hand behavior. Potential use of Right Elbow joint parameters to map human hand's paths and define the hand's workspace. This insight gives foundation for mimicking the identified workspace in the design of an Intelligent harvest robot.

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Analysis of Cyber Attacks in Power Grids with Increasing Renewable Energy Penetration

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Keywords — cyber- attacks, Power system, cyber security, PSCAD

I. Introduction

With the application of advanced computer and communication technologies, traditional power systems are converting to cyber-physical power systems. [1] Several secondary systems, like SCADA (Supervisory Control and Data Acquisition), WAMS (Wide Area Monitoring System), AMI (Advanced Metering Infrastructure), and smart substations, are the main cyber-physical subsystems that could be vulnerable to cyber-attacks. [1], [3] Mathematically modeled cyber-attack types such as FDIA (False Data Injection Attack) [1], [2], [3], [4], DoS (Denial of Service) [1], [3], replay attacks, etc. can be modeled using the PSCAD power system model with the addition of renewable power source models to the system. The goal of this project is to develop a PSCAD power system model with increasing renewable power sources, simulate the different kinds of cyber-attacks mentioned above in the PSCAD power system model, collect faulty data, and develop a deep learning model to detect and act against the cyber-attacks.

II. Literature Review

To overcome the lack of labeled data and address the class imbalance, Generative Adversarial Networks (GANs) have emerged as a contemporary approach. GANs enable the reproduction of synthetic samples that maintain the distribution of original samples.[5] The scenarios include short-circuit faults, line maintenance, and various cyber-attacks like RTCI, RSC, and DI attacks. Each scenario represents a specific challenge in power grid security.[6],[7] Detailed analysis of cyber-attacks involving photovoltaic (PV) systems, such as extra reactive power compensation, PV farm inverter attacks, and linear load cutoff. These attacks simulate scenarios, where false data injection and data integrity attacks compromise power system stability.[6] Research gaps can be identified as follows.

- Only focusing on one type of attack
- Real scenarios are not simulated.
- Renewable energy penetration - less considered.

III. Materials and Methods

The study utilized software such as PSCAD and MATLAB Simulink are used to design a power system model with renewable energy sources, generate healthy data for seven transmission lines, simulate fault data injection and load alternating attack types, and collect data through simulations.

Fault data injection attack is simulated using the below model. [Fig.1] This model can generate random values for voltage, frequency, and phase angle and through the solar plant phasor measurement units these data were injected to the system communication network. Due to these types of fault data, some of diesel generators change their characteristics. Due to those changes, system instabilities occurred and by measuring wave patterns in transmission lines, fault types can be identified.

Load Alternating attack [Fig.2] model can cut off the loads in system by accessing through the solar system communication channel. The attack is directly done to breaker relay system and breakers can be controlled using the model.

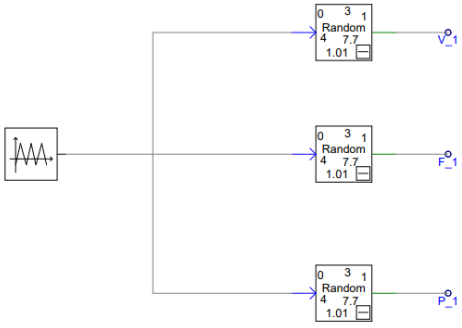

Fig. 1. Fault data injection model

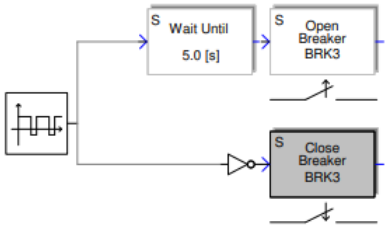

Fig. 2. Load alternating attack model

IV. Results and Discussion

Data was collected for healthy power system wave patterns, Fault data injection attacked system wave patterns and Load alternating attacked system wave patterns for the Instantaneous current, Instantaneous voltage, RMS voltage, Active Power, Reactive Power, and Phase angle.

A. Healthy data wave patterns

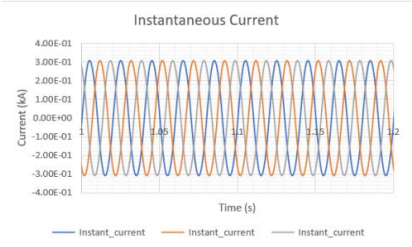

Fig. 3. Healthy data wave pattern for instantaneous current

Fig. 4. Healthy data wave pattern for active and reactive power

B. Fault data injection attack wave patterns

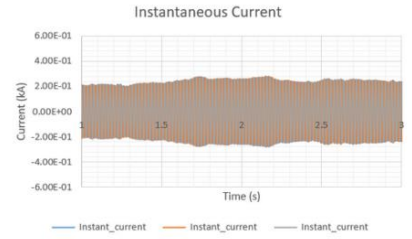

Fig. 5. Fault data injection attack wave pattern for instantaneous current

Fig. 6. Fault data injection attack wave pattern for active and reactive power

C. Load alternating attack wave patterns

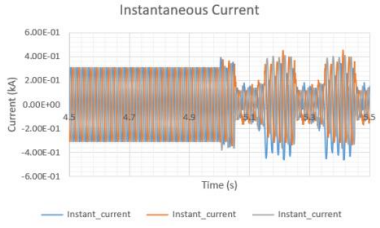

Fig. 7. Figure 1: Load alternating attack wave pattern for instantaneous current

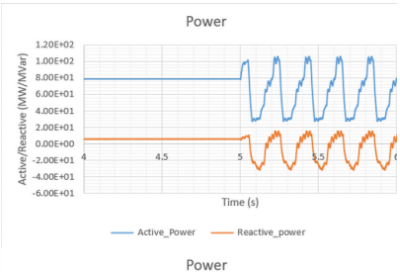

Fig. 8. Load alternating attack wave pattern for active and reactive power

V. Conclusion

Due to rapid development of cyber – physical power systems, attack detection and defense is becoming more complex day by day. Using the data collected from the power system model with and without attacks, our aim is to build a deep learning based neural network model to identify the attack type.

Future works to achieve the objectives:

- Analyze the attack patterns with common faults and improve the data set.
- Analyze the data set and feature extraction for neural network model.
- Develop the neural network model and optimize the model.

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Bimanual Tele rehabilitation Robot

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I. INTRODUCTION

Post-stroke patients lose their interlimb coordination and ability to do bimanual activities. This is common for arms, and usually, patients get one arm paretic. This is a heavy burden since everyday activities need both hands to do. For recovery, they need intensive bimanual therapy. The robotic approach is more effective than traditional rehabilitation for this kind of therapy. A bimanual master-slave robotic system can be used to do simultaneous exercises for patients' both hands. Our focus is to implement the two most basic and critical movements into this robot. One is Flexion and Extension, and the other is Internal and external rotation.

Stroke is one of the conditions that causes long-term disabilities. This causes a lot of struggles for patients to recover. To overcome that and speed up the recovery we propose a robotic approach, with reduced dependency on a therapist and increased repeatability and robustness.

When doing these exercises, the patient's shoulder must be in a relaxed position. Otherwise, the generated torques will depend on the shoulder position. Hence there must be adjustments for varying arm lengths as it changes the position of the elbow joint. Also, we are going to implement two exercises which are done in perpendicular planes into one 1 DOF (Degrees of Freedom), robot. And we need to provide methods to change the motor orientation for that.

II. LITERATURE REVIEW

As stated in [1] stroke is a condition that causes long-term disabilities and according to [2], 30% – 60% of patients are able to walk but unable to regain full functionality of arms. Early rehabilitation is a great help in recovering such conditions as for [3].

According to [4], bimanual physical therapy is crucial for patients with disabilities limited to one side of the body. The proposed robotic device aims to restore bimanual coordination. The cost-effectiveness and reduced dependence on a therapist's physical presence enhance the appeal of the device. Following this, [5] emphasizes the significance of rehabilitation robots, highlighting the effectiveness of increased repetitions achievable through robotic assistance.

In [6] they have introduced the use of various sensors, including EMGs and force sensors, in rehabilitation exoskeletons. Even so, it is important to recognize certain challenges including the complexity of the system, the potential discomfort of the patients, and considerations related to time consumption.

In the study of sensor-less rehabilitation [7], a master-slave configuration is presented. While the use of a reaction torque observer is notable, certain challenges persist, including the need for the presence of a therapist, maintaining non-relaxed shoulder positions, and limitations of mobility of the robot.

Following this, [8] introduces a bimanual rehabilitation robot with a reference torque profile (based on elbow angle), eliminating the constant need for a therapist. However, there are no means for relaxed shoulder position and only capable of flexion and extension of the lower arm. In contrast to that, our robot introduces unique feature of performing both Flexion & extension and Internal & External Rotation, while maintaining the shoulder in a relaxed upright position for optimal effectiveness. These innovations address significant gaps, offering a more efficient rehabilitation solution.

III. MATERIALS AND METHODS

The non-paretic and paretic arms are operated by a master robot and a slave robot. The target is facilitating bimanual movement while developing the arm strength to a healthy level (using the profile). The motor supplies a controlled resistance to the arm and the arm moves against it. Passive and assistive modes are used for non-paretic and paretic arms. Passive mode is a torque controller and assistive mode is a torque controller along with an assistance. The assistance is supplied by a virtual torsional spring based on the position difference between master and slave.

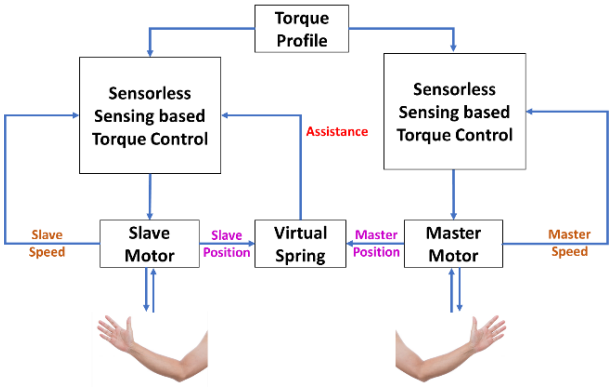

Fig. 1. System block diagram

The spring constant can be adjusted according to the patient condition.

Reaction Torque Observer is used to estimate the arm torque and Disturbance Observer is used for disturbance compensation. By those methods, we reduce measuring errors and complexity with less sensors and are able to increase the bandwidth of toque measurements as required. The outcomes are measurable as position and torque responses.

IV. Results and Discussion

The control system with above features has been simulated for a modeled system and the results are shown in Figure 2. The slave position is lower than the master position and the same happens with the torque produced. The resistance by the slave motor is reduced accordingly by the torque from a virtual spring to make the paretic arm move with the other.

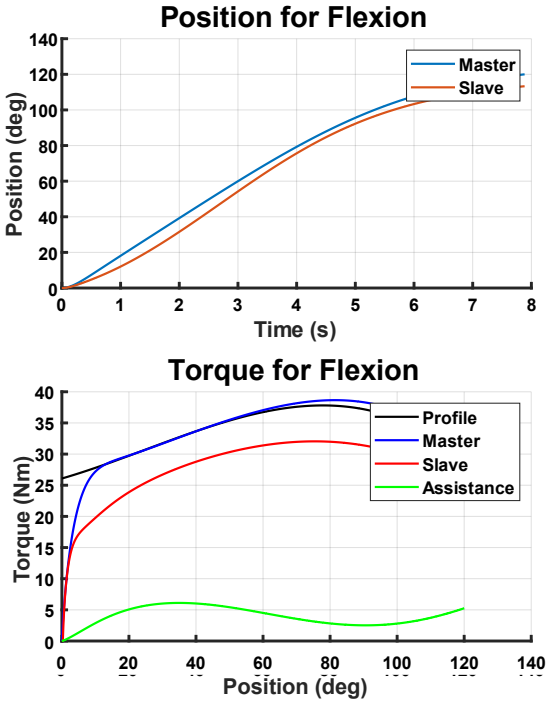

Fig. 2. Simulation results

The changing of the motor orientation is done by manually rotating the part on which the motor is mounted, by 90˚ as shown in Figure 3(b) and 3(c).

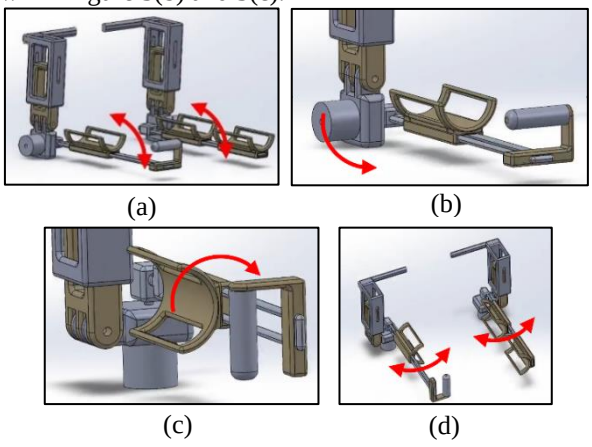

Fig. 3. Physical design

Figure 3 illustrates followings.

(a) Flexion and extension
(b) Rotation of motor-mounted part
(c) Rotation of forearm support
(d) Internal and external rotation

V. Conclusion

We are planning to develop a bimanual rehabilitation robot to perform exercises that reinstate the bimanual coordination of the human arms. The approach used is to give resistance to arm motion according to a healthy elbow torque profile. To assist the paretic arm to move with the healthy arm, a virtual torsional spring is modeled based on the lag of the paretic arm. By training with the robot, the bimanual coordination of the arms will be developed along with the strength of the paretic arm, to a healthy level. The results can be quantified, and the system parameters can be adjusted to give the optimal rehabilitation. For the maximum effectiveness and comfort of the patient, we provide the adjustment to keep the shoulder in a relaxed position. The robot will have the capability to do two exercises in perpendicular planes with 1 DOF control. Hence, this will provide a simple, mobile cost-effective, and adjustable solution for rehabilitation.

Acknowledgment

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Automated Guided Vehicle for Carrying Carts

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Keywords - Automated Guided Vehicle, Tugger part, Leverage, Differential Motor Drive, Slosh control.

I. INTRODUCTION

The growing demand for efficient and reliable transportation solutions in industrial and commercial settings is driving the development of innovative technologies, such as automated guided vehicles (AGVs). AGVs are unmanned vehicles that can navigate autonomously along predefined paths, offering a number of advantages over traditional transportation methods, including increased efficiency, reduced labor costs, and improved safety. However, conventional AGVs are typically designed to transport specific types of materials, limiting their versatility in industries such as food and beverage, where both solid and liquid materials need to be transported.

To address this challenge, we propose an AGV design capable of transporting both solid and liquid materials. It utilizes a line-following navigation system with a load type identification system and a speed controlling system, to ensure safe and efficient transportation of both solid and liquid materials. In this paper, we present a detailed overview of our AGV system design and implementation, highlighting its key features.

II. LITERATURE REVIEW

The project is based on designing a prototype of a tugger type Automated Guided Vehicle. So, the design will be a scaled down version of an actual AGV [1]. Designing a Tugger Automated Guided Vehicle (AGV) involves a critical synthesis of existing research and best practices. The key areas to be considered are navigation methods [2][3], load capacity, safety features, and efficiency. Previous studies have explored options with their advantages and limitations. Load capacity design should prioritize flexibility to accommodate various material handling tasks. Safety mechanisms, such as obstacle detection and collision avoidance, are paramount in AGV design to ensure a safe working environment.

Overall available designs are mostly designed to handle solid loads in industrial applications which means they follow the same speed controlling architecture for all types of loads [4].In actual sceneries, there are solid, liquid and fragile things too. Handling liquid with AGVs has unique challenges such as spillage prevention, weight distribution, and stability maintenance. There is a need to follow anti-slosh control strategies to ensure the safe and efficient transport of liquids by AGVs. So, by identifying the load type [5], our AGV will have a varying speed controlling mechanism which can handle solid, liquid, and fragile type loads in a safer manner.

TABLE 1. Summary of the review

Objectives	***Techniques so far***	***Research Gap***	***Our Design Idea***
Navigation Method	Laser guidance Line Following Guidance Barcode Guidance Magnetic Spot Guidance	Robust visual navigation	Line following guidance
Speed Control	PID Controllers Vision Based Controllers	Load type and load weight-based controlling	PID controller [4] with load type and weight-based control.
Load Type Identification	RFID Barcode QR code [5]	Hybrid approaches	QR code

The load type and the load weight-based speed controlling system are the primary areas of focus for our AGV.

III. METHODOLOGY

A. AGV and Trailer Design

While designing the physical structure of our AGV, we adhered to the principles of dimensional scaling, leveraging the design of existing AGVs while reducing their size to suit our specific requirements [6]. We also considered the dimensions of our chosen components and ensured force equilibrium under maximum AGV output. Additionally, we adopted a front-wheel driving mechanism to prevent rotation around the rear wheels when the tugger component is connected. This decision was driven by the realization that rear-wheel driving would lead to undesirable rotation due to the applied torque. Leveraging the calculated dimensions and variables, we meticulously constructed a 3D model of the AGV using SOLIDWORKS. Fig. 1, Fig. 2 and Fig. 3 show the structure of our AGV design.

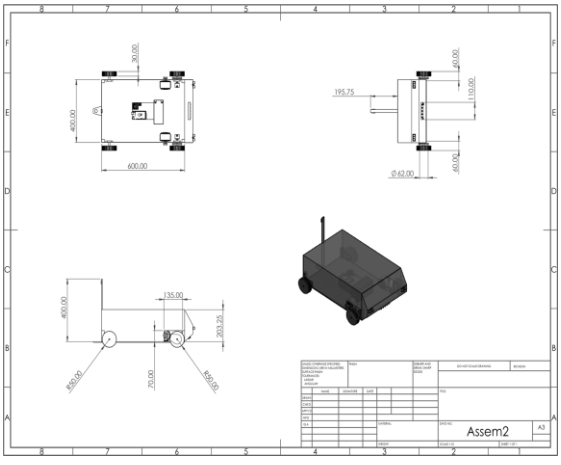

Fig. 1. The dimensions of the AGV

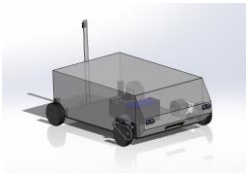

Fig. 2. Design of front part of the AGV

Fig. 1. Design of Tugger part of the AGV

The motor sizing for an AGV is a critical aspect of the design process, as it directly impacts the vehicle's performance, efficiency, and overall capabilities. The appropriate motor selection ensures that the AGV can meet its specified payload capacity, speed requirements, and gradability limitations.

To determine the required motor torque and speed for the AGV, we employed a comprehensive analysis of the vehicle's dynamics and load characteristics. Utilizing Equation (1), we calculated the total load inertia (JL), which encompasses the AGV's inertia and the inertia of the attached carts. Subsequently, we employed Equation (2) to determine the required motor speed (Vm2) based on the desired AGV velocity and the wheel diameter. Finally, we utilized Equation (6) to calculate the requisite torque(T), considering factors such as load inertia, gradeability, acceleration, and friction coefficient.

(m1 - vehicle mass, D1 - wheel outer diameter, md1 - wheel mass, n1 - number of wheels, μ -friction coefficient between wheel and floor, N - number of carts, m2 - mass of each cart, D2 - wheel outer diameter, mD2 - wheel mass, n2 - number of wheels per cart, Dp1 - primary Pulley diameter, Dp2 - secondary Pully diameter, α - Maximum angle of floor slope, V2-max speed, t1-tome to get max speed, Jv-inertia of AGV, Jc – inertia of cart, J_{Dp1}-inertia of primary pully)

$$JL = (J_V + J_C + J_{Dp2})(D_{p1}/D_{p2})^2 + J_{Dp1} \quad (1)$$

$$Vm2 = V2/(\pi D1 \times 10^{-3})(\frac{Dp2}{Dp1}) \quad (2)$$

$$F = 9.8((m1+n1\times mD1)\times(\sin\alpha + \mu\cos\alpha) + (m2+n2\times mD2)\times(\sin\alpha + \mu\cos\alpha)) \quad (3)$$

$$TL = \frac{(F \times D1 \times 10-3)}{(2\eta \times 0.01)(Dp1 / Dp2)} \quad (4)$$

$$Ta = JL\left(\frac{Vm}{(9.55 \times t1)}\right) \quad (5)$$

$$T = (Ta + TL)(Safety\ Factor) \quad (6)$$

B. System Overview

Fig. 4 shows the overall system overview of the Automated Guided Vehicle.

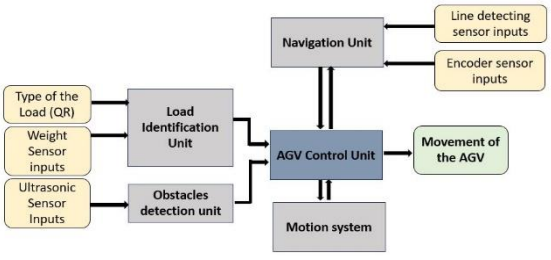

Fig. 3. System Overview

A load identification unit [5] will be used to identify the type of load which the AGV is going to carry and its weight. AGV will follow different speeds according to the load types. There is an obstacle detection unit to avoid collisions during transit. AGV will navigate with the principle of line following method. The motion of the AGV will be controlled by two DC motors which are connected to the front wheels, based on differential motor control.

IV. Results

Parameters of the AGV: -
Front part: Length -60 cm, Width – 40 cm, Height - 20 cm
Tugger part: Length -60 cm, Width -40 cm, Height – 25 cm

We have designed a simulation for the navigation of the AGV according to the developed line following algorithm. With the usage of the developed algorithm, the AGV will follow the line according to the input values from the IR sensor array. The following Fig. 5 illustrates the simulation created for this navigation process.

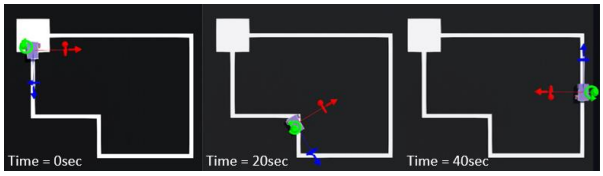

Fig. 5. Line Following Simulation in the interval of 20sec

The simulation software 'Webots' was used in conjunction with the 'Python' programming language, to simulate and develop the algorithm.

V. Conclusion

In this paper, we have presented the AGV design capable of transporting both solid and liquid materials safely and efficiently by combining a line-following navigation system, load-type identification technology, and a speed control mechanism. We have discussed the key components and functionalities of our AGV system, including line-following algorithm simulations, the designed 3D models for the AGV and tugger components, and the load type identification method using QR codes and motion system. These elements collectively contribute to the successful transportation of materials. As we move forward, we aim to continue enhancing its capabilities and accuracy and ultimately increasing the reliability of the material transportation process.

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Neural Network Based Model for Estimating the Resistance of Outdoor Distribution Substation Grounding

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Keywords—grounding structure, COMSOL, Finite Element Method (FEM), neural network

I. INTRODUCTION

Grounding is one of the most important parts of an electrical system. Earthing systems are done to protect the power system and the personnel from the danger of electrical shocks. Ceylon Electricity Board (CEB) uses a special structure for transformer earthing arrangement. The used structure is copper bonded earth rod with a concrete filled steel cage.

Due to the complexity of the structure and the nonlinear variations in soil parameters, it is challenging to determine resistance before implementing the structure.

We can use an analytical formula for structures to find the resistance. [4] But for complex structure, as we use here, it is challenging to produce an analytical formula. The other solution is to use a Finite Element Method(FEM) to solve the problem.[2] But is also a time-consuming task.[1] So, we propose a combination of FEM and a neural network-based solution for this task.[1]. We propose to generate a data set using FEM and implement it in a neural network.

II. LITERATURE REVIEW

Numerical simulation of electromagnetic fields is a technique used in electrical engineering to design, optimize, and validate equipment behavior in the field. The Finite Element Method (FEM) is the most commonly used tool for this purpose. FEM offers accuracy and flexibility in modeling complex geometries and boundary conditions and can handle nonlinear material properties and dynamic behavior. However, FEM requires significant hardware tools and time consumption. Every configuration requires another FEA to be performed.

There are four types of artificial neural networks: Forward Neural Networks, Radial Basis Function (RBF) Neural Networks, Recurrent Neural Networks (RNNs), and Convolutional Neural Networks (CNNs). Feedforward Neural Networks are the simplest type and have no feedback loops or cycles. RBF neural networks have a hidden layer with radial basis functions, are suitable for interpolation and function approximation, and use linear regression to determine the weights of the output layer. RNNs have feedback loops or cycles, store, and process sequential or temporal data, can model complex dynamic systems, and capture long-term dependencies in the data. CNNs have convolutional layers and are designed to exploit the spatial structure and locality of the data. The best method to generalize the FEA result for any variation of the geometrical and material parameters of the base configuration is to use a combination of FEA and neural networks. Neural networks are well-known for their capability to approximate functions using a concept called "regression." When training the neural network, it is recommended to use only 60% of the available data, with 20% for testing and 20% for cross-validation.

In terms of frequency domain vs. DC analysis, the earth resistance for low-frequency AC and DC is almost the same. However, the resistance starts to show a significant deviation in the MHz range. As the frequency of AC rises, the earth's impedance will increase. Impedance with a phase angle less than ±5° is considered resistive.

III. METHODOLOGY

In this project, we propose a method to approximate the resistance of transformer neutral earthing of outdoor distribution substations. This model contains two subsections, simulating the model using COMSOL, and designing a neural network-based solution and an empirical solution.

A. Simulating the model using COMSOL

COMSOL is a simulation software used to determine various parameters and coefficients in our calculations. In the simulation software, we will design a model in which we can vary several parameters. By varying these parameters, we expect different observations.

B. Designing a neural network-based solution

We are expecting to retrieve data from the above-mentioned simulation. After gathering enough data sets, we will train the neural network model by adding the data. The neural network will be evaluated multiple times to increase accuracy.

IV. Model Design

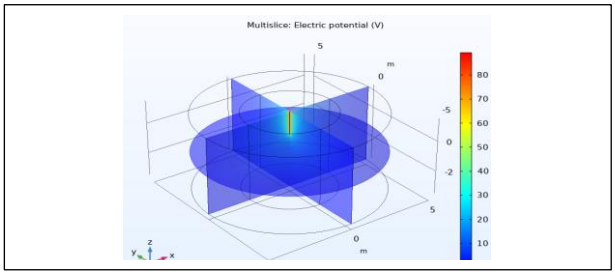

Figure 1

Figure 1 illustrates the view of the single Copper Rod COMSOL model that we developed.

V. Results and Discussion

A. *Frequency domain and Direct Current analysis*

We simulated a single Copper Rod in COMSOL, injecting an Alternating Current of 50Hz and a Direct Current. From the results we obtained it was confirmed that the Impedance of the Alternating Current source of 50Hz was almost equal to the Resistance of the Direct Current source. There was a slight difference in the values in the nano-ohm(nΩ) range. It was concluded that simulating the COMSOL model with a Direct Current source would not change the results.

B. *Analysis of the single Copper Rod*

When simulating the single Copper Rod, we had to consider several facts. The considered soil radius should be higher than the length of the Copper Rod. The considered soil depth should be at least 2 times the length of the Copper Rod. The model that has these parameters will cover more than 90% of the total soil resistance.

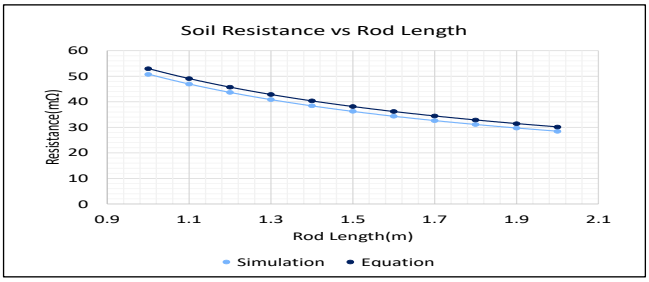

Figure 2

We used the soil layer with a radius of 7m and a depth of 7m. Therefore, we were able to contain more than 90% of soil resistivity in our model.

Initially, we needed to validate that the simulation software would give accurate results. For this, we changed the parameters of the Copper Rod and simulated to get a data set of the resistance. We also calculated the resistance from the empirical equation for the same parameters.

The results obtained by changing the Copper Rod length are presented in Figure 2. The similarity between simulation results and the results taken from the empirical formula can be observed in Figure 2.

C. *Analysis of the soil layer*

As said earlier, the soil layer which we considered consists of 90% of the total soil resistance. This value can be increased by considering more of the soil layer. However, we cannot simulate a very large soil layer since it will require a large number of virtual resources.

Figure 3 presents the data gathered by changing the radius and length of the soil layer. The empirical equation result can also be observed. As the value of the soil radius gets higher, the change in the soil resistance per increased radius becomes lower. Therefore, we can find a value for the soil radius which the change in soil resistance will be negligible for higher radius values. This value will not reach the empirical equation value since the empirical equation is not 100% accurate for all situations.

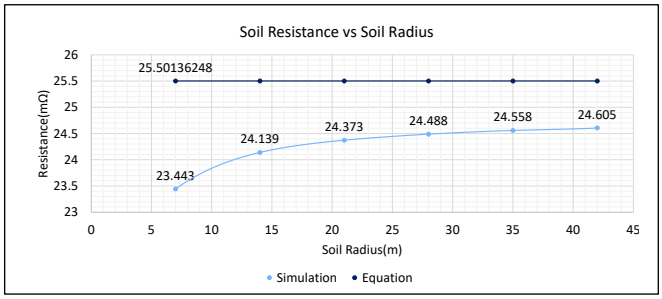

Figure 3

VI. Conclusion

We have been able to prove the accuracy of using COMSOL for this project. Figure 4 illustrates the side view and Figure 5 illustrates the top view of our final design. The actual structure will be made with a Copper rod in the center and a steel cage. The steel cage will have a depth of 1.2m and a radius of 0.5m. The radius of the metal rods is 6mm. Cement is used for fixing the structure. This is the progress of our project, and we will continue to develop the model that we designed for the CEB. This structure will be used to generate the data for the Neural Network. The Neural Network will be trained by a proportion of this data while another proportion will be used to cross validate them. Finally, the neural network will be tested with actual data gathered from the CEB.

Figure 4

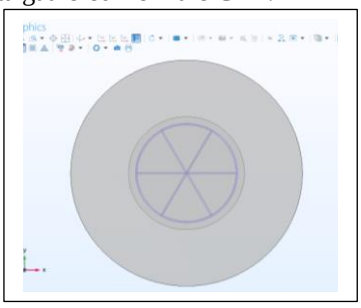

Figure 5

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Deep Learning-Based Power Baseline Modelling of a Range of Electrical Loads in Smart Green Buildings

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I. INTRODUCTION

Energy consumption modelling of electrical loads plays a crucial role in modern-day energy management systems for green commercial buildings. This project focuses on the development of power baseline modelling using deep learning techniques for a diverse range of electrical loads. The baseline model, an estimation of power or energy consumption before implementing energy management, is widely used to identify savings by comparing with the measured data after implementing energy management. Energy efficiency is crucial for both commercial and non-commercial applications. Power baseline models give reference to identify energy saving or loss. We can assess energy saving after implementing energy conservation strategies and identify energy wastage of the system when actual power consumption is higher than the power baseline model prediction. In this study specifically, a comparison is made between Karl's Pearson's and Random Forest-based deep learning approaches and Recurrent Neural Network (RNN) models. This project incorporates both simulations and real-world data to conduct the study.

Keywords: Power Baseline, Deep Learning, Neural Network, Energy Management, Abnormalities

II. OVERVIEW OF THE PROJECTS

A. *Aim*

Develop a power baseline model using deep learning techniques for diverse range of electrical loads in building energy management systems (BEMS) to optimize energy usage.

B. *Scope*

The intended scope of this project involves the development, testing and validation of a deep learning-based power baseline model using real-world data sourced from specific electrical loads (mainly focused on air conditioners) within the University of Moratuwa.

C. *Project Objectives*

- The precise acquisition of necessary data for training, validation, and testing the model.
- Identifying Power usage patterns for different electrical loads.
- Developing a model that can accurately derive the power baseline patterns of various electrical loads.
- Presentation of a baseline model output in an easily comprehensive manner.

D. *Expected Outcomes*

- Identify abnormalities of the electrical loads.
- Assess the energy saving or loss, reference to the power baseline model.
- Take necessary actions to reduce the energy consumption using power baseline model.

III. LITERATURE REVIEW

Power baseline modelling approaches are methods used to establish a foundational understanding of power systems and their behavior. These approaches help in estimating the power baseline of the building. There are three common power baseline modelling approaches included as follows.

A. Physical Modeling: Physical modelling, often referred to as "white-box approaches," are methods rooted in the principles of physics.

B. Data-Driven Modelling: Data-driven modelling relies on historical data and machine learning techniques to build models that capture the behavior of the systems. This approach can be more flexible and adaptable, as it can handle complex, real-world scenarios and data, but it may require substantial data for accurate modelling.

C. Hybrid Approach: The hybrid approach combines elements of both physical and data-driven modelling.

Here are the benefits of the deep learning approach in contrast to traditional machine learning methods.

- Deep learning can learn complex relationships in data without considering complex thermodynamic principles. It relies only on relevant accurate data that influences the application.
- Deep learning's use of backpropagation across multiple layers often results in reduced training times when compared to conventional machine learning models.
- Deep learning fosters interconnections between its layers, bridging the information gap typically encountered in traditional machine learning, particularly when dealing with time series data [6].

The literature review reveals certain research gaps. There is a noticeable absence of baseline models that address and describe the baseline for distinct ranges of electrical loads individually. Additionally, there is a lack of effort in visualizing the operational patterns of specific electrical loads to detect anomalies or normal functioning. Furthermore, another gap concerns the absence of applications that can detect energy wastage or savings in specific electrical loads through the utilization of baseline models.

IV. Materials and Methods

A. *Required Materials*

- OpenStudio
- Microsoft Excel
- Google Colab

B. *Methodology*

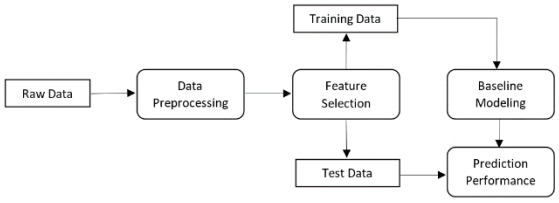

Figure 1: Methodology of Baseline Modeling

The data collection process for our study involves considering various loads such as air conditioners, and lighting systems. We measure power data, indoor temperature, and indoor relative humidity using specialized measuring units that we have developed. Additionally, real environmental data is obtained from the Weather station of the Faculty of IT, and we also collect simulated data through the OpenStudio EnergyPlus software.

Missing values are addressed, data is scaled, and outliers are removed in the data pre-processing stage to ensure the quality and accuracy of our dataset.

In the Feature Selection Process, Pearson's coefficient of correlation (r) is employed to identify which data attributes have the most significant impact on our modeling.

A deep learning approach for modeling will be employed due to the advantages highlighted in above literature review,

For performance evaluation, we utilize several metrics, including R-squared, the Coefficient of Variation of the Root Mean Square Error (CV-RMSE), and the Normalized Mean Bias Error (NMBE). These metrics help us assess the effectiveness and accuracy of our models in estimating power consumption.

V. Results and Discussion

An experimental environment was established through the utilization of OpenStudio / EnergyPlus software to simulate a seminar room capable of accommodating up to 100 students. Within this simulation, electrical load profiles were recorded under real-world weather conditions. The focus of the simulation was to observe the cooling load variations and to identify how it varies under varying weather conditions.

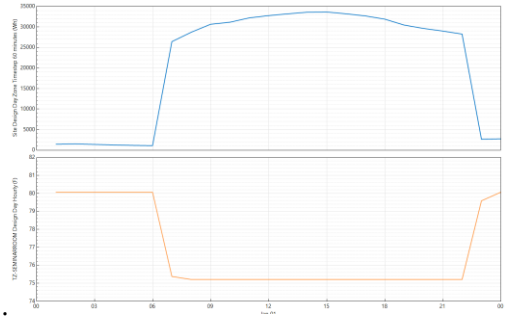

Figure 2: Sample simulation output: Hourly Cooling Load and Temperature variation.

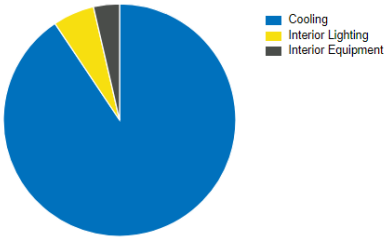

Figure 3: Contribution of Electrical Loads

VI. Conclusion

This project focuses on developing power baseline models for a wide range of electrical loads in the context of energy management for green commercial buildings. By employing deep learning techniques, including Karl Pearson's and Random Forest-based models, as well as Recurrent Neural Networks (RNNs), the study aims to accurately predict and assess energy consumption. The research combines both simulated and real-world data to provide a comprehensive analysis, contributing to the optimization of energy conservation strategies and the promotion of sustainability in commercial and non-commercial applications.

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Recycling Plastic Waste for Enabling Circular Economy

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Keywords—Solid Waste, Plastic, Circular Economy, Sustainability, Landfill

I. INTRODUCTION

Municipal solid waste management is a major issue for many nations striving for a sustainable future. According to the United Nations Environmental Programme report [1], Municipal solid waste management is both a resource and a burden as it contains valuables and leftover waste that need to be managed carefully to keep the public healthy. Biodegradable and non-biodegradable components make up the majority of this waste; the latter includes things like plastics, tires, e-waste, glassware, building debris, metals, ceramics, some textiles, and batteries. Notably, there is significant worry about non-biodegradable waste, especially plastics. Sri Lanka is currently experiencing an economic crisis, import restrictions, shortages of goods, and hike in foreign exchange rate, all of which highlight the need to adopt a circular economy. Natural ecosystems are seriously threatened by Sri Lanka's rapidly increasing plastic usage, which is increasing at a pace of 16% per year [2]. Every year, over 265,000 megagrams (Mg) of plastic are consumed [2], most of which wind up in landfills. Sri Lanka has not yet adopted practices akin to those of other nations that recycle plastic waste into the circular economy. Failure to convert plastic waste could lead to adverse impacts such as reliance on imports, financial losses, unstable foreign exchange rates, shortages of necessities, rising demand for plastics, problems with the carbon cycle and environmental equilibrium, resource depletion, and failure to meet the Sustainable Development Goals.

II. LITERATURE REVIEW

Using plastic in line with the circular economy idea was a major priority in the European Union region, with the goal of increasing resource efficiency and lowering resource dependency. This was accomplished by encouraging a system of production and consumption that recovered, recycled, and reused materials while repurposing waste [3]. Reclaiming plastics that were previously disposed of in landfills was thought to be possible through landfill mining, an alternate technique for reintroducing landfilled waste into the circular economy [4]. The mechanical recycling represented a green operation by minimizing environmental impact through recycling plastic waste and contributing to a circular economy [5]. When plastic waste was recycled and used as a raw material such as plastic pavement blocks, it helped to reduce total operating expenses, which in turn lowered the price of the finished product when compared to traditional concrete pavement blocks [6]. Plastic-Soil pavement blocks were produced in a number of nations, including Ghana, Mexico, Peru, and others, using recycled waste plastic. These blocks were used in parking lots, pavement walkways, and road infrastructure. Compared to traditional concrete blocks, their manufacture not only lowered building costs but also enabled faster installation. This offered a sustainable substitute for non-biodegradable waste, reduced the accumulation of plastic waste, and created jobs in addition to economic benefits [7]. Recycled plastic had become increasingly economically competitive with new ones due to declining recycling cost [8]. To do this, a significant infrastructure investment was required, especially in low- and middle-income countries [8].

Commonly for such feasible research, mixed-method strategy was used for data collection and employing field observations as a method for background study [9]. Secondary data obtained from official reports, and stakeholders in Municipal Councils' solid waste management units were the subjects of unstructured interviews [10]. It was imperative to recognize the constraints associated with localized "best" solutions because what works effectively in a local setting might not perform optimally when applied to a large regional or global context and the finding from these case studies were confined in their generalizability but the concept itself could potentially have broader applicability [11].

III. MATERIALS AND METHODS

The study examined the Oluvil, Pallakadu waste dumping site, which was the main open dumping facility in the South Eastern region of Sri Lanka. It managed waste that was both biodegradable and non-biodegradable and brought from the Kalmunai Municipal Council, Akkaraipattu Municipal Council and different Pradesha Sabhas in Ampara District. Since it was established in 2007, the Addalaichenai Pradesha Sabha was in charge of overseeing this 27-acre site. It was initially granted a 25-year permit, and it has been in operation for 15 years. It was observed that 16,308.6515 tons of waste was received annually, including 1236.02 tons of non-biodegradable and 123.03 tons of degradable waste each month. Significantly, a staggering 14,832.24 tons of non-biodegradable waste, mostly plastics were being carelessly disposed of without any sort of segregation [12]. A concerning composition of plastic waste, such as polyethylene bags, plastic bottles, wrapping and packaging materials, lunch sheet, yoghurt cups, straws, meal boxes, broken plastic furniture and milk packets, could be discovered [12]. Possible outputs through recycling plastic were discussed and the background study was done using field observations. A variety of data collection techniques were used in the study, including unstructured interviews with officials and secondary data gleaned from official reports. The discussion was held with the stakeholders to see the potential and available facilities around the Pallakadu

waste dumping site for any further recycling processes. Investigation was carried out with possible investors who were willing to take up any start up projects. The possibility for the required infrastructure and facilities as well as the feasibility of transferring plastic waste to the to be proposed manufacturing plant were investigated. The discussions were held with plastic manufacturers and wholesalers regarding marketing the finished product and ensuring a fair price, which included analyzing prices.

IV. RESULTS AND DISCUSSION

The study revealed that the Plastic-Soil pavement blocks were a viable solution for managing plastic waste. In comparison to some other recycling practices, the mechanical recycling like Plastic-Soil pavement block manufacturing by using plastic waste, cost saving, simplicity, and lower carbon impact. It also addresses plastic pollution and promotes sustainable construction. This innovative approach could attract investors due to its cost-effectiveness and ability to produce eco-friendly pavement blocks with value additions. The study highlighted the potential and available facilities around the Pallakadu waste dumping site as well as the location of the infrastructure and machinery installation (manufacturing plant) which were in front of the Pallakadu waste dumping site. It was found that there was feasibility for using conveyor belts to transport mined plastics from landfills to manufacturing plant, significantly cutting down labor cost and transport expense of raw materials. Plastic collected at segregated collection points could be directly transported to the manufacturing plant. The plastic waste was shredded by grinder and the shredded plastic mixed with sand. The shredded plastic was then melted by gently pouring this mixture of plastic and sand into a machine, turning it into a pulp that was both plastic and sand. The pulp was then compressed using a hydraulic press machine to create pavement blocks in a range of sizes and forms that might be customized to meet the needs of the customers.

TABLE 1. Cost of a pavement block

Pavement block Types	**Pavement Block Price in Rupees**
Plastic-Soil Pavement Block	50-75
Concrete Pavement Block	150-200
Other Pavement block	200-450

.

This cost efficiency makes these blocks a promising solution for managing dumped plastics and accommodating future collections. The use of Plastic-Soil Pavement blocks not only demonstrates sustainable waste management but also anticipates the development of new markets and employment opportunities, promoting innovative outputs such as parking lots, pavement walkways, and road infrastructure, and lucrative prospects for business owners. This study aims to support the transition of Municipal solid waste management from a linear to a circular economy model by promoting the use of Plastic-Soil pavement blocks. This technique has the potential to create jobs, encourage innovations, reduce reliance on conventional building materials, minimize plastic waste, deal with water contamination, manage the dumping yard capacity, and safeguard local wildlife, especially elephants affected by plastic ingestion. This eco-friendly approach might also enhance the area's aesthetic appeal, bringing in more tourists and promoting local tourism. Furthermore, plastic-soil pavement's long-lasting durability might lead to cheaper maintenance costs, solving environmental concerns and continuing to provide economic benefits. The transition to a circular economy promotes domestic manufacturing, lowers reliance on plastic imports, increases GDP.

V. CONCLUSION

The research aimed to address the challenge of plastic waste by proposing eco-friendly Plastic-Soil Pavement Blocks. It covered practical ways to handle plastic waste and how the end products benefit the circular economy, environment and our ultimate goal of a sustainable future. This study contributed to the ongoing debate concerning plastic waste and themes related to the circular economy.

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A Real-time, Scalable and Extensible Object Filtering and Detection System Using Kinect Sensor and ROS2 Foxy

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Keywords— Kinect, ROS2, Real-time, Shape filter, Color filter

I. INTRODUCTION

Object detection and filtering based on shape and color is an important capability for many robotics applications. For example, sorting objects by shape and color is a common industrial application. Service robots also need to detect and track objects based on visual properties. While powerful deep learning approaches like YOLO have emerged for general object detection, they require large datasets and extensive training. A simple shape and color filtering provide a lightweight and customizable alternative.

This work aims to provide a real-time modular and lightweight system that can identify objects of basic shapes and colors and allow extensibility of functionality by incorporating more custom color and shape filters. The proposed system for real-time shape and color filtering using a Microsoft Kinect RGB-D sensor and Robot Operating System (ROS2) can identify an array of regular shapes like circles, rectangles, and triangles over a spectrum of different colors. New shape and color filters can be added dynamically at runtime thanks to the modular, ROS-2-based implementation.

II. LITERATURE REVIEW

Segmentation and filtering by color is a well-established computer vision technique [1]. Basic shape detection approaches like contour analysis are also commonly used [2]. More advanced techniques use neural networks to identify shapes [3]. ROS1 has been used in several works for object sorting using RGB-D data [4]-[5]. There is limited prior work leveraging ROS2 for similar applications. A custom ROS2 package for detecting basic shapes like circles and squares was developed in [6]. This work builds on such efforts to create a ROS2 system for shape and color filtering using a Kinect.

III. SYSTEM DESIGN

A. Hardware

The system uses a Microsoft Kinect v2 RGB-D camera as the primary sensor. It captures 1920x1080 RGB images and 512x424 depth images at 30 FPS. The Kinect is mounted on a fixed location overlooking the workspace. All processing is done on a laptop with an Intel Core i5 CPU running ROS2 Foxy on Ubuntu 20.04.

B. Software

The overall system is implemented using ROS2 Foxy in C++. A publisher-subscriber model incorporates different color and shape filters to the input image and depth data streams sent from the Kinect camera. The kinect_ros2 library is used to interface the system with the Kinect sensor. OpenCV2 library is used for image processing and contour analysis.

IV. SYSTEM ARCHITECTURE

The nodes first subscribe to the raw image data published by the Kinect camera node. First, the color filter operations are done. Each color filter performs its filtering operation on the image received by subscribing to the image. Finally, the combined results of the color filter are published on the *filtered_rgb* topic. The shape filters then subscribe to this topic and perform their shape-filtering process on this data stream. All the shape filter outputs are then published on a single topic.

The following *rqt_graph* output gives an overview of the topics and nodes used in the workflow.

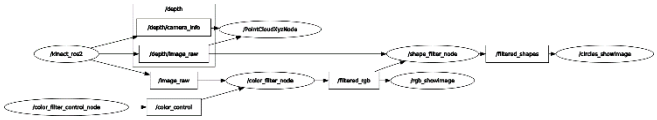

Figure 1.1- Topic and Node List

V. MATHEMATICAL REPRESENTATIONS

The system workflow goes through several crucial operations to perform the above functionality.

A. Conversion from RGB Color Space to HSV Color space

Given the values of the image from the RGB, space be *R, G, and B* the following transformation is used to convert the color space from RGB color space to HSV

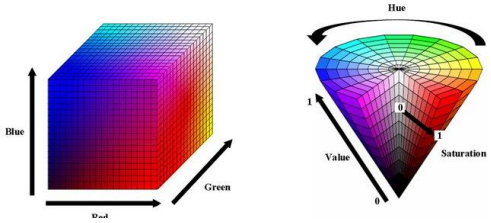

Figure 1.2 RGB color space vs HSV color space[7]

color space where *H, V, and S* represent *hue, value* and *saturation* values.

$$M = max(R,G,B) \quad m = \min(R,G,B)$$

$$H_0 = 60 * \begin{cases} 0 + \dfrac{G-B}{M-m}, & M = R \\ 2 + \dfrac{B-R}{M-m}, & M = G \\ 4 + \dfrac{R-G}{M-m}, & M = B \end{cases}$$

$$H = \begin{cases} H_0\,, & H_0 \geq 0 \\ H_0, & H_o < 0 \end{cases}$$

$$S = \frac{M-m}{M}$$

$$V = Max(R,G,B)$$

B. *Filtering Image stream based on color filter*

Define 2 bounds of HSV values that the extreme color values for the required color range. Define them using *OpenCV Scalar*. Then threshold the image using these limits. Let the source image be *I*, and the function *f* performs the filtering. *lower* and *upper* are the lower threshold and upper threshold values respectively. *I`* will represent the resulting image. Let *x, y* be the coordinates of the pixel considered.

$$I'(x,y) = f(x) = \begin{cases} I(x,y), & lower \leq I(x,y) \leq upper \\ 0, & otherwise \end{cases}$$

C. *Determine the bounding boxes*

Use *boundingRect* method of OpenCV to determine the bounding box of the required image. Filter out possible disturbances by defining the *width: height* ratio of the bounding box.

VI. Results

The system can seamlessly identify images according to the color filters and shape filters provided. The following image shows how the system identifies *red* and *green circular objects* in the image stream. The depth value (untransformed) is shown in the raw form as they are received from the Kinect Sensor. These depth values are not calibrated or represent the actual distance to the objects.

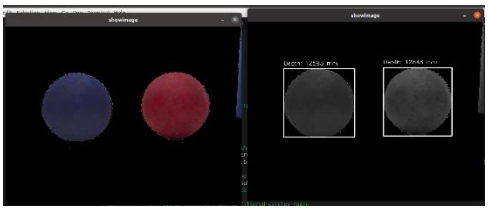

Figure 2.2 - Results of color filter and shape filter

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I would like to extend my thanks to Dr. Sulochana Sooriyarachchi for supervising this project.

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Associations Between Socioeconomic and Trip Characteristics of Bus Passengers to Plan for Transfer-Based Bus Transport Operations.

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Keywords— transfer, bus transport, socioeconomic, trip characteristics, associations

I. Introduction

There are mainly two types of bus routes in Sri Lanka. They are main routes and secondary routes. Secondary routes connect main town centers to secondary-level townships, while main routes often connect two main towns or city centers. Secondary bus routes' extensive service, including feeder buses, can create a lap length, impacting supply and demand cycles. In response to this challenge, the concept of a transfer-based bus transport network (TBBTN) emerges as a potential solution. Specifically, the study aims to discern the influence of socioeconomic factors and travel characteristics, thereby illuminating critical insights for the development of a system that maximizes operational efficiency while minimizing passenger inconvenience. By testing the associations between these key variables, this research endeavors to contribute to the advancement of a more effective and responsive bus transport network in Sri Lanka.

II. Literature Review

Urban traffic issues required public transportation (PT) [1], which required coordination and satisfaction [2]. Transfer-based systems were used in developed countries [3]. However, the whole industry depended on customer satisfaction [4]. Surveys and analysis of socioeconomic and trip characteristics were crucial for understanding passenger satisfaction and improving public bus transportation [5].

Different traveler groups had varying opinions about their trips [6] influenced by factors like age, gender, income, and time. Public transportation usage could be influenced by factors like price and parking issues [4]. Reasons to avoid public transportation included safety, comfort, and time efficiency. Passengers expected better services for higher satisfaction levels [7].

Female travelers faced challenges with travel planning, with low-income travelers often choosing the least expensive transportation [6]. They expected less out-of-vehicle time and prefer public transport for its affordability and relaxation [5]. However, they avoided PT due to parking issues, high time consumption, and safety concerns during night travel.

Planning for a door-to-door trip involves considering factors like waiting times, journey duration, and transfers, which were often overlooked in public transport accessibility studies and decision-support systems [8]. Factors such as cost, transfers, walking distance, safety, and convenience could affect trip satisfaction [5].

China prioritized urban passenger transport development, focusing on rapid rail transit, ground buses, and feeder buses. Research on transfer convergence was necessary for efficient, timely, and integrated transport [9]. Coordination of transfers could speed up service connectivity and reduce wait times [2].

III. Materials and Methods

The research focused on transportation systems for passengers, operators, and regulators. Background study and pilot test were used to identify variables. A questionnaire was designed which included details on passenger socioeconomic characteristics and trip characteristics of the passengers for their current trips and the perceived satisfaction on their existing and the to be proposed transfer-based bus transport networks. The questions targeted the alternative hypothesis that of there were associations between Socioeconomic and Trip Characteristics of Bus Passengers.

The Annual Reports of the Central Bank of Sri Lanka were used to identify the categories for the chosen variables such as passengers' age, gender, and income. Categories for trip characteristics such as reasons for using public transport, cost, waiting time, trip purpose, frequency and time of bus usage were developed based on the literature and the background study. A Likert scale was used to measure trip characteristics such as convenience and safety. Current trip information such as departure and arrival time, waiting time, cost, mode, and distance of each step of the journey were also collected. Information on the level of satisfaction on the current and the to be proposed TBBTN were collected through a rating scale. In addition, passengers were requested to rate the perceived bus fare for the proposed TBBTN considering 100 percentage for the bus fare for their current trip.

Data was collected from nearly 300 passengers through interviews. Cross-tabulation analysis (chi-square test) was conducted to test the existence of statistically significant association between the socioeconomic characteristics and the trip characteristics.

IV. Results and Discussion

The survey results are shown in Table 1. These findings underscore a statistically significant association between gender and safety, as well as convenience in the context of bus travel. Female travelers were more concerned with safety and expected seats and less standing time compared to male passengers. This finding holds true as women were more likely than men to be assigned the characteristics "travel shy," "reassurance seeker," and "cautious planner." [6]. The survey results revealed that passengers perceived switching to TBBTN could reduce the total waiting time and travel time since the frequency was higher. Therefore, it was suggested that regulators and operators should plan the TBBTN to provide less waiting time and walking distances. This would help with female passengers regarding their safety, expected services issues.

Table 1. Survey results and summery

Finding	Value	Sig. value
Female travelers expected more services and safety	80.3% females were concerned about safety	0.000
When age rose, expectations went high	Average of 73.6% elderly age passengers expected seats etc.	0.000
Middle aged people expected lesser travel time	74.6% of middle-aged passengers highly expected less travel time	0.000
Low-income travelers under age 25 mostly traveled for educational purposes while middle aged and older passengers mainly used for business purposes	82.6% of low incomers age less than 25. 93.2% of young passengers engaged in educational trips. 60% of middle-elderly passengers used buses for business trips	0.000
Passengers were concerned about the cost of a trip	75.3% passengers were concerned about the cost and expected a discount with the perceived stage	0.000

As per to data collected, it was noted that as age rose, passenger expectations were high. These findings hold true as passengers aged, they had higher expectations for services such as frequent bus service and short walking distances. Senior passengers encountered numerous challenges when using public transportation, such as physical and mental obstacles, availability, restrictive routing, and unreliability [6]. This finding could also be encouraging for aged passengers as TBBTN could increase service frequency. But the challenging factor was that aged passengers would not like frequent transfers.

According to data collected, low-income travelers under age 25 traveled mostly for educational purposes, while middle-aged and older passengers primarily traveled for business. Youngsters who happened to be categorized under 25, mostly were students who did not have earnings. Younger individuals worried more about the cost of the trip than other age groups. This finding was useful for determining the bus fare for the TBBTN. TBBTN should be operated in a manner that it could reduce the travel cost for the entire trips. But the existing transfer-based operations incurred more travel costs compared to direct based bus operations. Therefore, this finding emphasized the need to revise the bus fare.

Middle-aged people expected less travelling time. Middle-aged people were more concerned about punctuality as most of them were making work-based trips. Therefore, when properly planned, TBBTN could reduce overall travel time compared to the existing direct based transport operations as TBBTN could enable an increase in service frequency.

V. Conclusion

This study concludes that there were associations with socioeconomic characteristics of the passengers with their trip characteristics. These existing associations confirmed that increasing service frequency, reducing travel time, minimizing transfers, adjusting the bus fare, and providing service quality to bus operations could be the successive factors for TBBTN operations.

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Optimizing Transformer Fault Detection: An Investigation into Current Signal Feature Extraction

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Keywords—Transformer, Feature Extraction, Fault Detection

I. INTRODUCTION

Identifying faults is a crucial element in the realm of preventive maintenance and the condition monitoring of transformers. For fault detection of transformers many different conventional or advanced techniques such as short circuit impedance measurement, vibration and sound analysis, frequency response analysis (FRA), dissolved gas analysis and machine learning or deep learning have been used. Offline methods of fault detection are being experimented since faults can be detected at the earliest stages, the detection process does not disrupt power supply. By using feature extraction of the fault current waveform, the performance of the fault detection algorithm can be improved, and the accuracy of fault discrimination can be increased.

The purpose of this study is to evaluate the use of feature extraction of current in fault transformers using wavelet transform in order to enhance the effectiveness of the fault detection in transformers. A simulated PSCAD model derived using lumped parameter network in [1] is used for the generation of different types of faults and obtaining their fault current waveforms for feature extraction.

II. LITERATURE REVIEW

Numerous techniques have been employed for feature extraction in research studies related to power systems. As noted in [2], one frequently utilized signal processing method is the wavelet transform, which enables the extraction of both high and low-frequency components from signals. In this context, it has been applied to extract features from zero sequence currents. The selection of a specific wavelet depends on the nature of the application, and Daubechies wavelets are particularly prominent for detecting, localizing, and classifying disturbances, as highlighted in [3]. Additionally, the Daubechies family of wavelets, known for its versatility, is considered highly suitable for analyzing power system transients, as affirmed in [4].

Within the Daubechies family, there exists a wide range of wavelets, each with distinct characteristics. In [3], three Daubechies wavelets—Daub4, Daub12, and Daub20—are discussed. Daub4, due to its limited number of filter coefficients, stands out as a short wavelet, offering a higher level of temporal localization compared to other wavelets. It is noteworthy that this study follows suit by employing the Daub4 wavelet to extract features from the primary and secondary zero sequence currents, as well as the three-phase currents of transformers.

The transformer fault detection process has made use of a variety of machine learning models. Support vector machines (SVM), relevance vector machines (RVM), random forests (RF), decision trees (DT), and hierarchical ensemble extreme learning machines are the most often utilized methods. According to [5] SVM is inherently designed for binary classification. [6] states that RF offers non-linear classification and is a more potent classifier than SVM. According to the studied literature it is clear that Random Forest technique is a good fit for transformer fault detection.

III. MATERIALS AND METHODS

The zero-sequence current is a crucial indicator of malfunctioning circumstances. Therefore, initially, the three-phase currents were transformed into zero-sequence currents through the application of Fortescue's transformation.

$$x_P = [x_a \; x_b \; x_c]^T$$

$$x_F = T_{P>F} \cdot x_P$$

$$T_{P3>F3} = 1/3 \cdot [[1 \; 1 \; 1] \; [1 \; a_3 \; {a_3}^2 \;] \; [1 \; {a_3}^2 \; a_3]]$$

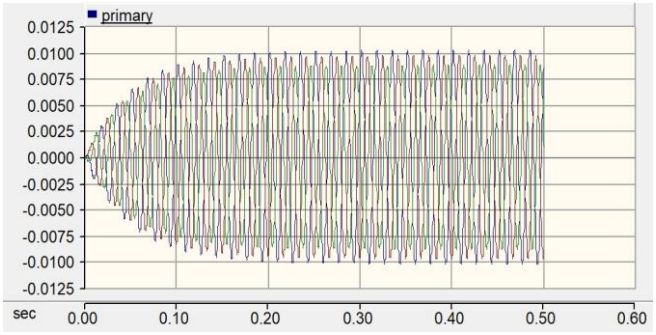

Fig. 1. Primary Current Waveform

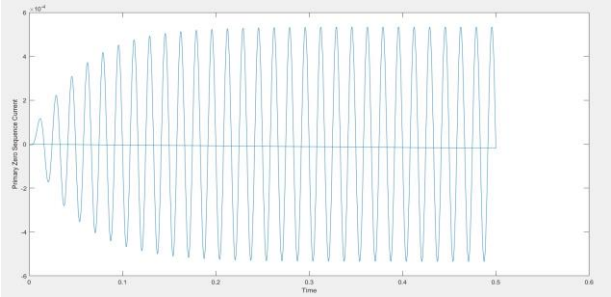

Fig. 2. Primary Zero Sequence Current Waveform

Subsequently, features were extracted from both the zero-sequence and three-phase currents on both the primary and secondary sides of the transformer with the aim of achieving better accuracy. As previously mentioned, this feature extraction process was accomplished using Daubechies 4 wavelet transformation with a level-2 decomposition.

In wavelet transformation, the process involves decomposing a given function, denoted as x(t), into a set of functions known as wavelets. Each wavelet is generated through a combination of scaling and translation operations applied to a fundamental function referred to as the mother wavelet.

During a level-2 decomposition, it is possible to extract three distinct coefficients, which are as follows: the level-2 approximation coefficient (cA2), the level-2 detail coefficient (cD2), and the level-1 detail coefficient (cD1).

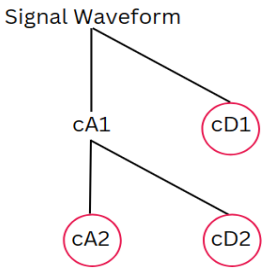

Fig. 3. Coefficients at each level of decomposition

From each of these coefficients, we have extracted a set of features, which includes the maximum coefficient, the minimum coefficient, and the wavelet energy entropy coefficient.

Following feature extraction, a machine learning model was created to use current waveform data to identify transformer fault states. The Random Forest approach, which offers highly accurate nonlinear classification, was applied.

IV. Results and Discussion

In this study, a total of 72 features have been successfully extracted from both primary and secondary side 3 phase and zero sequence currents.

The subsequent phase entails optimizing the number of features extracted according to the accuracy of the trained machine learning model.

V. Conclusion

Feature extraction was effectively performed from both fault currents and normal currents.

Based on insights garnered from the literature review and the obtained results, it is evident that optimizing the number of features extracted and the level of decomposition can lead to an improvement in model accuracy.

Acknowledgment

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Numerical Investigation on Laboratory-developed CdS/ CdTe Thin Film Solar Cell

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Keywords—CdS/CdTe solar cell, Numerical Analysis, SCAPS-1D

I. INTRODUCTION

Sri Lanka is aiming to make its electricity sector more environmentally friendly by 2050 by achieving carbon neutrality in the electricity industry. As a result, electricity generation is being planned to reach 70% of it by Renewable Energy (RE) sources [1]. According to the latest Long Term Generation Expansion Plan 2023-2042, our country will have 31% of its energy share from solar power [2]. However, the low efficiency and high cost of solar panels are currently a barrier to achieving this goal.

The purpose of this study is to propose a method to increase the efficiency of the glass/FTO/CdS/CdTe/Cu/Au solar cell which was developed under laboratory conditions. CdTe solar cells are second-generation thin film solar cells that are more economical and can increase efficiency subsequently than the first-generation Si solar cells [3]. Solar Cell Capacitance Simulator (SCAPS 1D) software is used for the simulations and the software is validated using practically measured cell output parameters and simulation results to ensure its suitability for the study.

II. LITERATURE REVIEW

Thin-film cells are leading in today's PV industry. At present thin-film solar cells (TFSC) are a promising choice in terms of device design, fabrication, and cost-effectiveness. Amorphous silicon and most TFSCs are second-generation (2G) solar cells. Second-generation solar cells offer better electrical performance. Production of these 2G solar cells is more profitable as compared to the first-generation wafer-based silicon solar cells. Leading TFSCs can be categorized as: a-Si: H (Hydrogenated Amorphous Silicon), CdTe (Cadmium Telluride), and CIGS (Copper Indium Gallium di-Selenide) [3].

Cadmium Telluride (CdTe) as thin-film polycrystalline solar cells is one of the most hopeful candidates for photovoltaic energy conversion [4]. The polycrystalline CdS is the best-suited hetero-junction n-type partner with a p-type CdTe absorber for CdS/CdTe solar cells[5]. Therefore, the glass/FTO/CdS/CdTe/Cu/Au solar cell has a good performance.

Numerical simulation is crucial for understanding and optimizing solar cell designs. The SCAPS simulator, compatible with Windows and Linux, is a valuable tool for analyzing and improving CdS/CdTe solar cell performance [6-8]. SCAPS 1D, a free simulation tool, is well-suited for thin-film modeling and offers flexibility for modifying parameters like thickness and doping in various solar cell structures [9, 10]. It was used to simulate the J-V characteristics of the CdS/CdTe solar cell.

III. MATERIALS AND METHODS

The thickness of each layer of the aforementioned solar cell was measured using Scanning transmission electron microscopy with energy-dispersive X-ray (STEM-EDX) analysis as shown in Fig. 1. The average of those thicknesses was taken as inputs in SCAPS 1D. The average thickness of the CdTe is 5.95 µm and the thickness of CdS is 0.294 µm. Other material parameters are extracted from [11, 12, 13].

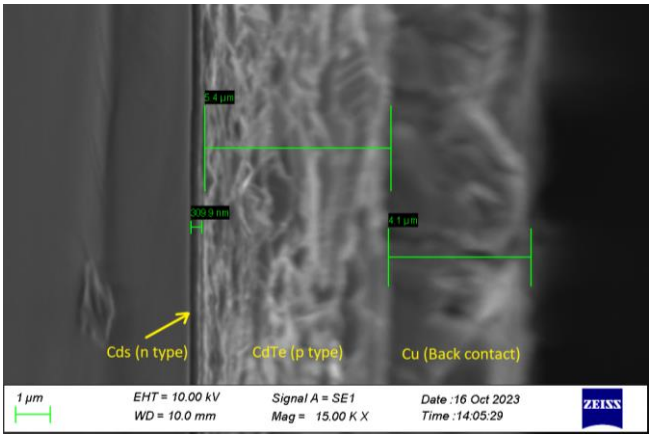

Fig. 1: Thicknesses of each layer of CdS/ CdTe solar cell, from STEM-EDX Analysis

Practical measurements for open circuit voltage (Voc), short circuit current density (Jsc), fill factor (FF), and power conversion efficiency (η) of the solar cell are needed to validate the software. Those parameters were measured using the solar simulator (PEC-L12).

IV. Results and Discussion

Results of electrical parameters with the variation of Thickness of the CdTe layer

In the simulation, the thickness of this layer varied from 0 µm to 10 µm, while other parameters remained constant. According to Fig. 2, Voc and Jsc are increased with the thickness of CdTe, while FF is decreased. As the thickness of the absorber layer increases, it can absorb more photons and enhance Jsc and Voc. Moreover, the increase in the absorber layer thickness can also increase the series resistance, which leads to reducing the FF. Since, the efficiency is determined by the Voc, Jsc, and FF, any change in Voc, Jsc, or FF can also lead to a change in Efficiency. Red lines refer to the reference solar cell.

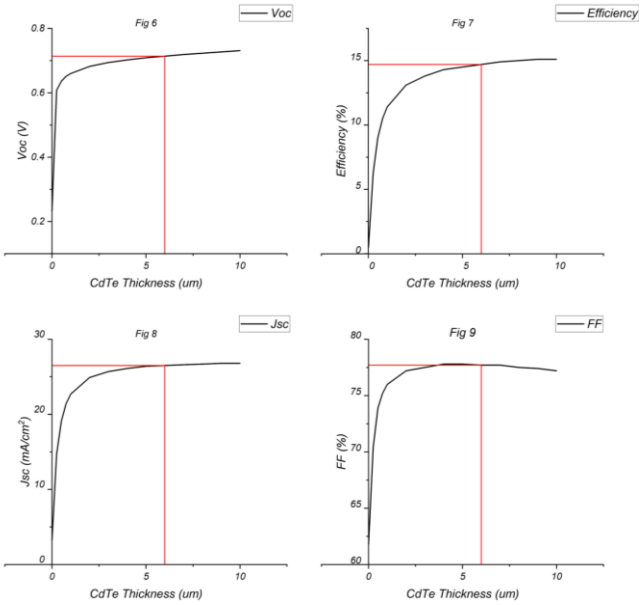

Fig. 2: Behavior of Electrical parameters with the thickness variation of the CdTe layer

Solar cells that exhibit a greater FF are considered more efficient and are preferred for practical applications. Therefore, a CdTe layer thickness of 4.85 µm was chosen, as it yielded the highest FF (according to Fig. 2).

Results of electrical parameters with the variation of Thickness of the CdS layer

From the simulations, the thickness of the CdS layer was selected as 20nm where height efficiency was obtained. From the results obtained, The highest efficiency of 15.5% was achieved for the simulated structure containing the CdS window layer (thickness 20 nm) on the CdTe absorber layer (thickness 4.85 µm). Moreover, Voc, Jsc, and FF were recorded as 0.7193V, 27.95 mA/cm2, and 77.775%, respectively. Therefore, setting the CdTe layer thickness at the same value of 4.85 µm, and reducing the CdS layer thickness to 20 nm can be proposed as a method to increase the cell efficiency.

V. Conclusion

Based on the analysis, it is suggested that the actual measured thickness of the CdS layer (2.94 µm) and the CdTe layer (5.95 µm) can be adjusted to 20 nm and 4.85 µm to achieve the highest efficiency of 15.28 % for Sri Lankan laboratory developed glass/FTO/CdS/CdTe/Cu/Au solar cell according to the simulation. For further enhancement of efficiency, the essence of the Back surface field layer can be identified as previously mentioned.

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