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Message from the Editor in Chief

On behalf of my co-editors (Prof. Ahmed Nawaz Hakro & Prof. Anupam Srivastav) and other members of Editorial Board, I am delighted to bring this Volume 5, Issue 1 of the Journal of Big Data and Smart City (JBDSC). This Issue, like its predecessor issues, is an open access journal, with an Arabic translation of the Abstract of every paper published.

The Journal of Big Data and Smart City (JBDSC) is providing an exciting platform to scholars, researchers, other related professionals, policy makers, and especially to the students, to showcase their scholarly ideas and research in Smart City applications, building on Big Data technologies. The journal has been accessible, engaging and motivating to the young researchers, as all the 6 papers in this Issue are joint work with students.

The journal has been successful in fulfilling its objective to publish original interdisciplinary research. All the published papers, which cover the areas of Expert Systems, IoT, Mobile Applications, etc, have been subjected to a double-blind review process. The multidisciplinary collaborative work combining multiple fields in wider possible contexts, published in this issue integrates theoretical, experimental, and computational approaches, providing solutions towards smart city/ information and communication technologies themes.

I am thankful to those who submitted papers, both individually or collaboratively from academia and industry. I take this opportunity to also thank all those who contributed in bringing out this issue of the Journal. I am extremely thankful for the continuous support of MoHERI and MoI for allowing this scholarly publication.

Special thanks to all the members of the Editorial Board for dedicating their valuable time and energy which made it possible for this issue to be published well in time.

Wishing the readers of the articles of this journal making a fruitful contribution in their future research pursuits.

Dr. Saleh Al Shaaibi
Editor in Chief
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Journal of Big Data & Smart City
كـلية الشـرق الأوسـط Middle East College

INFLUENCE OF THE EPOXY COATING ON CONCRETE STRUCTURES IN COASTAL AREAS IN SULTANATE OF OMAN

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Abstract

Concrete structure studies prioritize protecting facilities and residential structures from corrosion and rust. However, it causes material and human losses and increases maintenance costs, especially in coastal locations with unfavorable components and circumstances. This study examines facility owners' understanding of reinforcing bar corrosion and rust, determines the extent to which coastal facilities in the Sultanate are impacted by rust, and compares regular reinforcing bars and epoxy-coated reinforcement in preserving the bars from corrosion and rust. The questionnaire distribution technique was utilized to acquire the findings and achieve the objectives. The experts' interviews were monitored by designing questions linked to the study's objectives and assessing them using KOBO Toolbox and PSPP software. Information was taken from prior research. The significant findings reveal that respondents' understanding of iron bar corrosion causes and protection techniques varies by age and education. Furthermore, because some people were inexperienced with the effect of reinforcing bars and how to preserve them with epoxy coating, the findings were related to the reference literature. There was a discrepancy in research between a group that supported the use of the epoxy coating in reinforcing bars with laboratory tests and a group that did not help its users and revealed its ineffectiveness in protection. Due to the wide variety of opinions on epoxy coating, we recommend completing a considerable study on it and not utilizing it unless it is shown to preserve reinforcing bars or material development.

Keywords: *Epoxy Coating, KOBO toolbox, SPSS, Corrosion.*

الخلاصة

تعطي دراسات الهيكل الخرساني الأولوية لحماية المرافق والهياكل السكنية من التآكل والصدأ. ومع ذلك، فإنه يتسبب في خسائر مادية وبشرية ويزيد من تكاليف الصيانة، لا سيما في المواقع الساحلية ذات المكونات والظروف غير المواتية. تبحث هذه الدراسة في فهم أصحاب المنشآت لتعزيز تآكل البار والصدأ، وتحدد مدى تأثر المنشآت الساحلية في السلطنة بالصدأ، وتقارن بين قضبان التعزيز العادية والتقوية المغطاة بالإيبوكسي في الحفاظ على القضبان من التآكل والصدأ. واستخدمت تقنية توزيع الاستبيانات للحصول على النتائج وتحقيق الأهداف. تمت مراقبة مقابلات الخبراء من خلال تصميم الأسئلة المرتبطة بأهداف الدراسة وتقييمها باستخدام KOBO Toolbox و PSPP. تم أخذ المعلومات من بحث سابق. تكشف النتائج المهمة أن فهم المستجيبين لأسباب تآكل قضيب الحديد وتقنيات الحماية تختلف حسب العمر والتعليم. علاوة على ذلك، نظرًا لأن بعض الأشخاص كانوا يفتقرون إلى الخبرة مع تأثير تعزيز القضبان وكيفية الحفاظ عليها بطلاء الإيبوكسي، كانت النتائج مرتبطة بالأدبيات المرجعية. كان هناك تناقض في البحث بين مجموعة دعمت استخدام طلاء الإيبوكسي في تقوية القضبان بالاختبارات المعملية ومجموعة لم تساعد مستخدميها وكشفت عن عدم فعاليتها في الحماية. نظرًا للتنوع الواسع في الآراء حول طلاء الإيبوكسي، نوصي بإكمال دراسة كبيرة عنه وعدم استخدامه ما لم يثبت أنه يحافظ على تقوية القضبان أو تطوير المواد.

الكلمات الرئيسية:،KOBO,صندوق أدوات,SPSS,Corrosion

1. Introduction

In the 19th century, reinforced concrete was invented. Two billion cubic meters of concrete are made daily and used to create offices, high-rises, and industrial structures. Concrete helps build quickly and cheaply. Concrete is a composite material comprised of cement, fly ash, cement slag, aggregates (such as gravel or crushed rocks), water, and chemical additives. (Huttunen-Saarivirta et al., 2013). Unfortunately, the seaside concrete buildings are prone to corrosion and rust. Because coastal regions are directly or indirectly exposed to high saline saltwater by winds that transport sprays a few miles inland. As this impact has become a severe concern for people and structures in these places, it's an excellent time to assess the durability of concrete in these areas. McDonald, Pfeifer, and Sherman (1998) developed novel metallic, organic, and inorganic coatings for cement concrete reinforcement. This study checked the corrosion rates of concrete-reinforced materials and metals. This study evaluated corrosion on 12 concrete-reinforced bars: stainless steel 316 and 304, black bars, copper-clad, bendable, and non-bendable epoxies. The researchers examined half-cell potentials, linear polarization, macro cell voltages, and electrochemical spectroscopy. These procedures are used to evaluate each concrete-reinforced bar type visually. This research suggests using epoxy-coated reinforcing bars to prevent corrosion. Epoxy-coated bars demonstrate lower corrosion rates than black bars, are used as slab mats to prevent placement and shipping damage, cure concrete fissures, make decks, and can be used for the bottom and top mats. However, top mat bars are less durable. Paolo, Jirsa, and Hammed (1992) studied the influence of the epoxy coating on concrete bonds and anchoring. This research checked the bond properties of epoxy-coated concrete buildings and modified anchoring recommendations. Epoxy-coated concrete affects anchoring and bonding. This research examined the impact of epoxy coating on reinforcement bonding and anchoring in concrete structures. Three test series. Varying Pullout samples were examined to calculate the difference in shear transfer between Epoxy coated and uncoated bars using bars of different thicknesses, diameters, concrete strengths, and deformation patterns. Twelve spliced beams were tested in a continuous moment. Twelve inches of concrete covered the bars. Bar spacing, bar size, and reinforcement across the splitting plane are measured. Twenty-four beam-column junctions were used to evaluate epoxy-coated and untreated hooked bars' anchoring capabilities. Concrete cover, bar size, concrete strength, hooked geometry, and beam-column reinforcement are measured. All experiments evaluated epoxy coating on coated bars. David Darwin, Cynthia J. Hester, Steven L. McCabe, and Shahin Salamizavaregh studied epoxy coating bonding in 1991. Their study tested concrete-reinforced epoxy coatings' binding strength. This research investigated concrete compressive strengths. When concrete uses epoxy-coated bars, corrosion weakens epoxy-coated bars. So, epoxy corrosion prevention is essential. Epoxy coatings on concrete have lower bond strength than untreated epoxy bars. In this work, unique recommendations to increase bond strength and design requirements of epoxy coating in concrete were based on several sample testing of epoxy coated bars in concrete and their findings. This study assessed 65 slabs and beams. Epoxy-coated concrete formed these samples. The epoxy-coated concrete was tested at 38 to 41 MPa. This data show that epoxy-coated concrete reinforced bars have lower splice strength. Transverse reinforcement doesn't affect splice strength. Transverse bar reinforcement enhances splice strength. Darwin, Hester, McCabe (2020). Sabbir Hussain, G. M. Sadiqul Islam, S. M. Sharifuddin, and Ehsan Ahmed (2019) studied fusion-bonded epoxy-coated concrete reinforcement. This study evaluated and tested epoxy-coated reinforced bars' bond strength in concrete. Epoxy-coated bars prevent concrete deterioration. Epoxy-coated bars weaken concrete bonds. Experiments on epoxy-coated concrete reinforcement indicated bond strength. Tested variables Diameter, strength, and epoxy-coated bar diameter vary. After determining these parameters, uncoated concrete bars were compared. The 20mm bar's bond strength lowers from 33% to 25% when inserted 150-160mm. The 16mm bar's bond strength decreases from 33% to 25% when inserted 100-200mm. Embedded length promotes binding strength, but bar size diminishes it. Regardless of concrete strength, coated and uncoated bars bond. Concrete strengthens bonds. Increasing development time strengthens bonds. Alberto A. Sagues examined epoxy-coated rebar in Florida bridges in 1994. Epoxy-coated rebar corrosion in Florida bridges was studied. Florida has 300 ECR bridges. Thirty bridges tested epoxy-coated rebar corrosion. Testing was done on the epoxy-coated bridge rebar. These tests extract rebar and core concrete and measure corrosion potential electrochemically. Concrete, rebars, and Epoxy are also tested. No epoxy-coated rebar structures deteriorated, save for five bridges. Epoxy-coated rebar fails in lab tests. Five bridges are corroding owing to poor epoxy-to-rebar adhesion. Huu Nguen and Tuan Anh Nguyen (March 2018) wrote about employing epoxy nanocomposite coatings to preserve steel rebar in salt-contaminated cement mortar. This study tested steel rebar corrosion in salt-contaminated cement mortar and developed protective strategies. The Epoxy on a contaminated steel bar has two types of nanoparticles: Nano-SiO_2 and nano-Fe_2O_3 particles. Sodium chloride is used to increase chloride in portland cement. Nanoparticles affect epoxy-coated steel bars. Two approaches were utilized to examine nanoparticles on epoxy-coated steel bars. Electrochemical impedance spectroscopy and linear potentiodynamic polarization were used. Immersion of epoxy-coated steel bars in 0.1M NaOH for 56 days demonstrates that nano-Fe_2O_3 improves corrosion resistance for 0.3 wt. Percent chloride mortars. Electrochemical monitoring revealed results. Nano-Fe_2O_3 reduces the bar's corrosion current after 56 days. Immersion of epoxy-coated steel bars in 0.1M NaOH for 56 days demonstrates that nano-Fe_2O_3 does not improve the epoxy-coated steel bar's corrosion resistance for 0.5% chloride mortars. Electrochemical monitoring revealed results. Liliana Baltazar, Beatriz Lopes, M. Paula Rodrigues, Joao Santana, and Joao R. Correia studied the superficial protection of concrete with epoxy resin impregnations in July 2014. This study aimed to preserve concrete using epoxy resin impregnations and determine how roughness and wetness affected them.

Impregnation materials help protect concrete against corrosion or aggressive chemicals. The method works for new and old concrete structures. This study analyses how concrete's wetness and roughness affect impregnation materials. To test their performance, two concrete samples with various cement-to-water ratios were impregnated with epoxy resins. In addition, two concrete samples with various moisture levels and surface roughness's were prepared. Different tests evaluated outcomes. Bond strength, abrasion resistance, product penetration depth, impact resistance, and immersion water absorption are tested. Epoxy resins boost the performance of these two concrete forms while leaving their resistances the same. Concrete's wetness and roughness boost epoxy impregnation performance. Aleinikova, Y Kolomiiets, O Kabus, D Goncharenko (2019) studied epoxy coating's effectiveness against sulphuric acid corrosion. This study tested the efficacy of epoxy-coated concrete surfaces against sulphuric acid corrosion and developed measures to safeguard them. Epoxy-coated concrete buildings prevent sulphuric acid corrosion. First, check the epoxy-coated concrete's resistance to sulphuric acid corrosion. Acidic chemicals permeate coatings, causing swelling and increasing corrosion. Epoxy-coated concrete is resistant to sulphuric acid, but long-term exposure to acidic chemicals causes coating swelling and concrete degradation. Epoxy-coated concrete samples were subjected to hydrogen sulfide and a 5% sulphuric acid solution. Epoxy-coated concrete has a longer life against acid corrosion than bare concrete. The epoxy coating must be applied without flaws or fractures to prevent acidic chemicals from penetrating the concrete. Multilayer coating removes fractures on epoxy-coated surfaces. Periodically inspect layers to prevent corrosion. Marius Bodor, Catalin Negoita, and Nicoleta Cristache studied epoxy resins in 2000. This research aimed to show how epoxy resins are used across the world. Composite materials, coatings, fiberglass adhesives, and carbon fiber reinforcements employ epoxy resins. Dry protective coatings include an energy-efficient aqueous epoxy coating on metal substrates to prevent corrosion. The dry layer is abrasion- and UV-resistant. Epoxy resins preserve oil and gas fittings and steel pipelines against corrosion. The epoxy resin creates durable composite materials. Epoxy resins cost more than vinyl and polyester. Electronics use epoxy resins most. Electronic markets employ PCBs in tanks, computers, wind energy, and aviation parts. Epoxy resins coat PCBs. Epoxy resins are used more economically all over the world. Europe and the U.S. share the epoxy resin market. Epoxy resins are becoming more popular. Hence their market will rise. According to the research, epoxy resins will be employed in diverse combinations. Materials decrease the environmental effects. (Bodor, Negoita, Cristache, 2020). Frederick S. Gelfant and Frederick A. Pfaff studied epoxy coating osmotic blistering in 1997. This study aimed to determine what causes osmotic blistering of epoxy coating on concrete and how to stop it. Epoxy coatings blister because they're impervious to liquid water. Blisters make coating surface uneven and destroy continuity. The frequency and size of coating blisters vary. Random blisters cover the covering. Liquid causes were rusting in blisters. Concrete water contaminants cause blister liquid. Concrete tests and osmotic theory are used to analyze unsuccessful coating systems. Results show that floor coating blisters produce osmotic pressure. Composition and microstructure vary 2 cm inside the concrete's covering. High soluble salt levels in top-level concrete cause these variances. Concrete level changes cause osmotic cells and containing walls. Rakesh Kumar from the Central University of South Bihar developed Epoxy and polymer-based concrete in March 2016. This study compared polymer-based and polymer-based polymer concrete characteristics and formulations. High-quality concrete is polymerized with Epoxy and polyester thermoset resins. As petroleum supplies dwindle, thermoset resins can replace petroleum-based epoxy resins in polymer concrete. Furfuryl alcohol (F.A.) is a lignocellulose thermoset resin. A catalyst converts furfuryl alcohol to polyfurduryl alcohol (PFA). This reaction transforms furfuryl alcohol into polyfurduryl alcohol. Polyfurfuryl alcohol can resemble concrete. Polyfurfuryl alcohol resists bases and acids better than thermoset polymer concretes. Polyfurfuryl alcohol-based polymer concrete can be utilized with Portland cement. Epoxy polymer concrete has 18Mpa flexural strength. Epoxy and polymer resins combined with red mud and ash have greater flexural strengths than Portland cement concrete (21.3 and 18.5 MPa). PFA-based polymer concrete is (13 2 MPa) compressive. Epoxy-based polymer concrete is (60 10 MPa) compressive. Polymer concrete is stronger than Portland cement. Kumar (2020). Connor mills and Benjamin Z. Dymond studied epoxy rebar anchoring utilizing chemical adhesives in February 2019. Uncoated bars fitted with chemical adhesives corrode. Hence epoxy-coated reinforced bars are employed.

This study calculated the tensile pullout strength of epoxy-coated, chemically adhered reinforced bars. Second, define and examine design techniques for epoxy-coated, chemically adhered reinforced bars. The two lab tests meet these goals. Both tests require sampling and casting. These samples include uncoated and epoxy-coated reinforcing bars. Both bars have the same chemical adhesives. Traditional uncoated reinforcing bars are contrasted with epoxy-coated bars. Epoxy-coated reinforced bars have less tensile strength than untreated bars. Epoxy-coated reinforcing bar tensile strength ratio is 0.95 to 1.05. Recommendation based on results. First, a modification factor is used to calculate the bond strength of epoxy-coated, chemically adhered bars. The bar's value modifier is 0.9. Lance H. Francis, V. Gopu, Thomas E. Cousins, and J. Michael Stallings (1993) studied epoxy-coated Prestressing strand spacing and concrete cover requirements in unconfined sections. This study determined epoxy-coated prestressing strand spacing and concrete cover requirements. This was tested. The test picked concrete cover and spacing requirements for the 12.7 mm epoxy-coated prestressing strand. This investigation determined how three criteria affected an epoxy-coated prestressing strand. Concrete cover and strand spacing are parameters. These factors determine the test's concrete transfer length. Variable test conditions set minimal strand spacing and concrete cover, so sample specimens don't split owing to stress transmission. Epoxy-coated strands cause cover and spacing fractures in multi-strand specimens during prestressed transfer. Epoxy-coated strands with a fractured specimen create 50% greater transfer lengths. The second epoxy layer shows no prestress transfer fractures. This enhances prestress transmission in the second epoxy layer. These results prompted suggestions. To avoid spacing and cover fractures in epoxy-coated strands, concrete cover and strand requirements must be increased. Francis, Gopu, Cousins, and Stallings (2020). M. Sarumathi and S. N. Ramaswamy studied concrete coatings in June 2016 and defined and explained concrete coating performance and efficacy. Durability affects concrete's performance and efficacy. Durable concrete is ideal. Suitable materials and proportions boost concrete's durability. Low-permeability, high-strength concrete is durable. The coating increases concrete's performance. The coating waterproofs, cleans, decorates, and reduces dust. The concrete coating prevents corrosion, salt penetration, abrasion, mechanical stress, and frost damage. Good concrete performance depends on adequate surface penetration and environmental conditions. To examine concrete coatings' performance and efficacy, various tests were conducted. These experiments evaluated concrete coverings' effectiveness and durability. Acids and bases were administered to epoxy-coated concrete in a trial. The results reveal that epoxy coating on concrete outperformed alternative coatings. Another test used hydrophobic agents for concrete covering.

2. Methodology

This exploratory research verifies the extent of epoxy coating utilized in concrete structures and evaluates them for echo and corrosion. The study approach included quantitative analysis using a questionnaire and sending it to build materials-savvy engineers. The second sort of study uses interviews to get qualitative data.

3. Research methods

Individuals and experts were polled and interviewed using Kobo to acquire primary data. The survey is multipart. The first section contains customer demographic questions, the second section assesses facility owners' satisfaction with residential buildings in the Sultanate in terms of corrosion and echoes, and the third section verifies the extent to which coastal installations are affected by corrosion and rust and compares reinforcement without Epoxy or paint and its effectiveness in protecting reinforcement. The questionnaire was chosen based on current epidemiological circumstances, the difficulties of transportation, and the need for a competent sample to complete the study. It allows researchers to collect data across boundaries. It delivers unbiased, honest results. In addition to the questionnaire, the research also interviewed epoxy coating specialists. Due to the global epidemiological crisis, open questions were written in KOBO Toolbox and sent to specialists.

4. Data collection

After gathering data, it's evaluated using PSPP to meet research objectives and uncover solutions using primary and secondary data. The primary data is acquired from the experiment and not previously utilized for research purposes. It is exceptionally accurate. Primary data collection methods include:

Statistics: It collects measurable data and uses mathematical, statistical, or computational approaches. Sampling and delivering opinion surveys through the Internet with the KOBO Tool application are employed to collect quantitative research data.

The online questionnaire included optional open-ended questions and a 5-point Likert scale. Strongly agree to disagree on the Likert scale strongly. Strongly agree, agree, neutral/unaware, disagree, and strongly disagree.

Qualitative approaches are beneficial when historical data is unavailable. No numbers or math are needed. Qualitative research includes words, sounds, feelings, colors, and other intangibles. Experience, judgment, intuition, guessing, etc., inform these strategies. Experienced people were interviewed to acquire early study data. Quantitative approaches don't reveal the purpose behind participants' responses. Thus, they don't reach concerned groups and take a long time to collect data. Due to the epidemiological scenario, the interview questions were emailed to specialists. Respond.

Statistics: Internal data comes from periodicals or studies and government reports. It's old data. This data is readily available and less time- and cost-consuming than raw data. Secondary data were obtained from books, scholarly publications, journals, e-library, online resources, and government reports.

4.1 Data Analysis

This study's quantitative data came from a survey of engineers and coastal inhabitants. For qualitative data, engineers were asked a series of questions. I was using PSPP. This program processes and analyses survey and questionnaire data, while the interview is utilized for comparison.

4.2 Quantitative Data Analysis (Questionnaire)

A customer survey was used to collect primary data utilizing Kobo toolbox software to fulfill the study goals. The questionnaire is multi-part. The first component covers demographic questions about clients, the second piece analyses facility owners' contentment with Sultanate residential buildings in terms of corrosion and resonance, and the third survey verifies the satisfaction of coastal installations. Corrosion and rust, and the efficacy of reinforcing without Epoxy or paint. The questionnaire was chosen based on current epidemiological circumstances, the difficulties of transportation, and the need to collect a specialized sample for the study. The questionnaire includes DEMOGRAPHIC INFORMATION questions for the client, including nationality, age, gender, degree of education, and profession. From the obtained information, it is noticed that 75% of the people responded to most of the questions. Therefore, the next level of questions discussed with respondents specific to the project.

1. What causes rust and corrosion in concrete buildings' steel reinforcement?

57.14% (Figure 1) of participants said moisture, leakage, seawater, and carbonation cause corrosion in reinforcing steel. Humidity was picked for the 14.29% ratio, and the remainder of the percentages were spread. Corrosion of steel reinforcement and other embedded metals is the primary cause of intangible concrete degradation. When steel corrodes, rust consumes more space. This expansion causes tensile strains in concrete, which can cause cracking. Corrosion requires two metals with differing energy levels, an electrolyte, a metallic link, moisture, leakage, and carbonation. Clear, Hay 1973

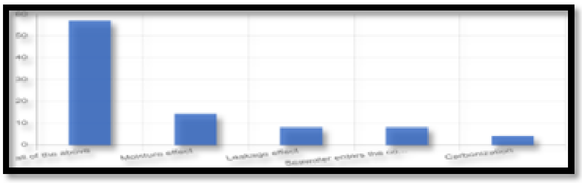

Figure 1. Responses to "What causes rust and corrosion in concrete buildings' steel reinforcement?"

2. How long until structures rust and corrode?

42.86% of participants estimate concrete wear and corrosion after 10-20 years, and 34.69% (figure 2) after 30-40 years. The guide in engineering said, "The life of concrete residential buildings is not less than 50 years at least according to the international design requirements for concrete structures, but when the construction area is based on factors that contribute to the corrosion of rebar, along with the presence of water in coastal areas, salts, and moisture, this ends with the risk of corrosion of the reinforcement Plus." 2008

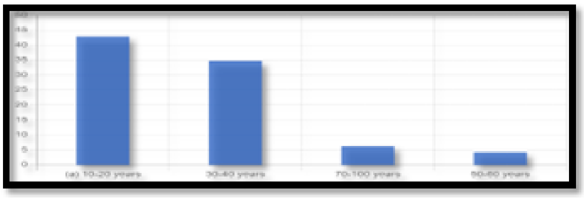

Figure 2. Responses to "How long until structures rust and corrode? "

3. Where are corrosion and rust most prevalent?

Most responders (61.22%) think coastal regions are particularly subject to erosion and rust, while 18.37% (figure 3) feel that all places are exposed to concrete constructions. Especially papers suggest that coastal locations are most prone to decay and corrosion. Corrosion of rebar is one of the world's worst concerns, as seen in coastal bridges and exposed places. Rebar Iron bars, for example, cost the U.S. $150 million in the last decade's rusting. Melting salt ice causes rust on American and European structures and bridges. In the U.K., restoring bridges damaged by rebar costs 616 million pounds sterling, and that's only for England and Wales, or 10% of all bridges. (2009)

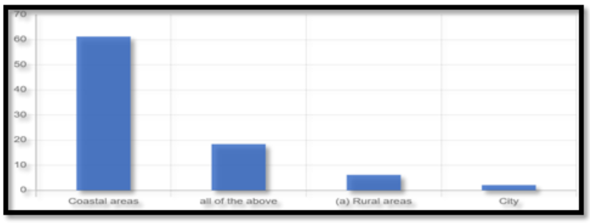

Figure 3. Responses to "Where are corrosion and rust most prevalent? "

4. Reinforcing steel needs a coating to prevent corrosion?

Participants were asked if reinforcing steel in concrete should be protected against corrosion and rust. 67.35% (figure 4) of findings favor rebar protection. Zaki Ahmed wrote that concrete has capillaries, pores, and fissures. Water may pass through concrete because it carries chloride. This leads to rebar corrosion," therefore, via his investigations, he underlined the necessity to manage concrete corrosion, as an effective anti-corrosion instrument must lengthen or reduce the time necessary for corrosion to develop. Cathodic safety is one of several pricey protective measures. Anti-corrosion coatings/additives. (2008)

Figure 4. Responses to "Reinforcing steel needs a coating to prevent corrosion?"

5. Do you think the Gulf States, notably Oman, employ corrosion-resistant concrete?

Twenty-one participants agree that Gulf nations protect concrete structures from corrosion and rust. However, 32.65% of 16 participants (figure 5) are neutral/unaware. Articles were examined to learn how to protect concrete from corrosion and rust. Qatar Metal Coating Company read an article that mentioned, "The degradation of concrete buildings due to reinforcing bar corrosion is a global problem that initially appeared in the 1970s in the U.S." Some roadways, bridges, and parking masses were identified. Offshore centers meant to last 75 years must be rebuilt or refurbished after ten years.

These installations and the best tactics utilized internationally and, in the Gulf, should be safeguarded from corrosion. Based on the graph, consider if the epoxy coating is a good solution for preserving rebar. 34. 69% of respondents feel the layer is suitable, and 30.6% are unaware. 18% of respondents agreed that an epoxy coating is needed for protection. Historically, epoxy-coated reinforcing bars have been the most popular worldwide. Field studies in Pennsylvania, New York, Florida, and the Department of Transportation in Virginia, Georgia, and North Carolina showed the long life of structures using epoxy-coated reinforcing bars.

A field study and laboratory examination on 240 reinforcement rods taken from 80 bridges in Pennsylvania and New York demonstrated high performance and long life of Epoxy-coated reinforcing bars extending to 75 years with minimum maintenance. QMC 2017

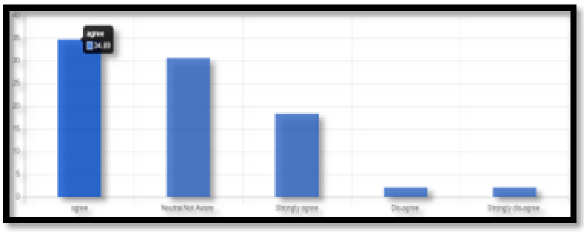

Figure 5. Responses to “Do you think the Gulf States, notably Oman, employ corrosion-resistant concrete? ”

6. Does the building owner have a background on Epoxy paint and its importance?

This question was asked to determine the extent of society's awareness of paint protecting their buildings from future corrosion. Through the results, we found that 38.78% (figure 6) are unaware of the extent to which the owners of the buildings know, while 53.53% do not agree, meaning that they are not available in their opinion. The knowledge of owners of the buildings, but a small percentage said that they know epoxy coating.

In my opinion, most building owners do not know this paint, and if they knew, they would use it in their buildings to protect them from corrosion and rust.

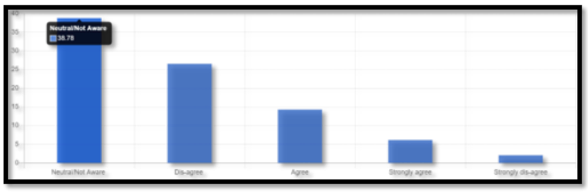

Figure 6. Responses to “Does the building owner have a background on Epoxy paint and its importance? ”

7. Do you suppose the Sultanate protects its steel with epoxy paint?

Each nation has different construction laws. This inquiry inquired if the Sultanate employs Epoxy paint on sea-facing structures. 38.78% do not know, according to the results (figure 7). The Sultanate utilizes paint, say 32.65%. References to Oman and the Gulf revealed an external specification. This international standard defines epoxy powders for reinforcing epoxy-coated concrete with bars, wires, and welded steel fabric. This standard contains sealing criteria for damaged areas, and rebar ends. This standard defines flexible (Type A) and inelastic coating (Type B). Unique design improves epoxy powder's adherence and moisture resistance. These upgrades diminish coating flexibility. (ISO 14656:1999)

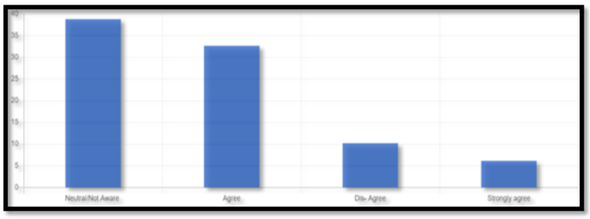

Figure 7. Responses to “Do you suppose the Sultanate protects its steel with epoxy paint? ”

8. How much does Epoxy protect the steel from corrosion and rust?

Thirty-two percent answered that the proportion of epoxy coating to prevent steel reinforcement from corrosion and rust is between 10-30 percent (figure 8) and 40-60 percent. Few said 70-100%.

No cracks were found in the concrete of North Carolina bridges. Thus epoxy-coated reinforcing bars should continue to be used. The coating helps Epoxy to stick to reinforcing bars long-term, protecting them from changing temperatures and weather. Epoxy-coated rebar has several benefits including concrete's long-term fracture resistance, salt resistance, bending ability, and cohesiveness.

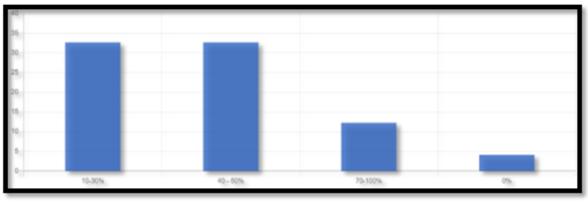

Figure 8. Responses to "How much does Epoxy protect the steel from corrosion and rust? "

9. Why don't Sultanate buildings employ Epoxy?

Why didn't building owners use this paint? 46.94% (figure 9) said cost is high, 26.5% said goods are unavailable, and a small proportion mentioned lack of understanding. M. Taj Al-Din said consultants in the Kingdom insist, based on old specifications, on obligating contractors in most large government projects in coastal and hot cities to use local epoxy-coated iron, which increases the Saudi government budget as epoxy-coated iron is 30% more expensive than ordinary iron (which is expensive these days). This is against a circular in favor of the Saudi and Saudi Council of Engineers. Civil Engineering Society must contribute 5% without losing concrete or building durability.

Epoxy iron only lasts five years, which is against BUI's guidelines in Dubai, Australia, and most of coastal North America. Third, using epoxy-painted iron will cost the Saudi government maintenance, as treating corrosion with American cathodic protection costs 1200 riyals per square meter with a 10-year repair warranty. Recent research showed epoxy coat non-bonding. Epoxy before or after installation allows chlorine salts to quickly penetrate steel reinforcement, causing corrosion in 4-5 years. This site has several alternatives to this sort of iron. 2008

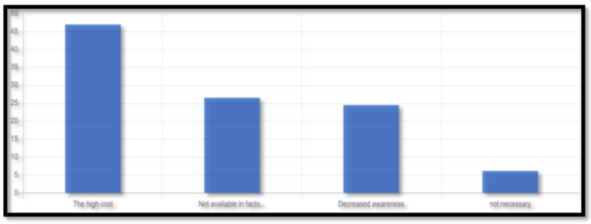

Figure 9. Responses to "Why don't Sultanate buildings employ Epoxy? "

10. How do you preserve concrete from rust and corrosion?

"Text," 18 of 49 people replied. (31 lacked data)

How do you keep concrete rust-free?

18/49 answered this open question. Good spacing, excellent concrete mix, optimum plaster, high-quality wall primers and paints, and epoxy-coated reinforcing bars were recommended. The key is constructing care and follow-up to minimize wall cracks or gaps that let moisture into reinforcing bars and follow building rules; FRP replaces steel, Damp-proofing. Epoxy paint isn't enough for corrosion protection since several errors can occur during transporting, placing, and binding. Therefore, corrosion can occur even with low chances. I like galvanized bars, but they're pricey and rare.

1. Concreting
2. Use bitumen liquid and sheets in rough soils.
3. Fill concrete fractures appropriately.

Anti-corrosion procedures.

Epoxy-application

Painting protects rebar.

Epoxy or oxide protects steel reinforcement (Walsh and Sagues, 2016)

5. Conclusion

This research examined how epoxy coating reduces rust and corrosion in coastal concrete structures. Based on an assessment of the knowledge of owners of residential facilities in the Sultanate regarding the extent to which they are affected by corrosion and rust and an analysis of the questionnaire results from the target audience, it became clear that they are aware of the effect of corrosion and rust on residential facilities, especially those in coastal areas. They are also aware of the causes. The second goal is to assess coastal corrosion and rust, notably in Oman. The Sultanate of Oman is one of the regions prone to iron erosion since it has all the factors contributing to facility corrosion, especially in coastal areas where moisture, salt leakage, and carbonation is present. Iron corrosion and rust damage structures by 40-60%. The final aim is to determine if epoxy coating can protect facilities from corrosion and rust and compare it to reinforcement without epoxy coating or paint. Some argued that painted reinforcement bars indicated Epoxy has successfully prevented corrosion in real-world coastal environments for over 35 years. Only stainless steel can equal this corrosion resistance. This lets the steel's surface corrode. Some studies have shown that it's not the most excellent solution for protection if the iron is exposed to rust.

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Review of Machine Learning Techniques in Estimating the LTE Network Congestions

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Abstract

The volume of traffic in telecommunication networks, particularly public land mobile networks, is consistently rising due to the increasing number of devices and services connected to these systems. Researchers are analyzing this growing traffic by uncovering complex dependencies, detecting anomalies, and identifying novel patterns to improve overall system performance. A rapidly advancing area in this field is the application of Machine Learning techniques, which aim to enhance network operations in the highly complex and heterogeneous environments of Long-Term Evolution (LTE) networks. This survey proposes a classification framework for cellular prediction problems, introduces a system for categorizing prediction models and evaluation metrics, and presents essential auxiliary techniques. It also highlights potential applications and suggests future research directions to inspire and guide further studies. Additionally, the survey reviews the current use of Machine Learning in the communications domain and addresses the key challenges and possible solutions for applying these techniques to estimate congestion in LTE networks. Future work will involve the development of a Machine Learning environment using a public cellular traffic dataset, with a comparative analysis of quality metrics and execution times across various models.

Keywords: *Telecommunication Traffic; cellular predictions; public land mobile network; artificial intelligence; machine learning models; performance metrics.*

الخلاصة

يتزايد باستمرار حجم حركة المرور في شبكات الاتصالات السلكية واللاسلكية، ولا سيما شبكات الهواتف المحمولة البرية العامة، بسبب تزايد عدد الأجهزة والخدمات المتصلة بهذه النظم. يقوم الباحثون بتحليل هذه الحركة المتزايدة من خلال الكشف عن التبعيات المعقدة، واكتشاف الحالات الشاذة، وتحديد الأنماط الجديدة لتحسين أداء النظام بشكل عام. من المجالات التي تتقدم بسرعة في هذا المجال تطبيق تقنيات التعلم الآلي، والتي تهدف إلى تعزيز عمليات الشبكة في البيئات شديدة التعقيد وغير المتجانسة لشبكات التطور طويل الأجل (LTE). يقترح هذا المسح إطار تصنيف لمشاكل التنبؤ الخلوي، ويقدم نظامًا لتصنيف نماذج التنبؤ ومقاييس التقييم، ويقدم تقنيات مساعدة أساسية. كما يسلط الضوء على التطبيقات المحتملة ويقترح اتجاهات بحثية مستقبلية لإلهام وتوجيه المزيد من الدراسات. بالإضافة إلى ذلك، يستعرض الاستطلاع الاستخدام الحالي للتعلم الآلي في مجال الاتصالات ويعالج التحديات الرئيسية والحلول الممكنة لتطبيق هذه التقنيات لتقدير الازدحام في شبكات LTE. سيشمل العمل المستقبلي تطوير بيئة التعلم الآلي باستخدام مجموعة بيانات مرور خلوية عامة، مع تحليل مقارن لمقاييس الجودة وأوقات التنفيذ عبر نماذج مختلفة.

الكلمات الرئيسية: حركة الاتصالات السلكية واللاسلكية ؛ والتنبؤات الخلوية ؛ والشبكة العامة للنقل البري ؛ الذكاء الاصطناعي ؛ ونماذج التعلم الآلي ؛ مقاييس الأداء.

1. Introduction

Cellular networks serve as essential communication infrastructures, providing voice, messaging, and data services to users within the coverage of base stations. Over the years, these networks have experienced continuous evolution, characterized by advancements in mobile communication technologies and increasing data transmission speeds. During the transition from 2G to 3G, the intermediary 2.5G network, utilizing General Packet Radio Service (GPRS), introduced basic Internet connectivity. The 3G network, powered by technologies such as the Universal Mobile Telecommunications System (UMTS) and CDMA2000, further enhanced mobile Internet capabilities, supporting a wider range of services, including web browsing, email, and multimedia transmission [1].

With the introduction of 4G networks, such as Worldwide Interoperability for Microwave Access (WiMAX) and Long-Term Evolution (LTE), a significant leap in speed and capacity was achieved. These 4G networks enabled high-speed mobile broadband services, facilitating seamless high-quality audio and video streaming, thus greatly improving user experience [2]. LTE, in particular, has become a globally adopted standard for delivering high-speed data services. However, the increasing demand for mobile broadband places growing pressure on LTE networks, leading to network congestion, which in turn degrades user experience by increasing latency and reducing throughput.

Network congestion occurs when the traffic load exceeds the available network capacity, leading to issues such as packet loss, delays, and diminished data throughput. The rapid growth in the number of connected devices and users each year exacerbates this problem, as network resources become strained. Additionally, the surge in connected devices increases the complexity of the network architecture, making it increasingly difficult to maintain high levels of Quality of Service (QoS). Traffic congestion has both direct and indirect impacts on the reputation of telecommunication service providers, as it affects the reliability and performance of their networks. As a result, modern cellular networks must meet more stringent requirements in terms of latency, reliability, security, and privacy. In LTE networks, congestion arises when the demand for network resources surpasses the available capacity, leading to performance issues that compromise user satisfaction and challenge the overall efficiency of the network. Addressing these challenges is critical to ensuring that future cellular networks can accommodate the growing demand for high-speed, reliable data services. Next section discusses the typical cell congestion prediction problems.

2. Cell Congestion Prediction Problems

Several factors contribute to congestion in LTE networks, significantly impacting their performance and user experience. These factors include increased User Traffic. As the number of users connecting to the network rises, particularly in urban environments or during peak usage hours, the demand for bandwidth can increase dramatically. This surge in user traffic can overwhelm the network's capacity, leading to congestion. In densely populated areas, the simultaneous connection of numerous devices generates substantial data requests, straining the available resources and causing delays in service delivery. Other important factor is the limited Spectrum Resources. LTE networks operate within a finite range of frequency bands, which are allocated to ensure efficient data transmission. As user traffic continues to grow, these limited spectrum resources become increasingly constrained. When demand for bandwidth exceeds the available capacity, users may experience slower data rates, increased latency, and connectivity issues. This limitation on spectrum resources makes it challenging to accommodate the growing number of devices and services that rely on mobile networks [3].

Similarly, as cell overloads when too many users connect to a single cell, the base station may struggle to manage the traffic effectively. Each base station has a maximum capacity determined by its design and the available resources. If the number of simultaneous connections exceeds this capacity, the base station may not be able to process data requests efficiently, leading to packet loss and degraded service quality. This cell overload is particularly problematic in high-traffic scenarios, such as concerts or sports events, where large crowds converge in a small area, dramatically increasing the load on the network. The external factors, such as environmental noise and interference from neighboring cells, can significantly degrade signal quality and exacerbate congestion in LTE networks [4]. Interference can stem from various sources, including physical obstructions (like buildings and trees), other electronic devices, and overlapping frequency usage among nearby cells. When interference levels rise, the effective data throughput decreases, resulting in a higher likelihood of congestion as the network struggles to maintain reliable connections and data transmission rates [5]. Although cellular traffic prediction has been considered in the literature, it remains a challenging concept. Artificial intelligence (AI) estimating the network congestion is vital for optimizing resource allocation, improving network performance, and enhancing user satisfaction [6] [7]. Next section discusses the role of AI in congestion prediction in LTE networks.

3. Data Preprocessing and Prediction Models

AI can use machine learning (ML), data mining, computer vision, expert systems, natural language processing, probabilistic models, deep learning, artificial neural network systems, game theory, robotics, and related applications while ML is the most popular branch of AI. ML techniques present promising solutions for predicting, detecting, and mitigating network congestion [8]. These approaches utilize both historical and real-time data to model complex network behaviors, enabling more efficient congestion management. ML's ability to detect new patterns and dependencies in large datasets is particularly valuable, as traditional network planning methods struggle to handle the vast data flows, prompting a shift toward more user-centric operations. As a result, ML offers an effective approach to addressing the challenges of managing large volumes of data in future networks.

ML algorithms can analyze input data to generate sub-optimal solutions, depending on the specific task, providing a new level of network and application management. These techniques often require only a logical overlay on the LTE network core, reducing issues like congestion hotspots. Despite the challenges of predicting network traffic, ML models have shown significant benefits in real-world scenarios, both for short-term and long-term applications [8]. In the short term, ML can provide predictions ranging from milliseconds to minutes, useful for optimizing resource planning, congestion control, and packet routing. Long-term forecasts can help anticipate future capacity needs, enhance network security, and minimize operational costs by optimizing bandwidth and energy usage [4].

Numerous ML algorithms can be applied to network optimization tasks, including Classical ML techniques like Linear Regression, Logistic Regression, Huber Regression, Bayesian Regression, and Support Vector Machines (SVM), as well as ensemble methods like Bootstrap Aggregating and Gradient Boosting. While linear models use fixed inputs to minimize a loss function, ensemble models combine multiple algorithms for more accurate predictions. Deep Learning, on the other hand, leverages neural networks to capture complex relationships within the data. [9]

ML tasks are typically categorized into Supervised Learning, Unsupervised Learning, Reinforcement Learning, or Hybrid models. The choice of algorithm depends on the specific task, data type, and available resources, and comparing algorithms can be challenging, as performance can vary based on the context. Therefore, it is essential to first identify the primary problems and applications of ML in the communications domain, relevant metrics, and current challenges to establish a foundation for selecting the most appropriate models for traffic prediction.

Models like Linear Regression, Huber Regression, Bayesian Regression, and Gradient Boosting can be implemented and compared for predicting traffic in cellular networks. By analyzing patterns in network monitoring data, such as traffic volume, signal strength, user mobility, and QoS metrics, ML models can predict congestion and recommend actions to alleviate it. These ML models can be used in estimating congestion in LTE networks [9]. The key Advantages of ML Techniques for Congestion Estimation are about the data-driven Predictions. The ML algorithms utilize real-time and historical data to anticipate network congestion. The adaptability of the ML models that can adapt to changing network conditions, such as varying user behavior and traffic patterns. Similarly the automation using the ML-based congestion estimation reduces the need for manual intervention, enhancing network efficiency [4].

4. Common Machine Learning Techniques Used in LTE Congestion Estimation

4.1. Supervised Learning:

Supervised learning models are developed using labeled datasets, where historical congestion data is utilized to train the algorithm for predicting future congestion. The training dataset comprises various network metrics, including traffic load, signal-to-noise ratio (SNR), packet loss, and latency. Decision Trees and Random Forests employ algorithms that divide the data into subsets based on different network characteristics (e.g., traffic load, user count) through a tree-like structure, facilitating predictions about congestion. In particular, Random Forests enhance accuracy and robustness by aggregating predictions from multiple decision trees. SVM classify network states into congested and non-congested categories by identifying an optimal boundary (hyperplane) that separates congested instances from non-congested ones based on input features. Artificial Neural Networks (ANNs) are adept at capturing non-linear relationships between network parameters and congestion levels. By processing input features across multiple layers of neurons, ANNs can learn to approximate complex patterns in the data, making them highly effective for real-time congestion prediction [10].

4.2. Unsupervised Learning:

Unsupervised learning models function without labeled data, making them effective for uncovering hidden patterns and anomalies in network traffic that could signal congestion. Clustering algorithms, such as K-Means and DBSCAN, categorize similar network states based on features like traffic load and signal strength. Anomalies or abrupt changes in cluster characteristics may suggest the likelihood of impending congestion. Principal Component Analysis (PCA) is employed for dimensionality reduction, streamlining large datasets by highlighting the most significant features that influence congestion. This technique helps minimize noise in the data and enhances model performance by concentrating on key indicators of congestion [10].

4.3. Reinforcement Learning:

Reinforcement learning models acquire knowledge through trial and error by interacting with the network environment. In the context of LTE congestion estimation, these agents can dynamically modify network parameters (such as bandwidth allocation and load balancing) to alleviate congestion. Q-Learning is a well-known reinforcement learning algorithm that employs a reward-based system to determine optimal actions for managing congestion. This algorithm adjusts network resources according to the current congestion state to minimize delays and packet loss. Deep Reinforcement Learning (DRL) integrates reinforcement learning with deep neural networks to effectively manage large-scale LTE networks characterized by numerous variables. DRL algorithms are capable of continuous learning and adaptation to changing network conditions, making them particularly effective for real-time congestion management [10].

4.4. Time-Series Forecasting Models:

Time-series models are especially valuable for forecasting congestion using historical network performance data. The Autoregressive Integrated Moving Average (ARIMA) is a statistical model that predicts future network congestion based on previous observations. It effectively captures trends and periodic patterns in traffic volume that contribute to congestion. Long Short-Term Memory (LSTM) networks, a specific type of recurrent neural network (RNN), are designed to recognize long-term dependencies in time-series data. In LTE networks, LSTM models can learn patterns over time, making them particularly effective for predicting congestion that occurs in cyclical patterns, such as daily peak traffic [10].

5. Application Scenarios

The study conducted by [11] highlights the growing popularity of predictive analysis in mobile network planning. Operators leverage this approach to anticipate mobile traffic for each LTE cell, enabling them to optimize investments in new locations and cell deployments while maintaining exceptional service quality for mobile broadband users. This research evaluates the feasibility of mobile traffic forecasting using Facebook's fbProphet algorithm, aiming to achieve short-term predictions that allow operators to proactively consider network expansion when traffic demands exceed user throughput. The model was trained on daily traffic data collected over a five-month period and subsequently tested and forecasted for an additional month. Additionally, hourly data from a 30-day period was incorporated into the analysis.

The authors in [12] propose a method to enhance the Quality of Service (QoS) for end-users in radio access networks by proactively mitigating network congestion. By anticipating congestion, Self-Organizing Networks (SON) algorithms can make crucial parameter adjustments, such as modifying handover settings for mobility load balancing. To achieve this, the research introduces an innovative hybrid model that effectively predicts congestion. This hybrid learning model combines both supervised and unsupervised learning techniques. The unsupervised component employs a co-clustering technique based on the Latent Block Model (LBM), grouping similar cells based on the behavior of their Key Performance Indicators (KPIs) over time. For congestion forecasting and alerting operators to avert congestion in mobile networks, logistic regression is applied to each cluster derived from the co-clustering model. The practicality of the hybrid model is validated using real data, represented by KPIs collected periodically over a 12-day period in an operational LTE network. The proposed hybrid model has demonstrated its effectiveness in predicting congestion, as evidenced by its accuracy, precision, recall, and F-measure.

The work presented in [13] asserts that energy conservation and network quality enhancement in mobile networks can be achieved through effective traffic forecasting. In the context of 5G networks, the efficiency of SON is directly influenced by the accuracy of traffic predictions. Notably, forecasting LTE traffic not only provides planners and optimizers with additional time but also reveals precise patterns of upcoming traffic. While several other KPIs are utilized in traffic predictions, most algorithms primarily rely on historical traffic data. To address this, the authors introduce a practical platform and methodology for traffic forecasting that leverages big data, machine learning, and network KPIs. This adaptable approach can accurately predict various statistical traffic characteristics for different cell types (GSM, 3G, and 4G) in both long-term and short-term forecasting scenarios.

The authors of [3] discuss the challenges associated with collecting data from a vast array of Internet-of-Things (IoT) devices in next-generation networks. The proliferation of numerous devices can result in significant congestion within both the Radio Access Network (RAN) and Core Network (CN). To address the congestion stemming from a high device count, the 3rd Generation Partnership Project (3GPP) has proposed various strategies; however, the specific configurations and implementations are left to the discretion of network operators and are not explicitly detailed in the standards. This study introduces two effective congestion control techniques that alleviate congestion. Based on simulation results, these proposed algorithms demonstrate superior performance, exceeding LTE-Advanced (LTE-A) by approximately 20–40% in terms of acceptance ratio, overload degree, and waiting time.

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The research presented in [14] proposes a solution to mitigate network congestion issues by introducing a novel cellular standard developed by 3GPP that utilizes packet switching technology. This standard, known as Long-Term Evolution (LTE), offers high data rates of 100 Mbps in the downlink and 50 Mbps in the uplink, and is designed to be adaptable, supporting various bandwidths ranging from 1.4 MHz to 20 MHz. In addition to enhancing data transfer rates, LTE aims to improve efficiency, reduce latency, provide spectrum flexibility, and increase capacity to prevent network congestion. This paper evaluates the congestion avoidance capabilities of the LTE network by analyzing system throughput, delay, and packet loss ratio, employing various scheduling algorithms implemented at the LTE base station, including Proportional Fair (PF), Maximum Largest Weighted Delay First (MLWDF), and Exponential/PF (EXP/PF) schedulers.

The work presented in [15] discusses the advancements in telecommunication systems across different generations, with the primary aim of enhancing the speed of information transfer and communication between locations. A notable advancement is Long-Term Evolution Advanced (LTE-A), commonly referred to as the 4G network. LTE-Advanced, a wireless cellular network, provides significant services by improving quality of service, security, and mobility compared to earlier networks. This LTE-Advanced technology is utilized in Machine-to-Machine (M2M) communications, facilitating extensive device connectivity with minimal human interaction. However, congestion remains a challenge in M2M communication, restricting network access for multiple devices and diminishing their responsiveness. This paper surveys various mechanisms proposed by researchers over the years to address the congestion issues encountered when numerous devices attempt to access the base station, known as eNodeB, as illustrated in Figure 1.

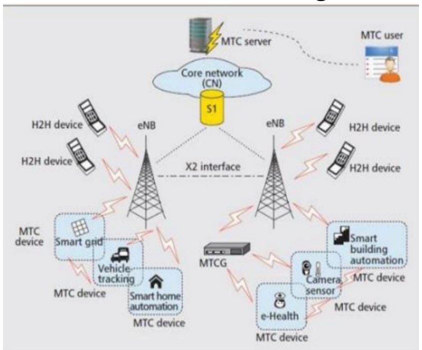

Figure 1: Machine-to-Machine Communication in LTE-A Networks

The research presented in [16] forecasts the average downlink throughput of an LTE cell using actual measurement data collected from various LTE probes. To prevent subscribers from experiencing dropped calls or reduced data speeds, the approach employs data analytics techniques, specifically forecasting algorithms, to anticipate cell congestion events. These predictions are then utilized in self-organizing network strategies to initiate network reconfigurations, such as reallocating coverage and capacity to areas where they are most needed, thus preempting failed calls or degraded data rates that could adversely impact users. The findings indicate that forecasting network behavior with a high degree of accuracy is feasible, enabling timely implementation of self-organizing network (SON) techniques.

This project provides advantages for real-time data transmission to external servers for rapid processing. It can efficiently convert data, transforming raw information into a relevant and comprehensible format. Additionally, it can overlay various types of data, including download and upload throughput, received signal strength indicator (RSSI), and cell ID (CID), with the geo-located positions of the LTE probes. It also offers visualizations that illustrate the behavior of different network Key Performance Indicators (KPIs) throughout the day or during specific time periods. However, a significant drawback of the project is that it necessitates a qualified technician to operate the sophisticated and specialized measurement equipment. Furthermore, it allows for the importation of measurements taken with cell phones through a dedicated application, but does not utilize precise measurement tools. The methodology relies on the concept of "virtual probes," which are essentially algorithms that perform data analysis and correlation using call detail records (CDRs).

The research presented in [17] introduces a novel machine learning model that employs the decision tree (DT) method to predict optimal strategies for enhancing congestion control in wireless sensor networks within 5G Internet of Things (IoT) frameworks. The model was tested on a training dataset to identify the most effective parametric configurations for a 5G environment. By training the machine learning model on this dataset, the study aimed to predict the best alternatives to enhance the performance of congestion control strategies. The DT technique is also applicable to other tasks, such as prediction and classification, and the graphs generated by the DT algorithms allow users to easily understand the prediction process. The DT C4.5 algorithm achieved promising results, with precision and recall exceeding 92%. This study focused on analyzing performance parameters based on the machine learning capabilities of Stream Control Transmission Protocol (SCTP) and aimed to develop a novel approach for forecasting congestion control systems tailored to 5G. Notably, the proposed method enhances overall network performance and congestion management, allowing for the identification of optimal congestion window management under specific conditions, such as high throughput, large queue sizes, and reduced packet loss. Additionally, it offers a tree-based graph that assists in determining the best actions for congestion control. However, the technology faces challenges, as factors like throughput, large queue sizes, and high congestion windows can affect the selection of the most suitable nodes in the network. Moreover, gathering a representative and diverse dataset that accurately reflects varying network conditions and IoT device behaviors within the context of 5G IoT can be difficult.

The research described in [5] proposes a model designed to facilitate intelligent load traffic prediction in cellular networks. It combines long short-term memory (SES-LSTM) with single-exponential smoothing to forecast cellular traffic. The network load is adjusted using a min-max normalization approach. Given the complexity and diverse nature of network traffic, the single-exponential smoothing method was employed to refine traffic quantities. Subsequently, an LSTM model was used to analyze the output from the single-exponential model to predict network load as demonstrated in Figure 2. The effectiveness of the system was evaluated using a Kaggle dataset that included actual mobile network traffic. Results demonstrated the proposed approach's enhanced accuracy, yielding R-squared metric scores of 88.21%, 92.20%, and 89.81% for three distinct one-month periods. The findings indicated minimal discrepancies between predicted values and actual data, with the proposed system outperforming others in cellular network traffic prediction.

This project presents several advantages, as these models can provide precise data for evaluating key traffic characteristics, necessitating highly effective analytical investigations. Furthermore, it significantly impacts overall network performance by capturing essential traffic features, including long-range dependence (LRD), short-range dependence (SRD), and self-similarity, making it a crucial element in supporting network architecture and minimizing bandwidth wastage. Additionally, it effectively records vital traffic characteristics such as self-similarity, SRD, and LRD. However, the project also has certain drawbacks; the model may struggle to generate reliable forecasts if there is insufficient data, particularly in varying situations or during rare events. The performance of intelligent models could be adversely affected by noisy, missing, or erroneous data, leading to inaccurate predictions when based on low-quality input. Thus, the model must be sufficiently adaptable to accommodate updates and advancements in technology.

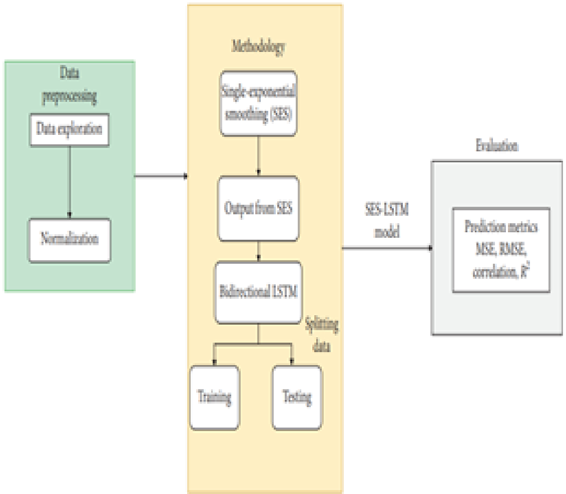

Figure 2: Cellular Traffic Prediction Based on an Intelligent Model [17]

The authors in [18] propose a model for predicting traffic congestion, encompassing several stages: data preparation, data splitting, modeling, classification, model evaluation, and optimization. Throughout the model analysis and tuning phase, the performance of various machine learning algorithms was assessed using metrics such as accuracy, F1 score, and others. Algorithms that underperformed were subsequently refined through hyper-parameter optimization. In the outcome phase, the results of the algorithms were compared, and the top-performing algorithm was selected for the final forecast. This study aims to predict traffic congestion in LTE networks based on user perceptions by leveraging machine learning algorithms, utilizing three months of mobile traffic data for analysis.

The advantages of this initiative include its reliability in predicting traffic congestion and its ability to enhance network performance by utilizing additional bandwidth, thereby reducing congestion. Furthermore, it can continuously read and analyze data from network administrators, extracting relevant features to estimate traffic congestion in real time, which assists traffic providers in minimizing congestion with fewer procedures. However, this project also has limitations associated with machine learning. Poor performance may occur if machine learning models trained on historical data are unable to adapt to sudden changes or unforeseen events. Additionally, operating in a resource-constrained environment may present challenges regarding memory, processing speed, and increased energy consumption. If the model is not designed to handle outliers or expected variations in the input, it may yield inaccurate results.

Implementation results indicate that the proposed concept outperforms the approach by Torres et al. (2017) on Data Analytics for Forecasting Cell Congestion on LTE Networks, as it utilizes precise measurement tools and allows for measurements from cell phones to be imported through a dedicated application. Additionally, it surpasses the Machine Learning Prediction Approach to Enhance Congestion Control in 5G IoT Environment proposed by [19]Najm et al. (2019), given that this system's selection of optimal nodes can be influenced by factors like throughput, large queue sizes, and high congestion windows. Moreover, collecting a representative and diverse dataset that accurately reflects various network conditions and IoT device behaviors in the context of 5G IoT poses challenges. The proposed model also improves upon the Cellular Traffic Prediction Based on an Intelligent Model by [5], which faces difficulties in generating reliable forecasts when data is insufficient, particularly during varied situations or rare events. Intelligent models can be adversely affected by noisy, missing, or erroneous data, leading to inaccurate predictions based on low-quality input. Therefore, this concept is more effective than the Users' Evaluation of Traffic Congestion in LTE Networks Using Machine Learning Techniques proposed by Kuboye et al. (2023), given that it operates in a resource-constrained environment, which may lead to issues with memory, processing speed, and increased energy consumption. Inaccurate results may arise if the model is not designed to manage outliers or anticipated variations in the input data.

6. Challenges and Future Directions in Applying ML for LTE Congestion Estimation

The effectiveness of ML-based congestion estimation is heavily reliant on the quality and quantity of data collected from the LTE network. Important data sources include:

- Network Traffic Data: This encompasses the volume of data transmitted over the network, the number of active users, and the types of applications being utilized (e.g., video streaming, web browsing).
- QoS Metrics: Metrics such as latency, jitter, packet loss, and throughput are essential for evaluating network quality and identifying congestion hotspots.
- Radio Signal Data: Metrics related to signal quality, such as Signal-to-Interference-plus-Noise Ratio (SINR) and Reference Signal Received Power (RSRP), provide insights into the physical layer's performance, which can influence congestion levels.
- User Mobility Data: Analyzing user movement patterns can aid in predicting congestion in specific geographic locations, such as during public events or peak traffic times.

Additional challenges include:

- High Dimensionality: LTE networks produce vast amounts of data across various dimensions, including time, space, and frequency. Efficiently processing this data while maintaining model accuracy can be a significant challenge.
- Real-time Constraints: Accurate congestion estimation necessitates real-time data processing and predictions. Ensuring that ML models provide timely and accurate predictions is crucial for effective congestion management.
- Model Interpretability: While some ML models, such as decision trees, are relatively easy to interpret, more complex models, like neural networks and deep learning algorithms, are often viewed as "black boxes." This lack of transparency can complicate decision-making, especially in network management contexts where understanding the reasoning behind predictions is vital.

In the transition from LTE to 5G networks and beyond, the increased complexity of network architecture will require the implementation of more advanced machine learning techniques. Integrating machine learning with Software-Defined Networking (SDN) and Network Function Virtualization (NFV) will facilitate more flexible and adaptive solutions for congestion management. Edge computing will bring processing capabilities closer to the network edge, thereby reducing latency and enabling real-time congestion estimation. Machine learning models deployed at the edge can analyze local data, alleviating the burden on centralized servers and enhancing response times. Additionally, hybrid machine learning models that combine various techniques, such as supervised learning and reinforcement learning, can produce more robust congestion estimation solutions. These hybrid models can harness the strengths of different algorithms to improve prediction accuracy and adaptability to evolving network conditions

7. Conclusion

A thorough survey on cellular traffic prediction was conducted, providing a classification of the reviewed problems and methods. The findings revealed that deep learning models were the most prevalent solutions among the studies examined. This area of research is still in its early stages, with many promising ideas yet to be explored. The survey also outlined various applications of cellular traffic prediction and highlighted potential research directions to inspire future investigations in the field.

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Modern Farming Using Drone Technology

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Abstract

Efficient irrigation and pesticide application, along with timely and accurate crop data collection, remain significant challenges for farmers. Drone technology has recently gained popularity in agriculture, offering benefits such as increased yields, cost savings, improved efficiency, and enhanced scouting and security. This paper introduces a project aimed at developing a drone-assisted, microcontroller-based embedded system to address these challenges. A comprehensive review of drone-based smart agriculture literature identified areas for improvement, guiding the design and analysis of the system. Remotely controlled, the drone carries a system equipped with distance sensors for safe operation and a camera for image processing to precisely apply water and pesticides. The farmer monitors the plant condition using this drone. Upon task completion, the drone autonomously returns to the farmer. Test results highlight the potential of drones for monitoring plant health, facilitating disease treatments, and advancing precision agriculture practices.

Keywords: *smart agricultural practices; crop irrigation; application of pesticides; crop data; embedded system.*

الخلاصة

لا يزال استخدام الري ومبيدات الآفات بكفاءة، إلى جانب جمع البيانات الدقيقة عن المحاصيل في الوقت المناسب، يمثل تحديات كبيرة للمزارعين. اكتسبت تقنية الطائرات بدون طيار مؤخرًا شعبية في الزراعة، حيث قدمت فوائد مثل زيادة الغلة، وتوفير التكاليف، وتحسين الكفاءة، وتعزيز الكشافة والأمن. تقدم هذه الورقة مشروعًا يهدف إلى تطوير نظام مدمج يعتمد على التحكم الدقيق بمساعدة الطائرات بدون طيار لمواجهة هذه التحديات. حددت مراجعة شاملة لمؤلفات الزراعة الذكية القائمة على الطائرات بدون طيار مجالات التحسين، وتوجيه تصميم وتحليل النظام. يتم التحكم في الطائرة بدون طيار عن بعد، وتحمل نظامًا مجهزًا بأجهزة استشعار المسافة للتشغيل الآمن وكاميرا لمعالجة الصور لتطبيق المياه والمبيدات بدقة. يراقب المزارع حالة النبات باستخدام هذه الطائرة بدون طيار. عند اكتمال المهمة، تعود الطائرة بدون طيار بشكل مستقل إلى المزارع. تسلط نتائج الاختبارات الضوء على إمكانات الطائرات بدون طيار لمراقبة صحة النبات، وتسهيل علاج الأمراض، وتطوير ممارسات الزراعة الدقيقة.

الكلمات الرئيسية: الممارسات الزراعية الذكية ؛ وري المحاصيل ؛ استخدام مبيدات الآفات ؛ وبيانات المحاصيل ؛ النظام المدمج.

1. Introduction

The global population is steadily increasing that necessitates improved agricultural practices, particularly in the realms of irrigation and pesticide application for crops. Recognizing that water is a precious resource, the implementation of sustainable technologies can enhance the efficiency of existing irrigation systems. Smart irrigation systems, utilizing sensors, control mechanisms, data processing, and fault detection, can prove instrumental in optimizing the agricultural performance. Concurrently, judicious pesticide use aids crops in combating diseases, contributing to enhanced agricultural productivity. The emphasis on the technology and sustainability has prompted governments to enact necessary legislation and provide guidance to farmers on adopting technological advancements. Consequently, there is a pressing need to enhance agricultural operations, with people actively seeking suitable methods to maximize output and optimize resource input in an ethical way and ensuring privacy (Kisters, 2023). Although the ethical concerns are multifaceted, drone benefits are well recognized by the authorities. The regulatory frameworks and the license options can ensure their effective utilization in variety of applications.

The future outlook for the global food supply chain seems poised to be more sustainable, efficient, and productive with continued improvements and collaboration among stakeholders. Certain plant species demand heightened attention and care in comparison to others which needs efficient solutions. In response to these requirements, agricultural automation is emerging as a prevalent industry trend worldwide including Oman. Contemporary agricultural processes can harness data generated by sensors for data acquisition to gain deeper insights into plant development and care, facilitating informed decision-making for a smart solutions (Little, 2023). Drones in agriculture are revolutionizing the traditional farming, increasing the production and reducing the cost. The drone technology in agriculture can enhance the yield of cultivation (Network, 2023). The drones can establish relayed cooperative network for long distance communication and communication in challenging terrains (Bashir, Iqbal, & Yusof, 2022) (Bashir, Yusof, & Iqbal, 2022). The integration of artificial intelligence (AI) is also offering diverse sustainable solutions for the agricultural sector. AI enabled drones can transform the crop monitoring by collecting the real time data. The AI algorithms can provide insight into the plat health conditions.

Currently, farmers grapple with various challenges encompass issues such as the complexity of adequately irrigating vast expanses of land and accurately gathering comprehensive crop data. The task of monitoring crops, collecting pertinent information, and distinguishing between different crops of interest can prove daunting for farmers. Moreover, there is a considerable reliance on pesticides and chemicals, posing potential dangers to farmers due to exposure to these hazardous substances, thereby adversely impacting their health. In this scenario, drone technology can help to overcome few of the above mentioned challenges. This project aims to address these concerns by designing a system tailored to serve farmers in terms of irrigation and ensuring the safety of plants and crops through the utilization of drone technology. The adoption of Modern Farming Using Drone Technology offers multiple advantages (Arrow, 2020) as demonstrated in figure 1. Firstly, the system efficiently covers expansive lands for irrigation, treatment, and photographic documentation of plants. This not only saves time for farmers but also facilitates the acquisition of more accurate data on plants and crops, providing a detailed perspective. Secondly, the implementation of a modern farming system employing drone technology mitigates risks to farmers by reducing the reliance on manual labor and minimizing the use of herbicides and pesticides (Shah, 2023). This strategy supports the operation safety and efficiency along with ensures farmers wellbeing.

Figure 1: Drone watering (Little, 2023)

In the realm of agriculture, drone technology has brought about a revolutionary transformation (Arrow, 2020) and are being used for tracking processes and distribution purposes. The agricultural industry is radically changed as a result of these innovations, which have given farmers significant cost savings as well as greater production and profitability. The suggested system in this research work is designed in next phase using a distance sensor that can gauge the distance between the system and crops or plants. The irrigation process can start only when the close to ideal distance is reached, spraying the crops and plants with water and medication.

A camera component of the system takes pictures of the crops and plants, giving farmers information to evaluate their health. Two scenarios are communicated to the farmer via text messages using the GSM module built into the system. Initially, a warning is issued to the farmer telling them to keep the drone at a safe distance if it gets too close to a plant, posing a risk of entanglement and crop loss. In the second scenario, a text message alerting the farmer to the conclusion of the watering and spraying operation causes the drone to return. Given the occasional long distance between the drone and the farmer, hindering visual tracking, the system includes GPS functionality to enable the farmer to monitor the drone's movements. This system, mounted on the drone for operational ease, is controlled via radio commands by farmer. Addressing a prevalent challenge in agriculture, the difficulty for farmers to irrigate and apply pesticides to all crops efficiently compared to the manual methods requiring significant time and effort. Further to carry the automated system to the correct plant in a safe manner is challenging. This proposed modern farming system employing drone technology offers a solution. The project's main objectives are to integrate the drone technology into various agricultural processes in order to increase agricultural output, efficiency, and sustainability. This project is to design a microcontroller-based system that can be remotely controlled to precisely spray water and medication on target plants. Additionally, the system captured pictures of the plant are stored for future planning. System uses a GSM module to send an SMS to the farmer informing them of the drone's safe distance from the plant.

A distance sensor is included in the suggested system to gauge the distance between it and the plants. When it reaches the proper size, irrigation begins, spraying the plants with both water and fertilizer. The built-in camera takes pictures so farmers may evaluate the state of their crops. The system utilizes GSM for communication, sending alerts to the farmer in cases of potential entanglement or completion of tasks. With GPS functionality, farmers can track the drone's movement even at a distance. This technological ecosystem, enhancing the productivity and efficiency in agriculture through a versatile platform for drones, ensuring adaptability through hardware and software customization. The system, poised to facilitate modern farming with drone technology, offering a multifaceted solution for diverse agricultural tasks. This research work intended to:

- Design a microcontroller-based system to be carried using remote controlled drone to the target plants to spray water and medicine.
- Identify the target plants and take their images using camera.

- To stream the target plant images to the farmer, who can save observer real time status of the plants and can store images for future planning.
- To alert the farmer by sending SMS about instantaneous location of the target plant and distance from the plant by using GSM so that farmer can keep drone at safe distance from the plant.

An extensive literature has been reviewed to extract the basic knowledge required to do design and analysis of such system. Next Section II summarize the literature in this context, Section III provides the design and analysis, Section IV discusses the implementation results while Section V concludes the discussion.

2. Literature Review

A similar project to the objectives of the research work was designed by (Wilkerson, Gadsden, Cerreta, & AlShabi, 2019). They investigated use of drones in capstone projects as a student project by designing and developing the electronic system. The system was capable of surveying the agriculture farm using multispectral camera looking the governmental rules and regulations. They collected the data using drone for the farmers to analyze the captured images. Another article (Panwar & Parmar, 2022) delves into the role of drone technology in agriculture. It highlights the challenges faced in swiftly meeting the demand for food, addressing concerns about food safety, and overcoming various obstacles in the agricultural sector. The development of drones as a means of closing the knowledge gap between present agricultural output and future demands is the main focus of this research work. The classification, parts, and functioning of drones are explained in detail in this page. The article's investigation and findings center on a quadcopter that has four propellers on each corner. To maintain balance, the drone's motion is individually controlled for each motor, causing one diagonal pair of rotors to rotate in a counterclockwise direction and the other in a clockwise direction. With this setup, the drone may travel in three directions: forward, backward, and sideways, contingent on changes in rotor speed. The article also discusses challenges encountered by drones in agriculture, including the high initial cost associated with factors like sensors, software, hardware, and tools. Weather conditions significantly impact drone operations, limiting their use during storms or rainy weather. Connectivity issues on farmland may necessitate additional investments. Moreover, the lack of technological expertise among farmers hinders the adoption of these new technologies. This article suggests adding new start-ups, training facilities, and employment centers aimed at luring young people into the agriculture sector in order to address these issues. To improve operational protocols and validate and calibrate drone use, research is advised. Technological developments like lighter payloads and bigger batteries could increase flight durations and range, which would increase the advantages farmers receive from using drones in agriculture.

The work carried out by (Kalamkar, Ahire, Ghadge, Dhenge, & Anarase, 2020) highlights the drone technology usage in agriculture and its diverse applications. The agricultural industry faces numerous challenges today, with a shortage of labor being just one of the prominent issues, rendering it a promising sector for innovation. The essay promotes using cutting-edge drone technology to solve these problems and offer quick, effective fixes. Drones are a great tool for gathering information on a wide range of topics, including rainfall patterns, weather, crop yields, livestock health, and soil quality and nutrient measurements. In turn, this data makes it possible to map out current issues precisely, which makes it easier to build solutions based on extremely trustworthy data. The article's findings and analysis emphasize the employment of drones for agricultural appraisal and insurance, including their use in forensics for insurance claims. Drone images play a crucial role in obtaining accurate loss estimates. Companies like Skymet are leveraging drones to offer agricultural surveying services to insurance companies and Indian state governments in regions such as Madhya Pradesh, Maharashtra, Gujarat, Rajasthan, and the Republic of India. Moreover, drones find application in various fields, encompassing agriculture, disaster management, the military, and humanitarian aid. The UN has conducted tests involving drones in diverse contexts, including agriculture and humanitarian crises. Drone use in humanitarian crises is best demonstrated by partnerships like the one between the World Food Program (WFP) and the Belgian government. The essay suggests and advocates using drones in a variety of ways to gather useful data during the agricultural cycle. By producing three-dimensional (3D) maps of the current soil, drones are useful for monitoring possible problems with dead zones, nutrient management, and soil quality. With this information, farmers may choose the best planting patterns, manage their crops and land, and improve their overall agricultural techniques. Drone-assisted continuous observation contributes to better crop nutrient management and water resource optimization.

The research work published as (Zhichkin, et al., 2023) uses the U-30L-6 (BROUAV) as a case study to evaluate the economic feasibility of drone technology in agriculture. The purpose of the study is to evaluate agricultural drones' effectiveness in comparison to other available technologies. The article's approach involves evaluating the effectiveness of using agricultural drones, particularly the U-30L-6 (BROUAV), by establishing a list of tasks they can perform, assessing their advantages and disadvantages, computing the associated expenses, and conducting a comparative evaluation against alternative technological equipment. Numerous tools, including modeling, abstract-logical techniques, expert assessments, and monographs, were used throughout the project. The studies and findings presented in this article demonstrate how versatile quadcopters—such as the U-30L-6 (BROUAV)—are for activities including applying tricograms, watering in small spaces, spraying crops, delivering fertilizer, and producing fog. The benefits of utilizing drones in agriculture are outlined, emphasizing their ability to cover substantial areas in a short flight time, precisely dose and uniformly spray pesticides and fertilizers, navigate difficult-to-reach areas, and automatically log and resume tasks. In terms of production costs, the article recommends using agricultural aircraft, tracked sprayers, and self-propelled sprayers as the first priorities, with helicopters coming in second. It does, however, advice taking into account the economic impact of agricultural drones, which in 2023 will outweigh alternative solutions in terms of rubles per hectare, even with lower spraying rates and possible losses due to trampling.

Similarly, the article (Lawrence, Agnishwar, & Vijayakumar, 2023) discusses the notable growth of drone usage in various industries over the past few years, with drones now being employed across virtually every sector. Specifically, the article highlights the success of drones in fostering ecologically sustainable agricultural practices. Precision agriculture benefits greatly from the analysis of field crops and the collection of site-specific data that drones provide. The essay looks at ways to guarantee data quality appropriate for agricultural usage and the usefulness of these drones, examining both novel and current uses for agricultural drones. According to the report, putting these suggestions into practice can help businesses become sustainable over the long run. According to the report, structural elements and carbon fiber are frequently utilized in drone construction to lighten weight and increase flexibility. Military drones profit from high-carbon composite construction since it allows for high-speed rotation. Various drone models equipped with modern technologies, including infrared sensors and GPS, are utilized in residential, commercial, and military settings. Telecommunications systems facilitate task uploads and comprehensive instructions for drone control, often providing live video streams from drone cameras. Despite the advantages, the article discusses several challenges associated with drones, including shorter flight times, limited flight ranges, and higher costs for long-range and feature-rich drones. Authorization from authorities is another hurdle, along with the challenge of flying drones in severe weather conditions, especially considering shared airspace with commercial aircraft. The article suggests that while drone technology offers significant benefits in agriculture, it also raises concerns, particularly related to privacy. Drones have the capability to capture images and collect data that may infringe upon private rights, posing privacy concerns for individuals, neighboring properties, and sensitive areas. The recommendation is for farmers to be cognizant of privacy laws and ensure compliance with local ordinances to safeguard the privacy of others during drone operations.

An embedded system designed to take benefit of the drone (Meah, Hake, & Wilkerson, 2020) presented a full design and development of an electric vehicle to enhance safety and reliability of the drivetrain as a combinational logic control system. This articles provides range of perspectives in design and test of such embedded systems that are useful for our aims and objectives. Similarly a book section (Mogili & Deepak, 2020) focuses on low cost solutions for modern agriculture using low cost UAVs. The UAV follows APM planner application while scanning the fields and is controlled by ground control station using the MAVlink networking and telemetry protocol. The system captures information about water stress management in the target fields, crop protection level, crop management and crop harvesting progress. Another article (Mansingh, Amrutha, Roobasree, & Yuvarani, 2021) Uses UAV to catch the affected plants pictures using trained zones of the leaves by using the improved k-mean grouping calculation. The system design uses the shading based division model to characterize the contaminated leaves and plants. The designed algorithm does picture securing, picture division, pre-paring and characterization processes of the pictures using MATLAB.

Despite the evident benefits, it's crucial to acknowledge the challenges associated with implementing drone technology in agriculture, including specialized training needs, initial investment costs, and regulatory constraints. Overcoming these hurdles requires collaborative efforts among farmers, technology developers, and legislators. In conclusion, while recognizing the obstacles, the research underscores the transformative potential of drone technology in contemporary farming. The literature review advocates for the development of drones to bridge the knowledge gap between current agricultural productivity and future demands. It emphasizes understanding the drone classification, components, and operations and potential advantages. Identified inconsistencies reveal a lack of technological expertise among farmers, particularly in analyzing data and interpreting drone images. The proposed improvement involves the integration of drone technology in agriculture to collect the images of the crops using drones and using drone to remotely do irrigation activities. This strategic approach aims to enhance agricultural practices and sustainability through innovative drone technology. Next section provides the design and analysis of an embedded system that uses drone to reach to the target plant.

3. System Design

To ensure the effective utilization of drones for various agricultural tasks such as irrigation, spraying and monitoring, a versatile platform is indispensable. This platform serves as a specialized tool for the farmers seeking to employ drones for agricultural purposes. Programmable and customizable drones offer flexible hardware that can be adapted to diverse needs. Figure 2 delineates the components constituting this system. Initially, farmer uses the plowing process readies the soil for cultivation, employing efficient methods to scatter seeds across extensive areas. Farmer then utilizing the monitoring cameras enhances the clarity of observing crops, plants, and land, facilitating comprehensive analysis. For the tasks like pest control involving chemical spraying, monitoring in forecasting future growth cycles, while the camera assesses the quality of crops, plants, and soil. The system recommends optimal harvesting times and techniques, aids in land clearance, and provides real-time feedback on soil health and condition. The functional block diagram is provided in figure 2.

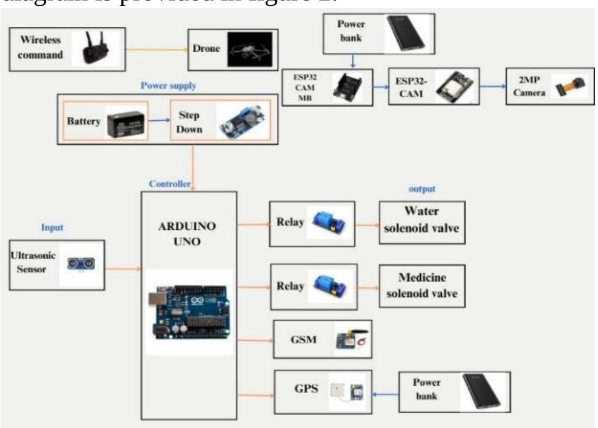
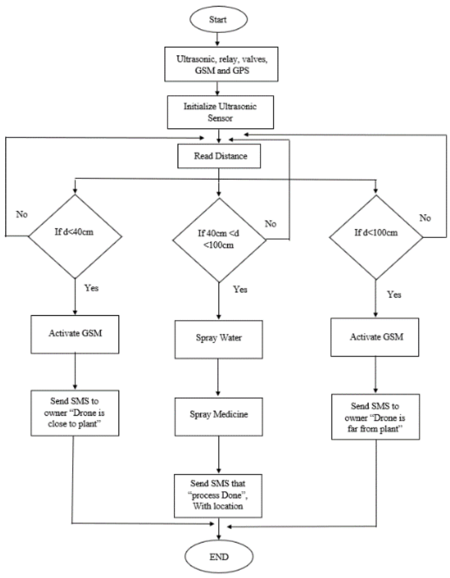


Figure 2: System Block Diagram

The block diagram illustrates eleven primary functions of the system. Initially, wireless commands are employed by the farmer to control the drone flights. The microcontroller communicates with a distance sensor to determine how far away the drone is from the plants. The camera effectively scans the region by taking pictures of the crops, plants, and soil thanks to its connection to the microcontroller. Following the establishment of the necessary target distance, the microcontroller employs the medication and water gun relays for irrigation and spraying after interpreting the data from the target plant's distance sensor. As switches, these relays open in response to any electrical signal and send that signal to the outlets, which are the medication and water guns. The GSM sends text messages to the farmer in two scenarios: when the drone is in proximity to the plant and after the completion of the irrigation and spraying process. In the latter case, the text message informs the farmer of the process's completion, prompting the drone to return to the farmer. The GPS operates to determine movements and track the drone's locations. The sequence of operations performed by the proposed system are illustrated by a flowchart in figure The flow chart shows how a modern farming system that makes use of drone technology operates. This system has five outputs: water spray, medicinal spray, pictures, GSM, and location determination. Its three inputs are the distance sensor (ultrasound sensor), the camera, and GPS. The drone is controlled wirelessly to start the operation. As the drone gets closer to the plants, the ultrasonic distance sensor calculates the distances. It reads again and sends the farmer an SMS to let them know the drone is getting close to the plants if the distance is less than 40 cm. The device starts spraying water and medication on the plants and crops at a distance of 40 to 100 cm. Concurrently, images are captured, and the drone's location is determined. After completing the spraying process, an SMS notifies the farmer of the treatment's conclusion, prompting the drone's return via wireless command. These sensors monitor the length of a wave's path, reflection, and return to the ultrasonic sensor. The relationship between the time gap between sending and receiving the signal and the air's constant speed of light is then used to calculate the distance. In this project, the distance between the ultrasonic sensor and the agricultural crops are calculated.

The Ultra Sonic HC-SR04 produces ultrasonic waves that travel through the atmosphere at a frequency of 40,000 Hz. A crop bumps into the Ultra Sonic device when it's nearby and then bounces back.



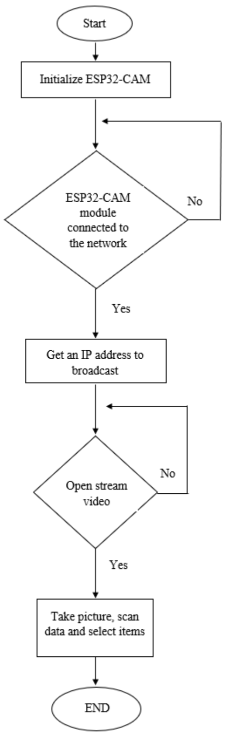


Figure 3: System Flow Charts

Equation 1 expresses the formula for calculating distance.

Distance = Speed ∗ Time (1)

Assume that the plants are 60 cm away from the system's distance sensor and that the sound speed of the air is 0.034 cm/μs. This suggests that the sound wave travels for 1764 microseconds. However, the echo pin doubles the distance (forward and backward). To find the distance in centimetres, multiply the travel time value that the echo pin obtained by 0.034 and divide the result by two.

Time = 60 / 0.034 =1764 μsec

Table 1 provides various distances corresponding to various speeds based on equation 2.

Distance= (Time × Speed) / 2 (2)

Distance= (1764 × 0.034) / 2=30 cm

The system sends SMS to the Farmer that the Drone is close from the plants.

Distance= (3000 × 0.034) / 2=51 cm

The system starts spry water and medicine, take picture and note the location.

Distance= (7000 × 0.034) / 2=119cm

Table 1: Distance in centimetres

Speed	**Time**	**Distance**
0.034 cm/μs	1764 μsec	30 cm
0.034 cm/μs	3000 μsec	51 cm
0.034 cm/μs	7000 μsec	119 cm

When the distance between the system and the plants is too great, the system shuts down. We're going to design a circuit with multiple components for modern farming using drones. A distance sensor in this system measures the distance between the system and the plants. When it reaches the right size, the irrigation system starts to spray the plants with insecticides and water. The built-in camera takes pictures so farmers may evaluate the state of their crops. The system employs GSM to send text messages to the farmer in two scenarios: proximity to plants, risking entanglement, and completion of irrigation and spraying. To aid in tracking, the system includes GPS, facilitating the farmer in monitoring the drone's movement. The circuit employs a Microcontroller PIC16F877A with a distance sensor (HC-SR04) using capacitors and resistors based on design calculations based on circuit diagram of figure 4.

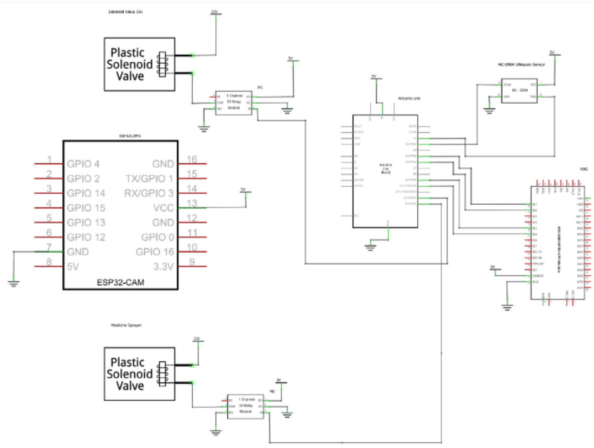


Figure 4: Circuit Diagram

The project and user interface is programmed and developed using the Arduino program (IDE) as indicated in figure 5. The project takes inputs from a variety of sources, including buttons, light sensors, or tweets, and turn them into outputs, such as starting a motor, turning on an LED, or posting something online (AndProf, 2023). The Arduino programming language, built on Wiring, allows to create and upload your own code to the board's microcontroller. Mac, Windows and Linux are the operating platforms on which the Arduino IDE can be accessed. The Arduino has been used in hundreds of projects over the years, from simple household tools to sophisticated scientific equipment, and has attracted the interest of a global community of makers, students, hobbyists, artists, programmers, and professionals. The Arduino IDE offers a C framework that includes helpful functions, libraries 13, and a predefined program structure.

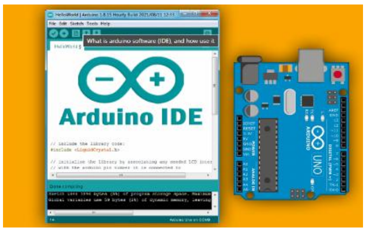


Figure 5: Arduino IDE

The selected distance sensor for the project is HC-SR04, ultra-Camera PCB, Microcontroller PIC16F877A, *SPDT Relay*, and Water and medicine gun, GPS Module, GSM Module and Drone and are illustrated in figure 6. Main risks involved in the utilization of this project are related to general public who may view drones as an invasion of their privacy. The regulations that restrict the use of drones in specific locations or circumstances apply to this project as well. The designed circuit undergoes simulation in Proteus software for parameter finalization before programming the microcontroller and implementing the circuit. The testing plan, following the V-model methodology, ensures the development of a high-quality product. The test results validate the designed system in second phase.

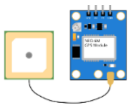
 *HC-SR04*	 *camera mainboard PCB*	 *PIC16F877A Microcontroller*	 *SPDT Relay*
 Water and medicine gun	 *NEO-6M GPS Module*	 *Sim300 GSM DJI*	 *Mini 4 Pro Drone*

Figure 6: Hardware Components

4. System Implementation And Testing

The system for the project was simulated using Tinkercad. The Arduino Uno, ultrasonic sensor, and buzzer were used, with two components representing the GSM A9G and two representing the relay and LED in place of the solenoid valve due to the unavailability of parts in Tinkercad. The system is divided into three parts: input, control unit, and output. The ultrasonic sensor sends readings to the control unit, which then controls the outputs based on the data. To verify functionality, an LED and buzzer were added, ensuring the system works as programmed according to the code's requirements as shown by figure 7.

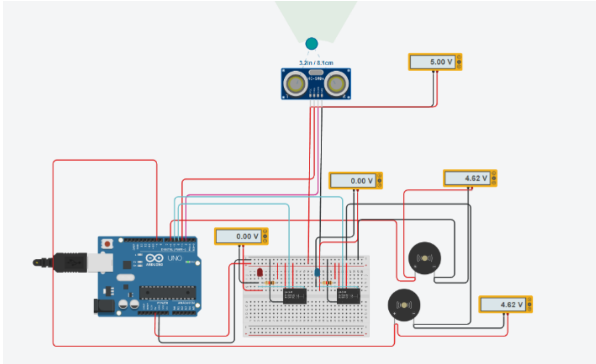


Figure 7: Simulation the circuit diagram

If the distance is less than 10 cm, the system sends an SMS via SIM900A to the farmer, notifying that the drone is near the plants, with location details. The operation of the two buzzers in the simulation provides evidence of this. If the distance is between 10 and 100 cm, the water valve activates, represented by the red LED in the simulation, followed by the drug valve. Once irrigation is complete, another SMS is sent to the farmer confirming successful completion, including the location. The operation of the two buzzers in the simulation verifies the process. if the distance is less than 100cm, the system sends an SMS via SIM900A to the farmer that the drone is far from the plants, indicating the location. The evidence for this is the operation of the two buzzers in the simulation. The ESP32 camera module was tested using Arduino IDE and PyCharm programming. The ESP32 camera of the prototype of figure 8 detects and identifies objects, and the owner can save images and data as demonstrated in figure 9 while results are communicated to the own via Blynk App and GSM module as shown in figure 10.

Figure 8: Hardware Prototype

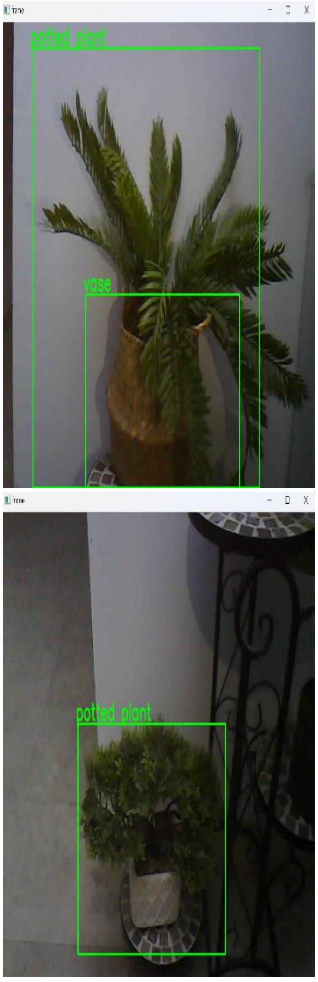


Figure 9: Camera Detection

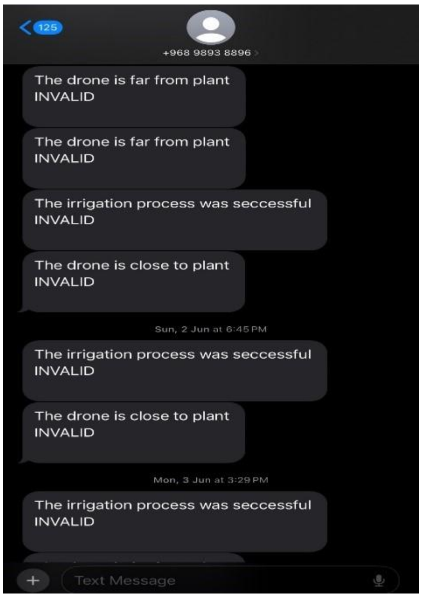


Figure 10: GSM messages on Blynk App

The hardware testing of the implemented system revealed several critical challenges and considerations that impacted its functionality. Ultrasonic sensors, while versatile, faced issues related to interference and environmental factors. The crosstalk between multiple sensors, combined with reflections from nearby surfaces, resulted in inaccurate readings. To mitigate these issues, better sensor placement and signal processing techniques are necessary. Furthermore, environmental factors such as temperature and humidity affected the propagation of sound waves, which requires careful calibration and system design to ensure reliable operation. The ESP32-CAM module, known for image processing, posed power consumption issues. High power usage, especially during camera operation, could cause battery drain or overheating. Implementing efficient power management and camera usage strategies is essential to mitigate these challenges, particularly in battery-powered setups.

For solenoid valves, environmental limitations such as temperature and humidity were major concerns, which required selecting valves suited for harsh conditions to ensure functionality. However, the use of LEDs and buzzers as substitutes for unavailable hardware during simulation provided a simplified method to test the system’s operations, though it could not fully replicate the real-world scenario. Despite switching to Tinkercad for simulation due to Proteus' lack of libraries and cost, testing was limited by the absence of essential libraries for components such as GSM, A9G, and valves. Furthermore, the A9G GSM module failed to provide responses, necessitating a switch to the SIM900A, which successfully sent SMS notifications. These challenges highlight the importance of adaptability in hardware selection and simulation tools for successful project implementation.

5. Conclusions

Integrating drone technology into modern farming has the potential to revolutionize the agricultural industry. This project showcased the diverse applications of drones, such as data collection, pest control, and crop monitoring, leading to improved productivity and resource efficiency. Despite challenges like weak network areas, limited off-the-shelf components like the A9G, and drone capacity limitations, drones provide real-time data that enhances farm management. Overcoming these obstacles will require collaboration between farmers, technology developers, and policymakers. It is expected that such solutions will significantly influence the restructuring of agricultural practices and contribute to the improved economic outlook for farmers Future advancements, such as solar-powered drones and integrated cameras, could further enhance sustainability and cost-effectiveness in agriculture.

Acknowledgement

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Sustainable Waste Management: A Comprehensive Analysis of Recycling Food and Agricultural Waste for Economic and Environmental Benefits

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Abstract

This study examines the management of food and agricultural waste in Oman, exploring methods to enhance collection and recycling systems. The objective is to divert 60% of waste by 2030, targeting an 80% diversion rate. Biogas and compost production from these wastes are both economically viable and environmentally sustainable renewable energy sources. Recycling these waste types can offer economic benefits through biogas and compost production. The European Union has set renewable energy consumption and waste management goals, promoting a circular economy to recycle and reuse organic and agricultural waste rather than landfilling. The study is crucial for those in waste management or aiming to boost a country's economic performance while preserving environmental integrity. Effective waste management and recycling safeguard human health and ecosystems by mitigating risks like fire hazards, toxins, and pests. Recycling can yield economic benefits through biogas and compost production, contributing to national economies and supporting industrial growth and diversification. Achieving waste management sustainability is essential for environmental and human health protection. This study fills a research gap by exploring ways to improve the effectiveness and efficiency of food and agricultural waste collection and recycling systems.

Keywords: *Food waste, Agricultural waste, Biogas, Compost, Recycling waste, KOBO toolbox.*

الخلاصة

تبحث هذه الدراسة في إدارة النفايات الغذائية والزراعية في عمان، واستكشاف طرق لتعزيز أنظمة الجمع وإعادة التدوير. الهدف هو تحويل 60٪ من النفايات بحلول عام 2030، مستهدفًا معدل تحويل 80٪. وإنتاج الغاز الأحيائي والسماد من هذه النفايات مصادر طاقة متجددة مجدية اقتصاديا ومستدامة بيئيا. يمكن أن توفر إعادة تدوير أنواع النفايات هذه فوائد اقتصادية من خلال إنتاج الغاز الحيوي والسماد. وقد وضع الاتحاد الأوروبي أهدافا لاستهلاك الطاقة المتجددة وإدارة النفايات، معززا اقتصادا دائريا لإعادة تدوير النفايات العضوية والزراعية وإعادة استخدامها بدلا من دفن النفايات. تعتبر الدراسة حاسمة بالنسبة لأولئك الذين يعملون في إدارة النفايات أو الذين يهدفون إلى تعزيز الأداء الاقتصادي لبلد ما مع الحفاظ على السلامة البيئية. تحمي الإدارة الفعالة للنفايات وإعادة التدوير صحة الإنسان والنظم الإيكولوجية من خلال التخفيف من مخاطر مثل مخاطر الحريق والسموم والآفات. ويمكن لإعادة التدوير أن تحقق فوائد اقتصادية من خلال إنتاج الغاز الحيوي والسماد، والمساهمة في الاقتصادات الوطنية ودعم النمو الصناعي والتنويع. إن تحقيق استدامة إدارة النفايات أمر أساسي لحماية البيئة وصحة الإنسان. تملأ هذه الدراسة فجوة بحثية من خلال استكشاف طرق لتحسين فعالية وكفاءة أنظمة جمع النفايات الغذائية والزراعية وإعادة تدويرها.

الكلمات الرئيسية: نفايات الطعام، النفايات الزراعية، الغاز الحيوي، السماد، نفايات إعادة التدوير، صندوق أدوات KOBO.

1. Introduction

Waste management sustainability is of paramount importance, and Oman aims to divert 60% of the country's waste by 2030 to achieve an 80% diversion rate. This objective can be accomplished through the establishment of international standards for recycling and recovery technologies. Food waste constitutes approximately 30% of the waste generated in Oman, and a substantial quantity of green waste is currently disposed of in landfills without being recycled [1]. Oman plans to construct a facility in one of the landfills to generate electricity from food waste and environmentally friendly waste. Furthermore, an agreement has been reached with the Nakheel-Oman Company to utilize all agricultural waste for compost production, which will be applied to palm plantations [2]. Biogas represents an economically viable and environmentally sustainable renewable energy source [3]. It has the potential to reduce energy requirements from raw materials, decrease greenhouse gas emissions, and minimize resource depletion, while simultaneously mitigating climate change and improving human health [4]. Biogas is produced through the combination of several gases, including carbon dioxide (CO_2) and methane (CH_4), with traces of water vapor (H_2O), hydrogen sulfide (H_2S), hydrogen (H_2), and siloxanes [5]. The production of biogas occurs through anaerobic digestion, which involves the addition of bacteria to food waste in the absence of oxygen, resulting in a biochemical reaction [6]. Biogas undergoes purification and enhancement to biomethane before being utilized in the gas grid and as a vehicle fuel [7]. Renewable energy serves all consumers and has numerous resources, including food waste. Agricultural waste is also utilized to generate compost through fermentation, and the resulting compost is used to enhance soil fertility [8].

The production of biogas and the exploration of new renewable energy sources are becoming critical issues, as they will contribute to reducing the environmental impact of greenhouse gases currently generated by the combustion of fossil fuels. This necessitates the establishment of policies and coordination of renewable energy generation. By 2020, the European Union aimed to have renewable energy constitute 20% of total energy consumption. They also established a minimum objective for all European nations, mandating that 10% of transportation fuel by energy produced from renewable sources be increased to 27 percent by 2030. In 2016, European nations generated approximately 392 million tons of green waste from agricultural operations, with approximately 31% of this waste collected and utilized for recycling and compost production. To achieve the goals of producing energy from renewable resources, composting agricultural waste, and reducing waste sent to landfills, the concept of 'circular economy' was developed to encourage the utilization of emerging innovations to recycle and reuse organic and agricultural waste instead of disposing of them in landfills. Food waste and green waste management are essential to explore because a country's primary objective is to diversify its sources of revenue, and these types of waste can contribute to achieving this goal. Furthermore, recyclable materials reduce landfill pressure while protecting the environment from pollution. Consequently, the purpose of the project is to provide effective techniques for managing and extracting value from various types of waste.

1.1. Significance of Study

This study is of critical importance for individuals engaged in waste management or seeking to enhance a country's economic performance while preserving environmental integrity. This study will elucidate an effective waste management strategy (encompassing both food and agricultural waste) and provide comprehensive insights into the potential benefits derivable from food and agricultural waste. Moreover, the utilization of food and agricultural waste for energy generation and operation across various industries, as opposed to relying on raw resources, may contribute to economic improvement in any given country. Agricultural waste is utilized in the production of organic compost, which serves to enhance soil fertility and plant health. Manufacturers of organic compost may also introduce these products to the market. Ultimately, and most significantly, a robust waste management strategy for food and agricultural waste will contribute to environmental protection, ensuring its suitability for human habitation.

1.2. Food Waste.

Food waste is a critical issue affecting global populations. Food preparation inefficiencies result in the majority of food waste being discarded prior to consumption. The United Nations' 2015 Sustainable Development Goal 12, "Ensuring Sustainable Consumption and Processing Patterns," aims to halve per capita global food waste at retail and consumer levels by 2030. It also seeks to reduce food loss throughout the entire food supply chain. Achieving these objectives necessitates the implementation of enhanced policies, initiatives, and regulatory changes [9]. However, the reduction of existing food waste must be complemented by improved waste management strategies, as some degree of food waste is inevitable. Moreover, certain food products deemed unsuitable for consumption must be discarded. While various techniques exist for managing food waste, landfilling remains the predominant method worldwide, despite its significant environmental and health implications. To optimize food waste management, it is essential to establish a clear definition of "food waste." In this study, food donated to charities by businesses is categorized as food waste due to its economic cost to the food industry, even though it retains its biological and legal status as food and may be classified as surplus food. [10]

1.3. Agriculture Waste

Agricultural waste is a byproduct of agricultural production and processing, potentially containing valuable materials. However, its economic value is lower than the cost associated with collecting, transporting, and processing agricultural items beneficial to humans. Consequently, quantitative data on agricultural waste is limited, although it is widely acknowledged to constitute a substantial portion of total waste in developing nations. The injudicious application of industrial farming techniques and pesticides often leads to pollution that accompanies agricultural productivity, significantly impacting rural environments and global ecosystems [11].

1.4. Anaerobic Digestive Process

The process of converting organic materials, such as animal or vegetable waste, into biogas and biofertilizer is known as anaerobic digestion. This mechanism occurs in the absence of oxygen within an anaerobic digester or enclosed oxygen-free tank. According to the Welsh Assembly Administration and Union of National Farmers, anaerobic digestion is one of the most effective processes for treating food waste, agricultural waste, and sewage sludge. The term "anaerobic" denotes "oxygen-free." A combined heat and power (CHP) unit utilizes biogas that naturally develops in sealed tanks as fuel to generate sustainable energy, such as heating and electricity.

1.5. Biogas

Biogas represents a renewable energy source worthy of investigation. It is not classified as a fossil fuel but rather as a highly calorie-dense renewable fuel. The lower calorific value (LHV) ranges from 13,720 to 27,440 kJ Nm-3 for methane (CH_4) concentrations of 40 to 80 percent. Renewable energy sources are gaining prominence as the cost of fossil fuels increases, and their utilization reduces greenhouse gas (GHG) emissions [carbon dioxide (CO_2) equivalents]. With a 2020 target of 10% renewable energy in transportation and 20% renewable energy in final energy consumption promotes renewable energy [13].

1.6. Compost

Compost is a complex combination of organic materials and decomposed plant detritus utilized in horticulture and agriculture. It is essential for organic farming due to the prohibition of synthetic fertilizers. Furthermore, compost enhances soil composition, provides plants with various nutrients, and introduces beneficial soil microorganisms [14].

2. Methodology:

This study examines the waste management system, regulations, current practices for extracting benefits from food and agricultural waste, the outcomes of recycling these waste types, and their potential economic impact. The project objectives were addressed through the distribution of a questionnaire to the project contact person via the Kobo Toolbox platform. The survey aimed to enhance waste management procedures, assess public awareness of waste management, composting of agricultural and food waste, and the benefits of generating specific waste types, as well as the importance of implementing waste disposal regulations. The survey administered to respondents can be accessed through the provided link. (https://ee.kobotoolbox.org/x/1EN2w4k3)

3. Results and Discussion:

A questionnaire survey was conducted in this study. The discussion is based on questionnaire findings and supported by a literature review. This section presents the analysis and results of the use of food waste and agricultural waste to produce biogas and compost, as well as a discussion. The survey received participation from 28 individuals. According to the available data, 17 participants completed the questionnaire, whereas 11 did not. There were nine male and eight female participants with a male-to-female ratio of 32.14 to 28.57. The participants were categorized into five age groups: 10–19, 20–29, 30-39, 40–49, and 50 and above.

The groups were stratified to obtain responses from individuals of various ages. However, all three groups produced responses. The study included seven participants aged 30-39, six individuals aged 20-29, and four individuals aged 40-49. As many of the participants were from Oman, the findings are primarily applicable to that region.

Participants were asked to evaluate their country's waste management system in the fourth question. The results were favorable, with 12 participants assessing the system as good, two as very good, and three as poor. Most of those policies satisfied the country's current waste management system.

Question 5 addressed adherence to guidelines issued by waste management companies. As all participants responded affirmatively, the outcome was positive. This is advantageous because the results indicate that society is willing to follow the duties and directions of waste management. The issue concerned the current practice of utilizing food and agricultural waste. Based on these responses, food and agricultural wastes currently provide no significant benefits to Oman. Some human efforts have been made to extract advantages from food waste and agricultural waste, such as animal feed and soil enrichment. This is beneficial as it reduces the amount of waste directed to landfills.

Conversely, the Oman Environmental Services Holding Company established a plan to utilize such waste. Food waste is employed to generate energy and gases, while agricultural waste is composted to enhance soil fertility. The objective of this study was to determine the potential benefits of processing agricultural and food waste. The results were conclusive: food waste can be utilized to produce biogas and convert it into energy. Agricultural waste can also be used to produce compost, which can then be employed to enhance soil fertility. [15] asserted that the anaerobic digestion process utilizes no oxygen to decompose food waste and produces methane gas, which is subsequently transformed into biogas and utilized to generate electricity or fuel for vehicles. Additionally, agricultural waste is shredded and stored in open heaps to decompose. The shredded material is then rotated to allow oxygen into the waste and facilitate microbial growth, aiding in decomposition. This process can take between 8 and 16 weeks.

Question 9 addressed the recycling of food and agricultural waste in the country's economy. According to the responses, recycling food and agricultural waste may benefit the country's economy through the sale of recycled products such as energy and compost, the generation of renewable energy, the reduction of waste transported to landfills, and the decrease in landfilling costs. Food waste is recycled to produce biogas and converted to energy, which is then used to generate power and fuel for vehicles, reducing nonrenewable energy consumption and benefiting the government [16].

Agricultural waste can contribute to the country's wealth through various means, including composting, utilization as soil fertilizer, production of abundant agricultural products for market sale, minimization of environmental impacts, and reduction of expenditure required to address these concerns [17]. This question focused on mitigating the environmental impact of food and agricultural waste recycling. Recycling food and agricultural waste would benefit the environment by reducing greenhouse gas (GHG) emissions, minimizing waste, decreasing odor, lowering the risk of fires, and limiting leachate development. Food and agricultural waste management has become increasingly complex in recent years, as a significant portion of this waste is disposed of in landfills, where it decomposes and emits substantial quantities of greenhouse gases (GHG). These gases accumulate in the atmosphere, contributing to climate change and global warming. However, recycling this type of waste has a reduced environmental impact, emits fewer greenhouse gases (GHG), conserves natural resources and energy, and generates less odor and leachate [18].

Question 11 addressed the role of inadequate food waste and agricultural waste management in contributing to global warming. There is a consensus that improper waste management contributes to global warming by producing a significant amount of greenhouse gases (GHG), thereby increasing the likelihood of global warming. Ineffective food waste and agricultural waste management indicates a lack of efficient recycling processes, resulting in increased greenhouse gas (GHG) emissions such as methane and carbon dioxide. Food losses and waste increased gaseous emissions by 8-10% between 2010 and 2016, which are directly responsible for global warming [19].

Question 12 was designed to assess and rank the level of concern among individuals regarding the waste management system in their respective countries. The majority of respondents expressed high or extreme concern about their nations' waste management systems, with only one individual indicating no concern. This outcome is favorable, and the most concerned individuals will be engaged to conduct awareness seminars to increase public knowledge of the importance of the national waste management system. Additionally, they inform the public of the risks that improper waste management poses to humans, animals, and the environment. Ineffective waste management affects soil, air, and water quality, contributes to climate change, harms wildlife, and is detrimental to human health [20]. This question was included to evaluate the participants' knowledge and comprehension of food and agricultural waste.

Furthermore, as indicated by their responses, the results suggest that all participants demonstrated a high level of knowledge and understanding of food and agricultural wastes. Food waste is generated by households, supermarkets, and other consumers. This waste impacts humans, the environment, and animals if it is not properly disposed of [21].

Agricultural waste refers to the waste produced by farms and other agricultural operations. Compostable agricultural waste can be utilized as a soil fertilizer [22]. The question was included in the questionnaire to assess the participants' knowledge and awareness of the benefits of recycling food and agricultural waste.

Most of the participants (12 individuals) assessed their knowledge as good to very good, while five evaluated it as poor to very poor. Based on these findings and the predominance of participants (12 individuals) who rated themselves as good or very good, it is anticipated that most questionnaire responses will be positive and originate from experienced individuals. This will contribute to the study's structure and enhance the reliability of the data and feedback collected. The initial investigation focused on the potential health and environmental implications of food and agricultural waste. Non-recycled waste has detrimental effects on human and environmental health. These waste materials contaminate water, air, and soil.

Furthermore, retaining such waste would result in the production of greenhouse gases (GHG), which are detrimental to human health and the environment. Food waste landfilling emits approximately 3.3 billion tons of greenhouse gases (GHG), accelerates climate change, and exacerbates global warming. Additionally, agricultural waste can spontaneously combust, causing ecological damage and air pollution [23].

Question 15 addressed the creation of waste management legislation and was introduced to ascertain if the participants concurred on establishing stringent waste management laws. Ten individuals strongly agreed, while the remaining seven agreed. The findings indicate that waste management legislation is crucial for coordinating waste management and establishing an effective waste management system. It is widely acknowledged that laws are enacted to govern, coordinate, and facilitate implementation.

Consequently, waste management legislation is essential as it significantly impacts the environment and human health. The waste management law will establish a comprehensive waste management program while safeguarding the environment and human health. Furthermore, waste management laws will enhance the efficiency of waste collection, transportation, disposal, and treatment. Moreover, the waste management law regulates waste recycling, and the revenue generated from waste [24].

The study was concerned with an energy plant to evaluate whether individuals would accept residing in proximity to such facilities. The majority of responses were affirmative or negative, and some respondents associated it with the safety of the electricity plant. Consequently, to preserve human and environmental health, energy plants should be designed using state-of-the-art technology and comprehensive safety measures. The energy plant will be constructed in one of the landfills because the purpose of the study is to produce power from food waste, and energy plants are typically located near load centers to reduce costs.

Furthermore, the generated energy may provide power and fuel for the internal equipment of the facility. Moreover, energy plants should be situated as far from residential areas as possible [25].

The challenge here is how to recycle and utilize the waste within the household. The five aspects of the conventional waste management hierarchy are reduction, reuse, recycling, recovery, and disposal. The first aspect is reduction, which should commence at home with decreased purchasing and waste generation, and improved material durability. Materials that can be reused include clean and refilled old garments, machinery, bottles, jars, cartons, and tools. Recycling aims to transform waste into usable forms and return the raw resources to the market. The process of obtaining value from waste products such as electricity, fuel, and compost is known as recovery. In the final step, any residual waste from the reduce, reuse, recycle, and recover aspects will be disposed of in landfills; hence, waste transported to landfills after this operation will account for approximately 20% of the total waste produced [26].

4. Conclusion

1. Food and agricultural waste pose potential risks to human health and ecosystems, but they can be addressed through the development of methods to produce biogas and compost from these waste types.
2. This study found that recycling both food and agricultural waste can yield economic benefits through the production of biogas and compost, which can be utilized as renewable energy sources and soil fertilizers, respectively.
3. Appropriate waste disposal can contribute to economic growth while mitigating harm to both human populations and the environment.

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Smart Laboratories: Shaping the Future of Materials Design and Innovation

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Abstract

The advent of smart laboratories marks a transformative era in materials science, integrating advanced technologies such as artificial intelligence (AI), automation, the Internet of Things (IoT), and data analytics to revolutionize materials design and development. This article explores the evolution, current state, and future prospects of smart laboratories, highlighting their impact on accelerating discovery processes, enhancing precision, and fostering innovation. By examining case studies and technological advancements, the paper underscores how smart laboratories are poised to redefine research methodologies, optimize resource utilization, and enable the creation of novel materials with unprecedented properties and applications.

Keywords: *Smart Laboratories, Materials Design, Artificial Intelligence (AI), Automation and Robotics.*

الخلاصة

يمثل ظهور المختبرات الذكية حقبة تحويلية في علم المواد، ودمج التقنيات المتقدمة مثل الذكاء الاصطناعي (AI) والأتمتة، وإنترنت الأشياء (IoT) ، وتحليلات البيانات لإحداث ثورة في تصميم المواد وتطويرها. تستكشف هذه المقالة التطور والحالة الحالية والآفاق المستقبلية للمختبرات الذكية، وتسلط الضوء على تأثيرها على تسريع عمليات الاكتشاف، وتعزيز الدقة، وتعزيز الابتكار. من خلال فحص دراسات الحالة والتقدم التكنولوجي، تؤكد الورقة على كيفية استعداد المختبرات الذكية لإعادة تعريف منهجيات البحث، وتحسين استخدام الموارد، وتمكين إنشاء مواد جديدة ذات خصائص وتطبيقات غير مسبوقة.

الكلمات الرئيسية: المختبرات الذكية وتصميم المواد والذكاء الاصطناعي (AI) والأتمتة والروبوتات.

The paper/chapter Objectives

- To define and characterize the concept of smart laboratories in the context of materials science.
- To analyze the key technologies enabling smart laboratories and their applications in materials design.
- To evaluate the benefits and potential challenges associated with implementing smart laboratory technologies.
- To showcase real-world examples and case studies demonstrating the effectiveness of smart laboratories.
- To forecast future trends and the long-term impact of smart laboratories on materials development and related industries.

1. Introduction:

The landscape of materials science is undergoing a profound transformation, driven by the integration of cutting-edge technologies that redefine traditional research methodologies. At the forefront of this evolution are **smart laboratories**, which leverage advancements in artificial intelligence (AI), automation, the Internet of Things (IoT), and data analytics to revolutionize the design and development of materials. This article delves deeper into the background of traditional laboratories, the emergence and definition of smart laboratories, the technological drivers behind this transition, and the critical importance of this shift in the context of various industries.

The following sections will delve into the evolution of laboratory technologies, the core technologies enabling smart laboratories, the benefits and challenges of their implementation, real-world case studies, and future trends shaping the landscape of materials science. By examining these aspects, the article will highlight how smart laboratories are set to revolutionize materials research, driving advancements that address contemporary challenges and open new avenues for innovation.

2. Literature Review/ Background

2.1 Traditional Laboratories in Materials Science:

Historically, materials science has relied on conventional laboratory setups characterized by manual experimentation, iterative testing, and extensive human oversight. These laboratories have been the bedrock of advancements in creating new materials, from polymers and metals to ceramics and composites (Kaledio, Oloyede, & Olaoye, 2023; Rajendra, Girisha, & Naidu, 2022). The traditional approach involves:

- **Manual Processes:** Experiments are conducted manually, requiring significant human intervention for tasks such as mixing, measuring, and monitoring reactions.

- **Iterative Testing:** Developing new materials often involves a trial-and-error approach, where multiple iterations are necessary to achieve desired properties.
- **Time-Consuming Procedures:** The experimental cycles can be lengthy, delaying the discovery and optimization of new materials.
- **High Costs:** Manual experimentation and the need for specialized equipment contribute to the high operational costs of traditional laboratories.
- **Limited Scalability:** Scaling up successful experiments from the lab bench to industrial production poses significant challenges, often requiring substantial modifications and additional resources.
- **Instrumentation:** Traditional labs are equipped with various instruments such as spectrometers, microscopes, and tensile testers, which require expert operation and maintenance.
- **Data Recording:** Data is often recorded manually or through basic digital tools, limiting the capacity for comprehensive data analysis.
- **Human Oversight:** Significant reliance on the expertise and intuition of researchers to design experiments, interpret results, and make decisions.

2.2. Challenges in Conventional Materials Design and Development:

Despite the successes of traditional laboratories, several inherent challenges impede the rapid advancement of materials science. One major issue is **time constraints**, as the lengthy process of hypothesis testing and validation significantly slows down the pace of discovery. This delay often limits the ability to respond quickly to emerging scientific opportunities.

Another challenge is the **resource-intensive nature** of traditional laboratories. High costs associated with materials, equipment, and labor restrict the number of experiments that can be feasibly conducted. These financial limitations can impede progress and reduce the overall efficiency of research endeavors.

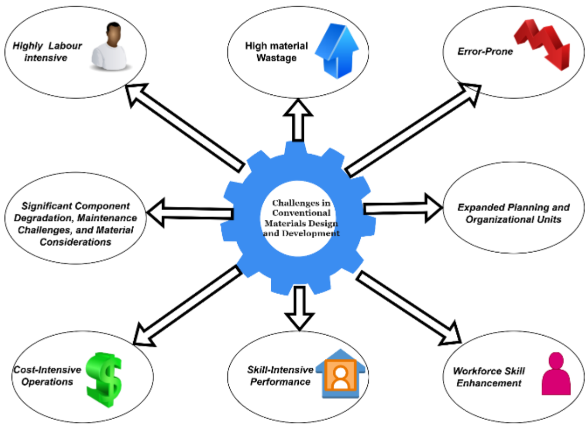

Figure 1: Challenges in Traditional Laboratories

Traditional material processing laboratories, heavily reliant on manual operations and skilled labor, face significant challenges in achieving accuracy, consistency, and cost-effectiveness. Human errors, such as inaccurate data recording, inconsistent experimental setups, and inefficiencies in material usage, are prevalent. Additionally, factors like tool wear, material wastage, and reliance on operator expertise drive up operational costs, making traditional laboratories less sustainable for large-scale or precision-focused tasks. Despite these challenges, their adaptability and lower initial costs make them suitable for small-scale industries.

In contrast, smart laboratories integrate automation, AI, and IoT to address these challenges effectively. AI-driven systems optimize tool usage, material efficiency, and operating sequences, while robotics ensure consistent performance in repetitive tasks. Automated monitoring and real-time analytics significantly reduce human errors and maintain precise experimental conditions. While smart laboratories require higher upfront investments and maintenance costs, they offer long-term cost savings and enhanced efficiency, making them ideal for industries that demand scalability and precision.

2.3. Emergence of Smart Laboratories

2.3.1. Definition of Smart Laboratories

Smart laboratories represent the next generation of research environments that integrate intelligent technologies to enhance every aspect of scientific experimentation and development (Häse, Roch, & Aspuru-Guzik, 2019; Potkonjak et al., 2016; Serrano et al., 2022).

A smart laboratory is defined by several key characteristics that set it apart from traditional setups. One of the most prominent features is the use of **automation and robotics**. Automated systems handle repetitive and precise tasks, significantly reducing the need for manual intervention and minimizing the potential for human error. This enhances efficiency and reliability in laboratory operations.

Another defining aspect is the integration of **artificial intelligence (AI) and machine learning**. These advanced technologies analyze data, predict outcomes, and optimize experimental conditions in real time, enabling more informed decision-making and accelerating the pace of scientific discovery.

The Internet of Things (IoT) is also a crucial element of smart laboratories. Connected devices and sensors facilitate seamless data collection, monitoring, and control of laboratory instruments. This interconnected ecosystem improves operational efficiency and ensures better oversight of ongoing processes.

Furthermore, smart laboratories leverage **big data and advanced analytics** to process the massive datasets generated during experiments. By analyzing these datasets, researchers can uncover patterns, correlations, and insights that drive innovation and enhance the quality of outcomes.

Lastly, **interconnectivity and integration** play a vital role in the functionality of smart laboratories. Systems within the laboratory are interconnected, enabling efficient communication and coordination among various devices and platforms. This holistic integration streamlines workflows and fosters a more collaborative and productive research environment.

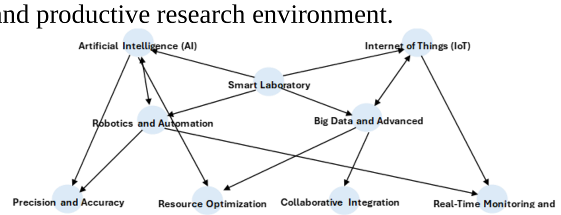

Figure 2: the key technologies within a smart lab environment

The flowchart in Fig. 2 illustrates the key technologies that enable smart laboratories (AI, IoT, Robotics, Big Data) and their interconnectedness, and provides an overview of how different technologies work together within a smart lab environment.

2.3.2. Technological Advancements Driving the Transition

Several technological breakthroughs have been pivotal in the transition from traditional laboratories to smart laboratories. Among these, **artificial intelligence (AI)** plays a crucial role by enabling predictive modeling, pattern recognition, and decision-making capabilities. These features significantly enhance experimental design and data interpretation, allowing researchers to achieve more accurate and efficient outcomes.

Machine learning (ML) is another transformative technology. By improving over time as it is exposed to larger datasets, ML algorithms provide increasingly accurate predictions and optimizations. This adaptability enhances the precision and effectiveness of laboratory operations.

Robotics and automation have revolutionized experimental workflows by performing complex tasks with high precision and consistency. These robotic systems not only increase the throughput of experiments but also minimize the chances of human error, ensuring more reliable results.

The **Internet of Things (IoT)** has introduced real-time monitoring and control capabilities, enabling dynamic adjustments to experimental conditions as needed. IoT devices foster seamless integration and communication within laboratory systems, promoting efficiency and responsiveness.

In addition, **big data technologies** have become indispensable in modern laboratories. Advanced tools for data storage, processing, and visualization allow researchers to manage and analyze the vast amounts of data generated, uncovering insights that drive innovation.

Finally, **cloud computing** has facilitated collaboration and scalability in smart laboratories. By offering centralized access to data and tools, cloud platforms enable researchers to share resources and work more effectively, regardless of their physical location. These technologies together form the foundation of the smart laboratory ecosystem, pushing the boundaries of scientific research.

2.3.3. Role of Materials Science in Various Industries

Materials science plays a pivotal role in driving innovation across a wide range of industries, each relying on the development of new and improved materials to push the boundaries of their fields. In the **aerospace industry**, the creation of lightweight, high-strength materials enhances the fuel efficiency and performance of aircraft and spacecraft. This advancement supports both economic and environmental goals by reducing fuel consumption and emissions (Himanen, Geurts, Foster, & Rinke, 2019; Meredig, 2017).

In **healthcare**, advanced biomaterials are transforming medical devices, implants, and drug delivery systems, leading to improved patient care and better treatment outcomes. Similarly, the **electronics sector** benefits from novel materials that enable the development of faster, smaller, and more efficient devices, driving advancements in consumer electronics, computing, and telecommunications.

The **renewable energy industry** relies on high-performance materials to boost the efficiency and longevity of technologies such as solar panels, batteries, and wind turbines. These innovations are critical for addressing global energy challenges and transitioning to sustainable power sources.

In the **automotive industry**, material innovations contribute to the production of lighter, more fuel-efficient vehicles with enhanced safety features, meeting the growing demand for eco-friendly and reliable transportation. Meanwhile, the **construction sector** benefits from advanced composites and smart materials that improve the durability, sustainability, and functionality of buildings and infrastructure.

Through these diverse applications, materials science serves as a cornerstone of progress, shaping the future of industries and addressing global challenges.

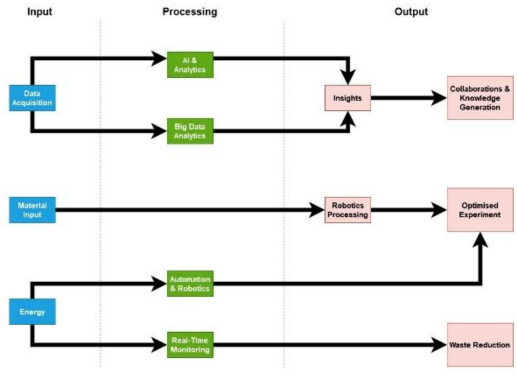

Figure 3: Resource Flow in Smart Labs

Fig. 3 illustrating the efficient flow of resources (data, energy, materials) within a smart laboratory setup. This diagram highlights resource optimization and demonstrates how different inputs are used efficiently to produce outputs, particularly relevant for industries like aerospace, healthcare, and renewable energy.

2.3.4. Necessity for Innovative Approaches

The rapid pace of technological advancement and the growing demand for sophisticated and specialized materials have created a pressing need for innovative approaches in materials design and development. To meet the **speed of innovation** required by fast-evolving industries, materials science must focus on accelerating the discovery and optimization of new materials. This urgency is compounded by the **complexity of modern requirements**, as many applications demand materials with highly specific and intricate properties, necessitating precise and tailored development processes.

Additionally, **sustainability concerns** are driving the need for environmentally friendly and resource-efficient materials. Innovative methods for designing and producing such materials are essential to address global environmental challenges. At the same time, the **intensity of global competition** requires nations and companies to invest in cutting-edge research methodologies to maintain a competitive edge and achieve groundbreaking discoveries.

Moreover, the **interdisciplinary integration** inherent in materials science emphasizes the need for intelligent research environments that seamlessly combine diverse scientific disciplines, data types, and methodologies. By embracing these approaches, the field can continue to drive progress and meet the complex demands of the modern world.

2.4. The Transformative Potential of Smart Laboratories

2.4.1. Accelerating Discovery Processes

Smart laboratories play a transformative role in accelerating the journey from conceptualization to the realization of new materials. By **automating routine tasks**, they streamline repetitive processes, freeing researchers to concentrate on more complex and creative aspects of experimentation. This not only enhances efficiency but also fosters innovation. Additionally, **advanced data analytics and AI** significantly improve data processing capabilities, enabling rapid analysis of experimental results and facilitating quicker decision-making and iteration. Furthermore, the ability to conduct **parallel experimentation** allows multiple experiments to be performed simultaneously, dramatically increasing throughput and expediting the discovery process. Together, these advancements enable smart laboratories to revolutionize materials research by reducing development timelines and driving faster innovation.

2.4.2. Enhancing Precision and Accuracy

The integration of intelligent technologies enhances precision and accuracy in materials research by addressing critical challenges in traditional methods. Automated systems minimize human error by performing tasks with consistent precision, eliminating the variability and inaccuracies often associated with manual processes. Additionally, AI-driven optimization ensures experimental parameters are finely tuned to achieve optimal outcomes, improving the reliability and reproducibility of results. Coupled with this, IoT-enabled sensors provide real-time monitoring of experiments, enabling dynamic adjustments to maintain desired conditions and prevent deviations. Together, these technologies create a robust framework for conducting highly accurate and efficient research, driving advancements in materials science.

2.4.3. Fostering Innovation

Smart laboratories foster an environment rich in innovation by enhancing data-driven insights, collaborative research, and iterative experimentation. Through advanced data analytics, they enable the examination of extensive datasets to reveal hidden patterns and correlations, paving the way for groundbreaking material discoveries. Furthermore, these labs support seamless collaboration among researchers by integrating cloud-based platforms and interconnected systems, promoting the exchange of ideas and interdisciplinary innovation. Additionally, the efficiency and scalability of smart laboratories facilitate iterative experimentation, enabling rapid prototyping and testing of new material concepts. This dynamic ecosystem accelerates the journey from concept to practical application, driving progress in material science.

2.5. Current Applications

Smart laboratories have found diverse applications across academic, industrial, and research settings, each leveraging intelligent technologies to enhance materials design and development.

2.5.1. Academic Settings:

In academic institutions, smart laboratories serve as hubs for cutting-edge research and innovation. Universities such as MIT and Stanford have integrated AI-driven platforms and automated experimentation systems into their materials science departments. For instance, MIT's Materials Research Laboratory utilizes machine learning algorithms to predict material properties, significantly reducing the time required for experimental validation (Sorkun, 2022). Additionally, academic smart labs often collaborate with industry partners, facilitating technology transfer and practical applications of research findings.

2.5.2. Industrial Settings:

In the industrial sector, companies like BASF and 3M have adopted smart laboratory technologies to streamline their materials development processes. BASF's Smart Lab integrates IoT sensors and automated synthesis equipment to monitor and control chemical reactions in real-time, enhancing product consistency and reducing waste (Learning, 2018). Similarly, 3M employs AI-powered data analytics to optimize the formulation of adhesives and coatings, resulting in faster product iterations and improved performance characteristics ("How 3M Deploys AI-focussed Tech," 2023) .

2.5.3. Research Institutions:

Leading research institutions like the National Renewable Energy Laboratory (NREL) and the Fraunhofer Institutes have implemented smart laboratory frameworks to advance materials research. NREL's smart laboratories utilize high-throughput experimentation and AI-driven modeling to accelerate the discovery of new photovoltaic materials, enhancing solar energy efficiency (Romero & Van Geet, 2024). The Fraunhofer Institute for Manufacturing Technology and Advanced Materials employs robotics and IoT-enabled systems to automate the testing and characterization of advanced composites, facilitating the development of lightweight and durable materials for automotive and aerospace applications (Niermann).

2.6. Case Studies:

To illustrate the successful implementation and outcomes of smart laboratory technologies, the following case studies highlight diverse applications across different settings:

Case Study 1: AI-Driven Material Discovery at **MIT**

The Massachusetts Institute of Technology (MIT) implemented an AI-driven platform within its Materials Research Laboratory to expedite the discovery of new alloys. By integrating machine learning algorithms with high-throughput experimental systems, researchers were able to predict the properties of potential alloy compositions before synthesizing them. This approach reduced the experimental cycle time by 50% and increased the rate of successful material discoveries (Kumar, Maiti, & Mukhopadhyay, 2025; Sha et al., 2020). The project not only accelerated research but also fostered collaborations with industry partners seeking innovative alloy solutions for aerospace applications.

Case Study 2: Automation in **BASF's Smart Lab**

BASF's implementation of automation and IoT technologies in their Smart Lab exemplifies the industrial application of smart laboratories. The Smart Lab employs robotic arms for precise chemical handling and automated synthesis, integrated with IoT sensors that monitor reaction conditions in real-time. This integration has led to a 30% increase in production efficiency and a significant reduction in material waste (Ferreira; Saling & Kurtz, 2023). Moreover, the data collected through IoT devices is analyzed using AI algorithms to optimize reaction parameters, ensuring consistent product quality and enabling rapid scalability from lab to production.

Case Study 3: High-Throughput Experimentation at **NREL**

The National Renewable Energy Laboratory (NREL) has established smart laboratories equipped with high-throughput experimentation systems and AI-driven data analytics to advance photovoltaic material research. By automating the synthesis and testing of solar cell materials, NREL has accelerated the identification of high-efficiency photovoltaic compounds. The integration of machine learning models allows for the rapid analysis of experimental data, facilitating the discovery of materials with optimized light absorption and charge carrier mobility (Nemett & Adams, 2022). This approach has significantly contributed to the development of next-generation solar panels with enhanced performance and lower production costs.

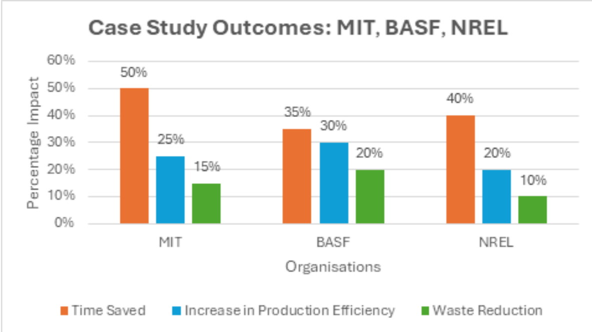

Figure 4: The key outcomes of the case studies

A multi-series graph in Fig. 4 depicts key outcomes of the case studies, such as **time saved**, **increase in production efficiency**, and **waste reduction** in different settings (MIT, BASF, NREL) showcasing the practical impact of adopting smart laboratories, allowing easy comparison across different implementations.

2.7. Future Trends

The future of smart laboratories in materials science is poised to be shaped by several emerging technologies and trends that will further enhance their capabilities and applications:

2.7.1. Advanced AI and Machine Learning Algorithms

As AI and machine learning technologies continue to evolve, their integration into smart laboratories will become more sophisticated. Advanced algorithms capable of deep learning and neural network architectures will enable more accurate predictions of material properties and behaviors. These advancements will facilitate the discovery of complex materials with multi-functional properties, driving innovation in areas such as metamaterials and nanomaterials (Kurni & KG, 2024; Srivastav, Das, & Srivastava, 2024).

2.7.2. Integration of Quantum Computing

Quantum computing holds the potential to revolutionize materials science by solving complex quantum mechanical problems that are intractable for classical computers. The integration of quantum computing with smart laboratory systems will enable the simulation and modeling of materials at the atomic and molecular levels with unprecedented accuracy. This capability will accelerate the discovery of materials with tailored electronic, optical, and mechanical properties (Boggs et al., 2023; Rodrigues, Florea, de Oliveira, Diamond, & Oliveira, 2021).

2.7.3. Enhanced Interconnectivity through 5G and Beyond:

The deployment of 5G and future wireless communication technologies will enhance the interconnectivity of devices and systems within smart laboratories. Higher data transfer speeds and lower latency will facilitate real-time data sharing and remote collaboration among researchers across the globe. This enhanced connectivity will support the development of decentralized smart laboratories, where distributed teams can seamlessly integrate their efforts and resources (Ahmad et al., 2024; Ibrahim, Hassan, Disina, & Pindar, 2021).

2.7.4. Sustainable and Green Smart Laboratories

There is a growing emphasis on sustainability within smart laboratories, driven by the need to reduce environmental impact and promote green chemistry practices. Future smart laboratories will incorporate energy-efficient systems, renewable energy sources, and sustainable materials in their infrastructure. Additionally, AI-driven optimization will be used to minimize waste and resource consumption, aligning materials development with environmental sustainability goals (Brown et al., 2024; Thurow & Junginger, 2022).

2.7.5. Personalized and Adaptive Laboratory Environments:

The concept of personalized and adaptive laboratory environments, tailored to the specific needs and preferences of researchers, is emerging as a significant trend. Smart laboratories will utilize AI to learn individual researcher workflows and adapt their systems, accordingly, providing customized interfaces, automated task scheduling, and personalized data analysis tools. This personalization will enhance user experience, increase productivity, and foster a more intuitive interaction between researchers and laboratory technologies (Gokcekuyu et al., 2024; Sha et al., 2020).

Figure 5: Timeline of technological advancements and future trends

Fig. 5 is a timeline that shows the evolution of smart laboratory technologies (e.g., AI, quantum computing, 5G) and forecasts future milestones, including the adoption of sustainable and green practices and showing the progression and future trajectory of smart laboratory developments.

3. Conclusion:

Smart laboratories represent a pivotal advancement in materials science, offering unprecedented capabilities that address the limitations of traditional laboratory settings. Through the integration of AI, automation, IoT, and data analytics, smart laboratories enhance the efficiency, precision, and innovation potential of materials design and development processes. The case studies presented demonstrate the tangible benefits of adopting smart laboratory technologies, including accelerated discovery, reduced costs, and improved scalability.

Looking forward, emerging technologies such as quantum computing, advanced machine learning algorithms, and enhanced interconnectivity will further propel the evolution of smart laboratories, enabling the creation of novel materials with complex and tailored properties. Additionally, the emphasis on sustainability and personalized laboratory environments will ensure that smart laboratories contribute to environmentally responsible and researcher-centric practices.

In summary, smart laboratories are not merely an incremental improvement but a fundamental shift that promises to revolutionize materials science. They empower researchers and industries to overcome existing challenges, drive rapid innovation, and address global needs through the development of advanced materials with transformative applications.

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Self-Automated Billing Smart Trolley to Reduce Queue at the Cashier Counter in Oman

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Abstract

A smart cart is an advanced, innovative shopping cart with great potential to enhance the shopping experience. Many of these trolleys are equipped with radio frequency identification (RFID), Internet of Things (IoT) technology, or other sensors that allow for seamless checkout processes, real-time inventory updates and automatic target scanning. In addition, these smart carts also allow interaction with mobile RX applications, personalized products recommendations, help navigate the store, and facilitate easy payments are the possible features. The emphasis of development that brings smart trolleys is to improve efficiency while making the finest shopping experience for clients in malls. Traditional smart trolleys, also known as traditional shopping carts, have been a critical component of shopping business centers for a long time. But there are downsides also like manual operations, limited access info, lengthy checkout, etc. It will also be integrated with sensors to provide contextualize with innovative shopping experiences. So, what exactly is a smart trolley well its regular trolley which is built along with technological features like sensors and connectivity – they have several advantages like automatic billing system, time-consuming checkout process without a long delay etc. Smart trolley that it is proposed to combine several technologies to improve user interaction, tracking and monitoring. The difference being it works on load cell measurement, RFID tagging and Laser barcode scanning to know the current weight, how many items there are, what items are there on the shelf in real time for efficient inventory management. The interfacing of buzzer and smart screen enhances human interaction and gives valuable feedback, ESP module and GSM connection options with 20 20 5000 enables data transmission and remote observation. Usage of the Thing speak indicates a cloud-based solution for the data handling and storage. The exceed paper uses Compression load cell to weigh the material, laser barcode scanner to read the barcode that stick on the item, up counter and down counter are utilized to keep track of how many item is put in trolley or removed from trolley, RFID reader is used as a substitute of ATM cards, smart screen is used to show the items, GSM is used to notify cashier about the payment and also send information to customer about item expiry date. All the components will be interfaced with Arduino for processing and complete the task.

Keywords: *Smart Radio Frequency Identification (RFID), Internet of Things (IoT), GSM, ATM cards*

الخلاصة

العربة الذكية هي عربة تسوق متقدمة ومبتكرة مع إمكانات كبيرة لتعزيز تجربة التسوق. تم تجهيز العديد من هذه العربات بتحديد تردد الراديو أو أجهزة استشعار أخرى (IoT) أو تقنية إنترنت الأشياء (RFID) تسمح بعمليات الخروج السلس وتحديثات المخزون في الوقت الفعلي والمسح التلقائي للأهداف. بالإضافة إلى ذلك، تسمح هذه العربات الذكية المحمولة، وتوصيات المنتجات RX أيضًا بالتفاعل مع تطبيقات المخصصة، والمساعدة في التنقل في المتجر، وتسهيل المدفوعات السهلة هي الميزات الممكنة. ينصب تركيز التطوير الذي يجلب العربات الذكية على تحسين الكفاءة مع تحقيق أفضل تجربة تسوق للعملاء في مراكز التسوق. كانت العربات الذكية التقليدية، المعروفة أيضًا باسم عربات التسوق التقليدية، مكونًا مهمًا لمراكز أعمال التسوق لفترة طويلة. ولكن هناك أيضًا جوانب سلبية مثل العمليات اليدوية، ومعلومات الوصول المحدودة، والدخول المطول، وما إلى ذلك. سيتم دمجه أيضًا مع أجهزة الاستشعار لتزويد السياق بتجارب التسوق المبتكرة. لذا، ما هي العربة الذكية بالضبط عربتها العادية المصممة جنبًا إلى جنب مع الميزات التكنولوجية مثل أجهزة الاستشعار والاتصال - فهي تتمتع بالعديد من المزايا مثل نظام الفوترة التلقائي، وعملية الخروج التي تستغرق وقتًا طويلاً دون تأخير طويل وما إلى ذلك. عربة ذكية أنه من المقترح الجمع بين العديد من التقنيات لتحسين تفاعل المستخدم والتتبع والمراقبة. الفرق ومسح RFID هو أنه يعمل على قياس خلية التحميل، ووضع علامات الرمز الشريطي بالليزر لمعرفة الوزن الحالي، وعدد العناصر الموجودة، والعناصر الموجودة على الرف في الوقت الفعلي لإدارة المخزون بكفاءة. تعزز واجهة الجرس والشاشة الذكية التفاعل البشري وتعطي ملاحظات مع 20 20 5000 تتيح نقل GSM وخيارات اتصال ESP قيمة ووحدة البيانات والمراقبة عن بعد. يشير استخدام حديث الشيء إلى حل قائم على السحابة

لمناولة البيانات وتخزينها. تستخدم ورقة التجاوز خلية تحميل الضغط لوزن المادة، الماسح الضوئي للرمز الشريطي بالليزر لقراءة الرمز الشريطي الذي يلتصق بالعنصر، يتم استخدام العداد العلوي والأسفل لتتبع عدد العناصر التي يتم وضعها في عربة أو إزالتها من العربة، يستخدم كبديل لبطاقات الصراف الآلي، يتم استخدام الشاشة الذكية RFID قارئ لإخطار أمين الصندوق بالدفع GSM لإظهار العناصر، ويتم استخدام وكذلك إرسال معلومات إلى العميل حول تاريخ انتهاء صلاحية العنصر. لمعالجة المهمة وإكمالها Arduino سيتم ربط جميع المكونات مع

الكلمات الرئيسية:
إنترنت الأشياء(RFID) الكلمات الرئيسية: تحديد ترددات الراديو الذكية (IoT) ،GSM، بطاقات الصراف الآلي ،

1. Introduction

Speech recognition apps allow people to talk into their phones and it spins out perfectly typed text in seconds or can transfer it and reply to messages with simple voice commands. This paper gives the idea of an embedded system of a self-automated smart trolley which is targeted for the consumers in these areas of Oman. The advantages of this idea are clear, with the potential to significantly lower customer wait times and waste a lot less of each shopper’s precious time. Smart Menu, Scan All Items, and simplify each customer pay process.

It was a supermarket offspring that was able to win so many people over to the routine of spending the whole day there. A supermarket also referred as the grocery store is the retailer which sells food items and many more other products. Supermarkets are places where people typically buy food, but as of late you can purchase sale products in (or a large amount of) a grocery store, from shampoo to toys to best-selling novels (Vocabulary, n.d.). The vast majority of time of wasted during the purchasing process, waiting in line at the cash registers. All the while, it takes more time to scan each item for all the customers who are there at the same time, increasing congestion in the store. My family spends 15 minutes waiting in a queue most of the time, sometimes waiting in a cashier ends up being more than spent for shopping. In the modernistic world which has faced the beauty of technology, it’s the time to concentrate on this issue. Americans wait in line at stores for a staggering 113 hours in a year or 14 working days (Goldman, S. N. (2021)). At the heart of all this, the Smart Shopping Cart where we have a well-thought-out design that can respond to rapidly changing needs of both the consumers and the retailers. Smart carts consist of shopping carts that have tablet computers or other similar electronic devices attached to assist consumers with managing their shopping lists, making payments, and finding things to buy in the supermarket (Black, D et al., 2020).

This paper suggests a smart cart that packs a lot of functions which can greatly enhance the complete shopping experience. This means, for example, that a barcode reader is integrated to allow each item that is added to the cart to be scanned, thus removing cashier checkout processes. Other than that, product name will display on GLCD screen instantly when added (Ng, Y. L. 2014). “The smart cart is integrated with a smart screen for a smoother shopping experience” (Gunawan, A et al., 2017) It shows all the features of products starting from the type of items added to their prices and expiration (Jackermeier, R., 2018). Furthermore, the smart screen has a smart menu that constantly records every item that is available in the market their assigned rack number and the section ensuring a smooth and convenient shopping experience (Solin, A., et al., 2018). In terms of installment choices, the eager cart benevolently offers purchasers the decision to choose between ordinary cash exchanges at the checkout counter or the accommodation of secure card installments specifically through the cart's directions framework (Siegwart, R., et al., 2011). In addition, by facilitating these modes of payment, the paper also reinforces its dedication to timesaving and convenience in consumers' life on a day-to-day basis (Ji, M., et al., 2015) To sum up, it is clear that this the paper has a huge potential to transform the way we shop. Utilizing state-of-the-art technology, this intelligent shopping cart significantly decreases congestion, and the duration of time spent at the cashier desk while maximizing an incredible consumer shopping experience.

Self-Automated smart trolley is used in daily basis at the time of supermarkets and shopping center (Gigl, T., et al 2007). It provides the consumer with a quick and good shopping experience without spending too much time standing in queues. It also has a smart menu concerning the product's locations that makes shopping flow better (Gigl, T., et al 2019) In addition, it saves time for the owner of putting the offers into the smart menu rather than sticking on the offers next to every product inside of the stores.

Although self-automated billing smart trolleys seem to be a viable solution for reducing long queues at cashier counters in Oman, there are so many disadvantages and challenges that need to be addressed:

i. Software bugs present within a system that has been designed can crash the entire thing and therefore must stick to good old-fashioned methodology.
ii. The smart trolleys should undergo periodic testing to prevent any discrepancies from occurring.
iii. As such, with the compliance of the smart trolleys largely relying on technology, any technical faults or glitches such as connectivity problems, tech outages or flaws in the software could cause the self-automated billing process to be knocked out.

An extensive literature has been reviewed to extract the basic knowledge required to do design and analysis of such system. Next Section II summarize the literature in this context, Section III provides the design and analysis, Section IV discusses the implementation results while Section V concludes the discussion.

2. Literature Review

We briefly discuss the literature covering the negative impacts of long queues within Omani cashier counters. Explain why addressing these issues is critical for enhancing customer satisfaction and improving operational efficiency. Identify key technologies—in self-automated billing smart trolleys—like computer vision, RFID, and Internet of Things. Type of review: Table below shows how reviewed papers fall into which category.

(Das, T. K., 2020) The smart trolley aims to improve inventory management, speed up checkouts, and provide a more productive and costlier way for consumers to visit the store. Smart trolleys, often equipped with a variety of technologies Like any technology, intelligent baths are not without limitations. An example limitation Dependence on Power Research

renewable energy sources or innovative power solutions that lessen reliance on traditional batteries.
(Rahul, R., et al 2023) Conference paper discussed a technical solution that utilizes RFID technology to develop 'Automated Smart Trolley System'. Shopping Cart Automation using RFID technology RFID tags that identify and track products added to the cart are likely used to help make the shopping experience more efficient. Drawbacks: * While the RFID-based Automated Smart Trolley System has many advantages, there may also be some disadvantages. There could be potential disadvantages of the system, one being power reliant. Explore renewable energy or next-gen power options that lessen dependancy on legacy batteries.
(Gunawan, A. A. S., 2021) The proposed work includes the development of Line Follower Smart Trolley with an enhanced version (V2) of Radio-Frequency Identification (RFID) technology. The scope of the paper must be reviewing the operational, design, and potential applications of the smart trolley upgraded system. One of the general limitations that could be applicable for RFID Technology is RFID Range Constraints. Right antenna, high frequency rfid tags tag orientation increases the range.
(Rajkanna, U., et al 2021) That's a little misleading, and I think a hint from the name itself is that "Trolley" emphasizes judging whether a state-of-the-art trolley system will work at a supermarket. A smart trolley system is a technology system used to enhance the shopping experience or speed up processes using RFID tags, sensors or other Internet of Thing's devices. Technology and infrastructure constraints are some of the limitations Artificial Intelligence and Machine Learning can be used to improve compatibility.
(Jaishree, M., et al 2021) The System using IoT in shopping trolleys to make shopping easier. The internet connections and real-time data sharing capabilities are among the foremost characteristics of a smart shopping cart. These include power consumption and reliability. Renewable energy sources are potential solutions for power problems.
Next section provides the design and analysis of an embedded system that uses drone to reach to the target plant.

3. System Design

To ensure Logistics, technology, and design-based usage modeling for a self-automated billing smart trolley are needed to reduce the line on the cashier counter. A brief description of how this type of system and safety was designed and analyzed follows. The design section involves hardware, automatic billing system, item identification, wireless communication, user interaction. Design of Software involves simulation, development of programming and making a complete prototype. Figure 1. shows the block diagram of the proposed system.

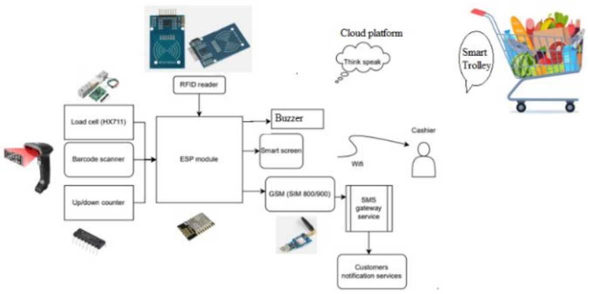


Figure 1: System Block Diagram

To make self-automated billing smart trolley system flowchart to reduce queue at cashier counter in Oman, we need to divide the process in steps. The proposed flowchart is shown in Figure 2. A detailed step-by-step process is mentioned below,
a. The shopping starts with the customer.
b. Select the smart trolley.
c. Set the smart screen as per your budget so if above budget, the buzzer will activate.
d. Walk around and choose the product!
e. Product weight checking by load cell.
f. The price shows on the screen upon scanning the product.
g. Repeat until the required number of items have been picked.
h. Pay by card or cash.
i. Scan the receipt to exit.
j. The data of customer and his/her purchase is pushed to think speak.
k. In case of product expiration the data is transmitted to manager/customer through GSM.

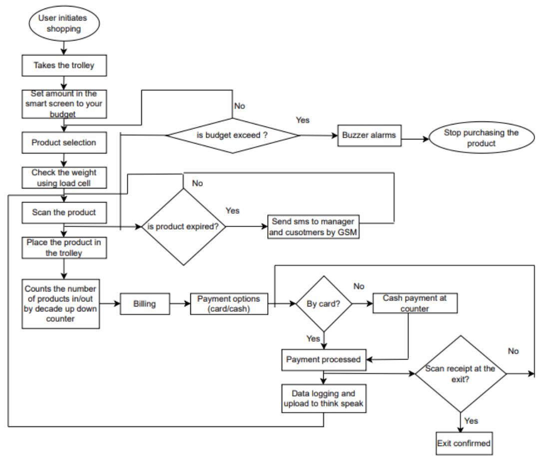


Figure 2: System Flow Charts

Following are the parameters that have been included in a summarized way from the data sheet (HowStuffWorks - Learn How Everything Works! n.d.):

- ESP-12E: The main parameters for the ESP-12E are ii. ESP 8266 Wifi chip and ESP8266 microcontroller ii. 32-bit processor iii. Clock speed of 80MHz iv. Integrated Flash memory of 4MB /8MB v. IEEE 802.11 b/g support vi. ESP-12E module has a number of GPIO pins. vii. Built in ADC viii. Operating voltage of 3.3 V

- GSM: Here are the principal values. jjjjj. 900MHz and 1800MHz frequency operate. ii. Gaussian Minimum Shift Keying is Used iii. Data transfer rate of 9.6kbps iv. Uses TDMA for channel access.
- Up/Down counter: It is a digital circuit IC configured with up and down counts. Following are the parameters: i. Available in different family TTL, CMOS ii. Accepts 4-bit, 8-bit, 16-bit. iii. The count range is 2^n.
- Barcode scanner: These devices capture the data and decode it from the barcode format. ii. Fixed mount scanner avec Barcode symbiology QR code in this project. ii. The scanning technology used is laser. iii. The number of scans measured per second or per minute. iv. Resolution is expressed in dots per inch. v. Used wifi connectivity.
- For smart screen: The smart screen parameter are as follows. i. Uses LCD technology. ii. The screen size is in inches. iii. It uses embedded processor and android based used operating system. iv. Uses Wifi connectivity. v. Built in storage. vi. Random Access Memory vii. Aspect ratios can be 16:9 and 4:3 ratios.
- RFID card reader: Key parameters of RFID card reader are as follows − i. Works within various frequency bands. ii. The read range is affected by several factors. iii. Compatible with multiple RFID standards. iv. RS-232, USB interface is communication v. The power supply is 5V.
- Load cell sensor: i. Maximum load in kg ii. Deriving the nominal volt in millivolts per volt. iii. Sensitivity is given in terms of mV/V. iv. This accuracy is presented as a percentage of the full-scale output. v. Analog voltage, analog current, or digital outputs are common output types.

4. System Implementation and Testing

Process steps of smart trolley working:
Step 1, Connect the system to power bank:

Figure 3. System to power bank connection

Step 2, LCD shows welcome message:

Figure 4. Welcome message

Step 3, System starts to search for available Wi-Fi network:

Figure 5. Wifi connection

Step 4, Select the wanted budget starting from 5 OMR and adjusting the budget with the two white push buttons:

Figure 6. Budget selection

Figure 7. Budget selection

Step 5, Press the blue push button to save the budget:

Figure 6. Save option

Step 6, 'Scan Your Items' message will appear to scan the items with barcode reader:

Figure 7. Scan items

Step 7, Scanned items' name and price will show on LCD:

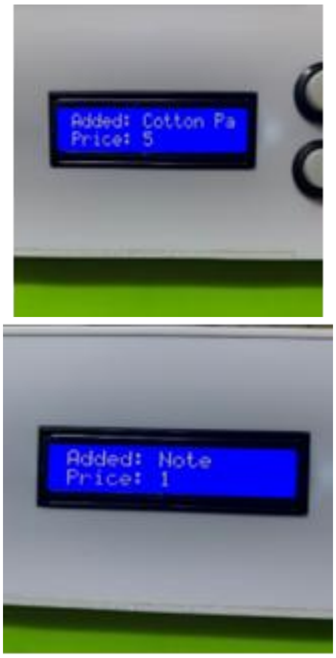


Figure 8. Scanned items

Step 8, 'Scan Your Items' message will appear again with the total:

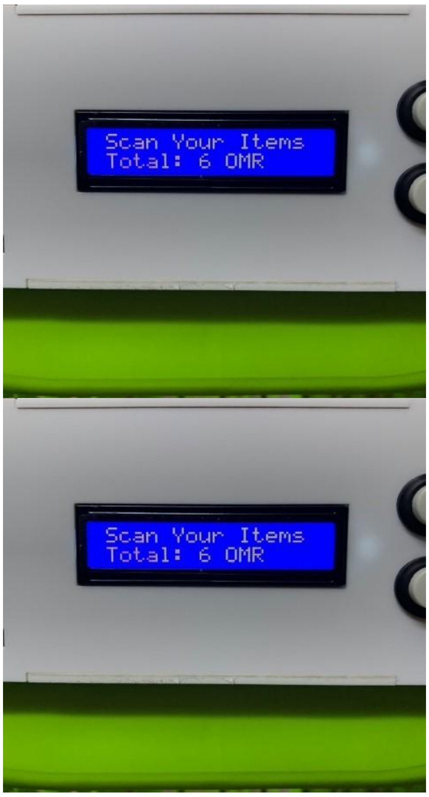


Figure 9. Scanned items

Step 9, If the customer goes over budget, the LCD will show the following and the buzzer becomes ON:

Figure 10. LCD display

Step 10, To remove any unwanted item, the same item should be rescanned while pressing the blue push button

Figure 11. Removing unwanted items

Step 11, Black push button is used to change between the two payment methods, Cash or Visa:

Figure 12. Payment display

Step 12, Cash payment represents by blue RFID tag and Visa payment with white RFID card:

Figure 13. RFID Tag

Step 13, Once the RFID tags are scanned as payment, the LCD will show 'Payment Done Successfully' message:

Figure 14. Payment Done Successfully

Step 14, GSM module sends the bill to the customer number with product expiration dates:

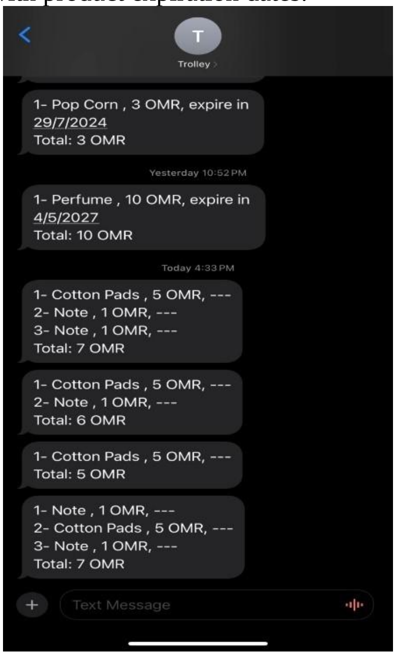
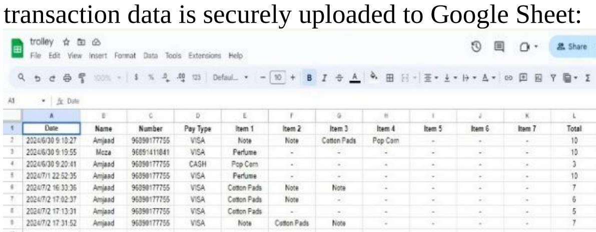


Figure 14. Bill send to the customer

Step 15, Upon completing payment and bill issuance, all transaction data is securely uploaded to Google Sheet:



Date	Name	Number	Pay Type	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Total
2024/6/30 9:18:27	Amjaad	96890177755	VISA	Note	Note	Cotton Pads	Pop Corn	-	-	-	10
2024/6/30 9:19:55	Mcza	96891411841	VISA	Perfume	-	-	-	-	-	-	10
2024/6/30 9:20:41	Amjaad	96890177755	CASH	Pop Corn	-	-	-	-	-	-	3
2024/7/1 22:52:35	Amjaad	96890177755	VISA	Perfume	-	-	-	-	-	-	10
2024/7/2 16:33:36	Amjaad	96890177755	VISA	Cotton Pads	Note	Note	-	-	-	-	7
2024/7/2 17:02:37	Amjaad	96890177755	VISA	Cotton Pads	Note	-	-	-	-	-	6
2024/7/2 17:13:31	Amjaad	96890177755	VISA	Cotton Pads	-	-	-	-	-	-	5
2024/7/2 17:31:52	Amjaad	96890177755	VISA	Note	Cotton Pads	Note	-	-	-	-	7

Figure 15. Google Sheet

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