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Track 1 - Information and Communication Technology

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Understanding the Magnetic Behavior of Three Spin Layer Ferromagnetic Thin Films Using the Fourth-Order Perturbed Heisenberg Hamiltonian

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Abstract

This study presents, for the first time, a detailed investigation of the magnetic properties of ferromagnetic thin films with three spin layers using the fourth-order perturbed Heisenberg Hamiltonian. The objective was to explore the influence of all seven magnetic energy parameters such as spin exchange interaction, second- and fourth-order magnetic anisotropy constants, in-plane and out-of-plane applied magnetic fields, demagnetization energy, and the stress-induced anisotropy constant on the magnetic behaviour of thin films with a simple cubic structure. The primary goal was to understand how these parameters affect the total magnetic energy and the arrangement of easy and hard magnetic directions in thin films. The fourth-order perturbed Heisenberg Hamiltonian was employed to formulate the total magnetic energy for ferromagnetic thin films, with variations in the fourth-order magnetic anisotropy constants while keeping other parameters constant. Three-dimensional graphs were generated to illustrate the total magnetic energy as a function of angle and spin exchange interaction, highlighting the differences in magnetic behaviour across the simple cubic structure and spin layers. Our findings indicate that peaks in the total magnetic energy graphs derived from the fourth-order perturbed Heisenberg Hamiltonian are more closely packed compared to those from the second and third-order perturbed Hamiltonians. According to the 3D plots, the total magnetic energy is in the range of 10^{13} to 10^{18}. The minimum magnetic energy was observed when the fourth-order anisotropy constant in the middle spin layer is less than those in the bottom and top spin layers. In this scenario, the total magnetic energy is significantly lower than that obtained from the fourth-order perturbed Heisenberg Hamiltonian with two spin layers in the same structured ferromagnetic thin films, as illustrated in the energy versus angle and spin exchange interaction graphs. These findings could guide future research and applications in magnetic thin film technologies.

Keywords: Fourth order perturbed Heisenberg Hamiltonian, Magnetic anisotropy constant, Magnetic thin films, Spin exchange interaction, Spin layers.

Introduction:

Ferromagnetic films are crucial for magnetic memory and microwave devices, with easy and hard magnetization directions significantly impacting their performance. Various models have been used to study these films, including Monte Carlo simulations for quasistatic magnetic hysteresis (Zhao et al., 2002), the Ising model for alternating superlayer films (Bentaleb et al., 2002), and first-principles band structure theory for FeCo alloys (Spišák and Hafner, 2005). The Korringa-Kohn Rostoker method has also been applied to nickel on copper layers (Ernst et al., 2000).

Magnetic moments often differ from theoretical predictions due to overlapping sub shells. During annealing, stress-induced magnetic anisotropy (Ks) arises from thermal expansion differences between the film and substrate, significantly affecting coercivity, especially in soft magnetic materials (Samarasekara and Cadieu, 2001). Our study investigates the magnetic properties of ferromagnetic and ferrite thin and thick films (Samarasekara and Ekanayake, 2020; Samarasekara and Mendoza, 2010; Samarasekara, 2006).

We analyzed the total energy of ferromagnetic thin films using the classical Heisenberg Hamiltonian, accounting for all energy components, including magnetic energy, spin dipole interaction, spin exchange interaction, second and fourth order magnetic anisotropies, and demagnetization factors. The fourth-order perturbed Heisenberg Hamiltonian was presented with seven magnetic energy parameters for simple cubic (SC) structures with three spin layers. MATLAB is employed to generate 3D and 2D graphs illustrating the relationships between energy, spin exchange interaction, and the azimuthal angle of spin.

Model:

The Heisenberg Hamiltonian of ferromagnetic films can be formulated as follows (Samarasekara and Ekanayake, 2020; Samarasekara and Mendoza, 2010; Samarasekara, 2006):

$$H = -\frac{J}{2}\sum_{m,n}\vec{S}_m.\vec{S}_n + \frac{\omega}{2}\sum_{m\neq n}\left(\frac{\vec{S}_m.\vec{S}_n}{r_{mn}^3} - \frac{3(\vec{S}_m.\vec{r}_{mn})(\vec{r}_{mn}.\vec{S}_n)}{r_{mn}^5}\right) - \sum_m D_{\lambda_m}^{(2)}(S_m^z)^2$$
$$-\sum_m D_{\lambda_m}^{(4)}(S_m^z)^4 - \sum_{m,n}\left[\vec{H} - (N_d\vec{S}_n/\mu_0)\right].\vec{S}_m - \sum_m K_s \sin 2\theta_m \quad (1)$$

Here $\vec{S}_m$ and $\vec{S}_n$ are two spins. Above equation can be simplified into the following form:

$$E(\theta) = -\frac{1}{2}\sum_{m,n=1}^{N}\left[\left(JZ_{|m-n|} - \frac{\omega}{4}\Phi_{|m-n|}\right)\cos(\theta_m - \theta_n) - \frac{3\omega}{4}\Phi_{|m-n|}\cos(\theta_m + \theta_n)\right]$$
$$-\sum_{m=1}^{N}(D_m^{(2)}cos^2\theta_m + D_m^{(4)}cos^4\theta_m + H_{in}sin\theta_m + H_{out}cos\theta_m)$$
$$+\sum_{m,n=1}^{N}\frac{N_d}{\mu_0}cos(\theta_m - \theta_n) - K_s\sum_{m=1}^{N}sin2\theta_m \quad (2)$$

Here N, m $(or\ n)$, J, $Z_{|m-n|}$, ω, $\Phi_{|m-n|}$, $\theta_m(\theta_n)$, $D_m^{(2)}$, $D_m^{(4)}$, H_{in}, H_{out}, N_d and K_s are total number of layers, layer index, spin exchange interaction, number of nearest spin neighbors, strength of long range dipole interaction, partial summations of dipole interaction, azimuthal angles of spins, second and fourth order anisotropy constants, in plane and out of plane applied magnetic fields, demagnetization factor and stress induced anisotropy constants, respectively.

The spin structure is considered to be slightly disoriented. Therefore, the spins could be considered to have angles distributed about an average angle θ. By choosing azimuthal angles as

$\theta_m = \theta + \varepsilon_m$ and $\theta_n = \theta + \varepsilon_n$

where the ε's are small positive or negative angular deviations.

Then, $\theta_m - \theta_n = \varepsilon_m - \varepsilon_n$ and $\theta_m + \theta_n = 2\theta + \varepsilon_m + \varepsilon_n$. After substituting these new angles in the above equation (1), the cosine and sine terms can be expanded to the fourth order of ε_m and ε_n as follows:

$$E(\theta) = E_0 + E(\varepsilon) + E(\varepsilon^2) + E(\varepsilon^3) + E(\varepsilon^4) + \ldots\ldots\ldots$$

If the fifth and higher order perturbations are neglected, then

$$E(\theta) = E_0 + E(\varepsilon) + E(\varepsilon^2) + E(\varepsilon^3) + E(\varepsilon^4) \tag{3}$$

Here

$$E_0 = -\frac{1}{2}\sum_{m,n=1}^{N}\left(JZ_{|m-n|} - \frac{\omega}{4}\Phi_{|m-n|}\right) + \frac{3\omega}{8}cos2\theta\sum_{m,n=1}^{N}\Phi_{|m-n|} - cos^2\theta\sum_{m=1}^{N}D_m^{(2)}$$
$$-cos^4\theta\sum_{m=1}^{N}D_m^{(4)} - N(H_{in}sin\theta + H_{out}cos\theta + K_s sin2\theta) + \frac{N_d N^2}{\mu_0} \tag{4}$$

$$E(\varepsilon) = -\frac{3\omega}{8}sin2\theta\sum_{m,n=1}^{N}\Phi_{|m-n|}(\varepsilon_m + \varepsilon_n) + sin2\theta\sum_{m=1}^{N}D_m^{(2)}\varepsilon_m + 2cos^2\theta sin2\theta\sum_{m=1}^{N}D_m^{(4)}\varepsilon_m$$
$$-H_{in}cos\theta\sum_{m=1}^{N}\varepsilon_m + H_{out}sin\theta\sum_{m=1}^{N}\varepsilon_m - 2K_s cos2\theta\sum_{m=1}^{N}\varepsilon_m \tag{5}$$

$$E(\varepsilon^2) = \frac{1}{4}\sum_{m,n=1}^{N}\left(JZ_{|m-n|} - \frac{\omega}{4}\Phi_{|m-n|}\right)(\varepsilon_m - \varepsilon_n)^2 - \frac{3\omega}{16}cos2\theta\sum_{m,n=1}^{N}\Phi_{|m-n|}(\varepsilon_m + \varepsilon_n)^2$$
$$+cos2\theta\sum_{m=1}^{N}D_m^{(2)}\varepsilon_m^2 + 2cos^2\theta(cos^2\theta - 3sin^2\theta)\sum_{m=1}^{N}D_m^{(4)}\varepsilon_m^2 + \frac{H_{in}}{2}sin\theta\sum_{m=1}^{N}\varepsilon_m^2$$
$$+\frac{H_{out}}{2}cos\theta\sum_{m=1}^{N}\varepsilon_m^2 - \frac{N_d}{2\mu_0}\sum_{m,n=1}^{N}(\varepsilon_m - \varepsilon_n)^2 + 2K_s sin2\theta\sum_{m=1}^{N}\varepsilon_m^2 \tag{6}$$

$$E(\varepsilon^3) = \frac{\omega}{16}sin2\theta\sum_{m,n=1}^{N}\Phi_{|m-n|}(\varepsilon_m + \varepsilon_n)^3 - \frac{4}{3}sin\theta cos\theta\sum_{m=1}^{N}D_m^{(2)}\varepsilon_m^3$$
$$-4sin\theta cos\theta\left(\frac{5}{3}cos^2\theta - sin^2\theta\right)\sum_{m=1}^{N}D_m^{(4)}\varepsilon_m^3 + \frac{H_{in}}{6}cos\theta\sum_{m=1}^{N}\varepsilon_m^3 - \frac{H_{out}}{6}sin\theta\sum_{m=1}^{N}\varepsilon_m^3$$
$$+\frac{4}{3}K_s cos2\theta\sum_{m=1}^{N}\varepsilon_m^3 \tag{7}$$

$$E(\varepsilon^4) = -\frac{1}{48}\sum_{m,n=1}^{N}\left(JZ_{|m-n|} - \frac{\omega}{4}\Phi_{|m-n|}\right)(\varepsilon_m - \varepsilon_n)^4 + \frac{\omega}{64}cos2\theta\sum_{m,n=1}^{N}\Phi_{|m-n|}(\varepsilon_m + \varepsilon_n)^4$$
$$-\frac{1}{3}cos2\theta\sum_{m=1}^{N}D_m^{(2)}\varepsilon_m^4 - (\frac{5}{3}cos^4\theta - 8cos^2\theta sin^2\theta + sin^4\theta)\sum_{m=1}^{N}D_m^{(4)}\varepsilon_m^4$$
$$-\frac{H_{in}}{24}sin\theta\sum_{m=1}^{N}\varepsilon_m^4 - \frac{H_{out}}{24}cos\theta\sum_{m=1}^{N}\varepsilon_m^4 + \frac{N_d}{24\mu_0}\sum_{m,n=1}^{N}(\varepsilon_m - \varepsilon_n)^4$$

$$-\frac{2}{3}K_s sin2\theta \sum_{m=1}^{N} \varepsilon_m^4 \quad (8)$$

Results and Discussion:

The results presented in this manuscript focus on ferromagnetic films with a simple cubic lattice and three spin layers. For films with a simple cubic (sc) (001) structure, the parameters used are Z_0=4, Z_1=1, Z_2=0, Φ_0 =9.0336 and $\Phi_1 = -0.3275$ (Hucht and Usadel, 1997, 1999).

Figure 1 illustrates a 3D plot of energy as a function of angle and spin exchange interaction for $\frac{D_1^{(4)}}{\omega} = 5$, $\frac{D_2^{(4)}}{\omega} = 10$ and $\frac{D_3^{(4)}}{\omega} = 10$. Here, other parameters are fixed at $\frac{Ks}{\omega} = \frac{H_{in}}{\omega} = \frac{H_{out}}{\omega} = \frac{N_d}{\mu_0 \omega} = \frac{D_1^{(2)}}{\omega} = \frac{D_2^{(2)}}{\omega} = 10$ for this simulation. The resulting energy values are in the order of 10^{18}. Notably, energy maxima occur at $\frac{J}{\omega} = 10, 33, 56$ and 81, with the most significant maximum observed at approximately $\frac{J}{\omega} = 33$. The minimum energy value recorded was zero.

Figure 2 presents another 3D plot, this time for $\frac{D_1^{(4)}}{\omega} = 10$, $\frac{D_2^{(4)}}{\omega} = 5$ and $\frac{D_3^{(4)}}{\omega} = 10$, with the same fixed parameters as before. In this graph, energy maxima can be observed at $\frac{J}{\omega} = 10, 33, 58$ and 81, with the major maximum occurring at around $\frac{J}{\omega} = 81$. The total energy was in the order of 10^{13}.

Figure 3 shows the 3D plot for $\frac{D_1^{(4)}}{\omega} = 10$, $\frac{D_2^{(4)}}{\omega} = 10$ and $\frac{D_3^{(4)}}{\omega} = 5$, again with all other parameters fixed as previously stated. Here, the energy maxima are found at $\frac{J}{\omega} = 12, 37, 60$ and 83, with a major maximum around $\frac{J}{\omega} = 60$. The total energy for this configuration is in the order of 10^{17}.

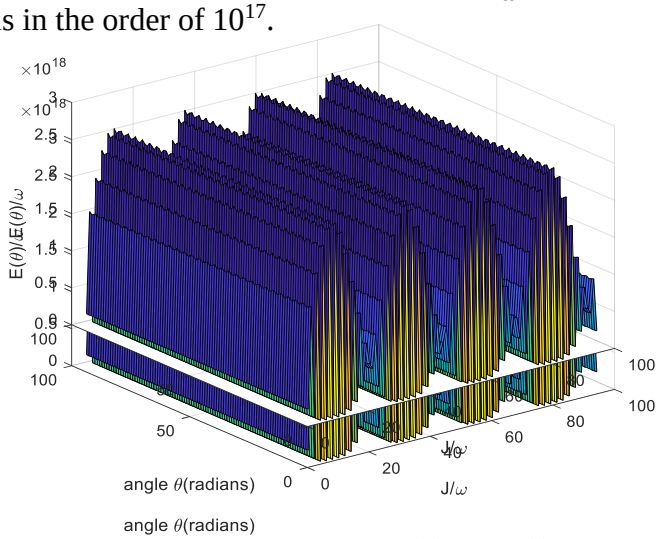

Figure 1. 3-D plot of $\frac{E(\theta)}{\omega}$ versus $\frac{J}{\omega}$ and angle for $\frac{D_1^{(4)}}{\omega} = 5$, $\frac{D_2^{(4)}}{\omega} = 10$ and $\frac{D_3^{(4)}}{\omega} = 10$

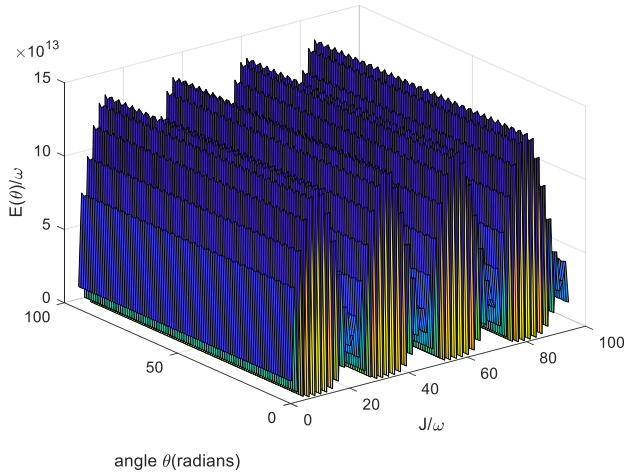

Figure 2. 3-D plot of $\frac{E(\theta)}{\omega}$ versus $\frac{J}{\omega}$ and angle for $\frac{D_1^{(4)}}{\omega} = 10$, $\frac{D_2^{(4)}}{\omega} = 5$ and $\frac{D_3^{(4)}}{\omega} = 10$

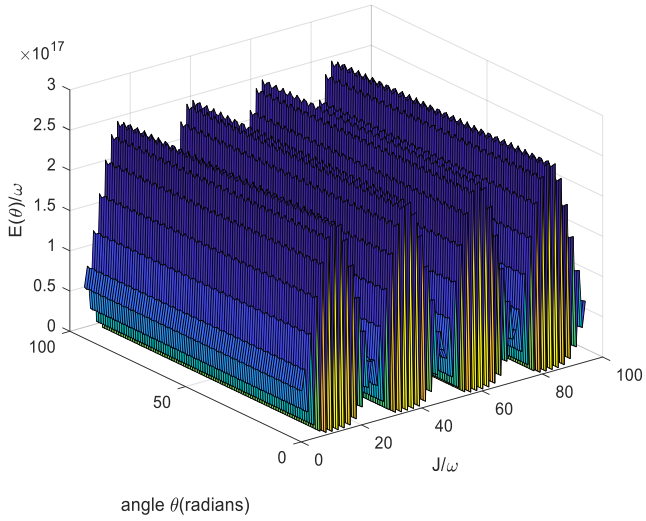

Figure 3. 3-D plot of $\frac{E(\theta)}{\omega}$ versus $\frac{J}{\omega}$ and angle for $\frac{D_1^{(4)}}{\omega} = 10$, $\frac{D_2^{(4)}}{\omega} = 10$ and $\frac{D_3^{(4)}}{\omega} = 5$

Conclusions:

All the graphs between total magnetic energy versus angle and spin exchange interaction were plotted using the fourth order perturbed Heisenberg Hamiltonian with all seven magnetic parameters for SC structure with three spin layers. According to 3D plots given in figures 1, 2 and 3, the order of the total magnetic energy is in the range from 10^{13} to 10^{18}. The minimum order of magnetic energy was observed, when the fourth order anisotropy constant in the middle spin layer is less than those of the bottom and top spin layers. The maximum order of magnetic energy was found, when the fourth order anisotropy constant in the bottom spin layer is less than those of the middle and top spin layers. The order of the total magnetic energy in this case is very significantly lower than the total magnetic energy obtained using the fourth order perturbed Heisenberg Hamiltonian with two spin layers in the same structured ferromagnetic thin films, based on the graph plotting energy versus angle and spin exchange interaction.

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Artificial Intelligence in Outer Space Activities and Exploration: Examining Legal Responsibilities, Policy Considerations and Future Pathways

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Abstract

The rapid progression of artificial intelligence (AI) in space exploration has engendered a multifaceted relationship between technological advancements and legal systems, undermining conventional space law paradigms formed prior to the AI epoch. This paper examines the evolving legal landscape surrounding AI deployment in outer space activities, focusing on the critical aspects of responsibility attribution, liability frameworks, and regulatory governance. The research problem addresses the significant legal vacuum in current space law regarding AI autonomy, particularly concerning decision-making authority, accident liability, and international responsibility for AI-driven space operations. This paper investigates critical research questions: How can legal frameworks effectively address responsibility and liability issues arising from autonomous AI decisions in space operations? What regulatory mechanisms and policy structures are necessary to govern AI applications in space activities while ensuring compliance with international space law principles and how should international space law evolve to accommodate AI-driven technological advancements while maintaining safety and security standards? The research employs a comprehensive mixed-methods approach, combining doctrinal legal analysis of existing space law instruments and case studies of AI implementation in current space missions. Key findings reveal substantial gaps in current legal frameworks, particularly regarding AI liability attribution, cross-border responsibilities, and regulatory oversight mechanisms. The paper identifies emerging patterns in national space policies and highlights the need for harmonized international regulations specifically addressing AI in space activities. The paper concludes by proposing a new legal framework that balances technological innovation with safety considerations, recommending the establishment of an international protocol for AI governance in space activities that includes specific provisions for liability determination, risk assessment protocols, and standardized regulatory approaches, and emphasizing the importance of international cooperation in establishing a comprehensive AI governance framework for outer space activities.

Keywords: AI-Space Liability, Autonomous Space Systems, Extra-Terrestrial AI Governance, Space-AI Legal Framework, Space Operations Regulation

Introduction:

The incorporation of artificial intelligence into space exploration represents a pivotal juncture in humanity's extraterrestrial pursuits, fundamentally altering the approach to off-world activities. As autonomous systems increasingly govern critical space operations, ranging from satellite navigation to deep space exploration missions, the legal frameworks overseeing these activities confront unprecedented challenges. The existing

corpus of space law, primarily developed during the 1960s and 1970s, has become increasingly strained by technological advancements that its original architects could scarcely have envisioned. This paradigm shift necessitates a comprehensive examination of the legal and policy structures that govern the deployment of AI in space activities (Pagallo et al., 2023). Recognizing the profound impact of AI on space operations, this paper seeks to elucidate the multifaceted legal implications arising from the integration of these autonomous systems, with a particular emphasis on the unique challenges posed by the hazardous and unforgiving environment of outer space. The AI tools incorporate machine learning for classifications and predictions across extensive datasets. This automation streamlines processes like project reviews, enhancing decision-making efficiency and maximizing workforce potential across the agency (NASA, n.d.). Voyager Space and Palantir Technologies have formed a strategic partnership to advance space and defense technology through AI integration. Voyager will utilize Palantir's Foundry and AI Platform for payload management on the International Space Station and future Star lab operations. The collaboration aims to enhance defense capabilities, including optimization of flight data and optical communications systems (Voyager Space, 2024). AI's potential to revolutionize space activities requires urgent regulatory attention. While the technology promises to transform satellite operations, telecommunications, and space exploration, current legal frameworks remain inadequate. The UN Committee on Peaceful Use of Outer Space should develop comprehensive guidelines to ensure safe and responsible AI integration in space activities (Tricco & Leaua, 2024).

The central challenge is the substantial legal void surrounding the autonomy of AI in space operations. Current space law frameworks, grounded in the Outer Space Treaty of 1967, are based on the assumption of direct human control and state accountability. However, the emergence of autonomous AI systems capable of making independent decisions during space activities has created new scenarios that existing legal structures struggle to address. This includes issues with attributing liability when AI systems make autonomous choices, determining the extent of state responsibility for AI-driven space activities, and establishing the necessary regulatory mechanisms to ensure the safe and responsible deployment of AI in space. Recent incidents involving autonomous satellite maneuvering have underscored the urgency of addressing these legal gaps (Graham et al., 2024).

The literature reveals critical gaps between AI advancement in space operations and existing legal frameworks. Martin and Freeland (2020) first highlighted the emerging legal challenges posed by AI in space activities. Pagallo et al., (2023) examined the normative challenges of AI in outer space, emphasizing the need to realign terrestrial standards with space operations. Richards et al. (2023) focused on safely advancing space exploration using AI while addressing legal considerations. Trager et al. (2023) underscored the importance of comprehensive regulatory frameworks. Vajiram et al. (2023) explored broader legal implications for space travel and environmental considerations. Recent work by Graham et al. (2024) specifically addressed legal liability issues for AI in outer space, while Bengio et al. (2024) examined managing extreme AI risks in space operations. The literature consistently identifies three critical areas requiring attention: liability frameworks, international responsibility attribution, and regulatory oversight mechanisms for autonomous space operations.

This study addresses three primary research questions that form the cornerstone of our investigation: (i) How can legal frameworks effectively address responsibility and

liability issues arising from autonomous AI decisions in space operations? (ii) What regulatory mechanisms and policy structures are necessary to govern AI applications in space activities while ensuring compliance with international space law principles? (iii) How should international space law evolve to accommodate AI-driven technological advancements while maintaining safety and security standards? (Richards et al., 2023; Pagallo et al., 2023)

The primary objectives of this research are to conduct a comprehensive examination of the existing legal frameworks that govern the deployment of AI in space activities, and to propose innovative solutions that address the emerging challenges posed by the increasing integration of autonomous systems in space operations (Martin & Freeland, 2020). Specifically, this study aims to: evaluate the adequacy and relevance of current international space law instruments in addressing the unique considerations and complexities introduced by AI autonomy; identify critical gaps in liability and responsibility attribution mechanisms for AI-driven space activities, particularly in scenarios where autonomous decisions or malfunctions lead to unintended consequences; assess the existing regulatory approaches and policy structures adopted by major spacefaring nations in order to understand the divergent approaches to AI governance in the space domain; and develop recommendations for a harmonized, international legal framework that can effectively balance the benefits of technological innovation with the imperative to maintain robust safety and security standards, while ensuring the responsible and transparent governance of AI systems in space activities (Bengio et al., 2024; Trager et al., 2023).

Methodology:

This research employs a mixed-methods approach, combining doctrinal legal analysis with case studies of current AI implementations in space missions. The methodology includes a comprehensive examination of existing space law instruments and their relevance to AI systems, an exploration of national space policies regarding AI deployment, detailed case studies of AI integration in recent space missions, and a comparative analysis of regulatory approaches across major spacefaring nations. The study draws upon both theoretical frameworks and practical applications, incorporating data from recent space missions that have utilized AI technologies.

Results and Discussion:

The regulation of artificial intelligence (AI) is imperative to address the ethical challenges posed by its rapid integration across sectors such as healthcare, finance, and education. While AI offers significant opportunities for innovation and efficiency, concerns surrounding bias, accountability, and privacy necessitate robust governance mechanisms. The fragmented regulatory landscape across nations impedes the establishment of cohesive ethical standards, creating disparities in AI governance. Recent initiatives, such as UNESCO's Recommendation on the Ethics of Artificial Intelligence and the 2024 Framework Convention by the Council of Europe, emphasize principles of transparency, fairness, and accountability. These frameworks advocate risk-based approaches and inclusivity, promoting equitable AI benefits. Establishing a unified and adaptable regulatory framework is crucial to safeguarding human rights, ensuring ethical development, and fostering global cooperation in AI governance.

The principal international space treaties, including the Outer Space Treaty (1967), the Liability Convention (1972), and the Registration Convention (1976), establish foundational principles for space activities but do not explicitly address the complexities introduced by artificial intelligence (AI) in this domain. The Outer Space Treaty mandates that states bear international responsibility for national space activities, whether conducted by governmental or non-governmental entities, and requires that such activities conform to the treaty's provisions. This framework implies that states could be held accountable for AI-driven operations in space, even though the treaty does not specifically mention AI. Similarly, the Liability Convention holds launching states liable for damages caused by their space objects, a principle that could extend to incidents involving AI systems, despite the absence of explicit references to autonomous technologies. The Registration Convention requires states to furnish details about space objects launched into orbit, yet it does not provide guidance on how AI-operated systems should be cataloged. The lack of specific provisions for AI within these treaties underscores the necessity for updated legal instruments or supplementary guidelines to effectively govern the deployment and operation of AI in outer space activities. Our findings reveal significant gaps and inadequacies in the current legal frameworks governing the deployment and integration of artificial intelligence systems in space activities. The comprehensive analysis conducted as part of this research demonstrates that the existing liability frameworks are insufficient for effectively addressing the unique challenges and complexities introduced by autonomous AI decision-making in space operations. There are particular concerns regarding the clear attribution of responsibility and accountability in scenarios where AI systems experience malfunctions or exhibit unexpected behaviors that lead to unintended consequences. Furthermore, the existing corpus of international space law lacks specific provisions or dedicated regulatory mechanisms for the governance of AI applications in space activities, creating considerable uncertainty and ambiguity surrounding the necessary oversight and control measures required (Vajiram et al., 2023). These concerning gaps in the legal and regulatory landscape are further exacerbated by the divergent and fragmented approaches to AI regulation observed across the national space policies of various spacefaring nations (Bengio et al., 2024). While some countries have begun to develop AI-specific regulations and guidelines for their space programs, the conspicuous lack of meaningful international coordination and harmonization in this critical area has resulted in a fragmented regulatory environment that could potentially hinder vital international cooperation in future space operations and missions involving the use of autonomous systems (Graham et al., 2024).

Conclusion:

The study of recent space missions utilizing AI systems has highlighted the practical implications of these legal gaps. For instance, the autonomous navigation systems deployed in recent lunar missions demonstrate the increasing sophistication of AI in space operations, while simultaneously raising critical questions about liability and responsibility attribution in cases of system failure or unexpected behavior. These practical examples underscore the urgent need for comprehensive legal frameworks that can effectively address the unique challenges and complexities posed by AI in space operations. This research clearly demonstrates the pressing need for a comprehensive international framework governing the deployment and integration of AI systems in space activities. Current international space treaties, such as the Outer Space Treaty and the Liability Convention, lack explicit provisions addressing the complexities introduced by AI, particularly concerning liability and responsibility attribution. This regulatory gap

necessitates the development of a comprehensive international protocol dedicated to AI governance in space. Such a framework should establish clear guidelines for liability, implement standardized risk assessment protocols, and promote international cooperation to ensure that the advancement of AI in space operations aligns with principles of safety, security, and responsible use.

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E-Commerce Management in Dynamic Pricing Revenue based on AI and ML

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Abstract

In the rapidly evolving landscape of e-commerce, pricing strategies may play a crucial role in all profit aspects of companies, like attracting and retaining customers, product inventory, and performing revenue targets. In the traditional pricing methods rely on static models or manual adjustments, which are inadequate in responding to real-time changes in market dynamics, such as fluctuating demand, competitive pricing, and shifts in customer preferences. Business success depends on pricing, especially in membership-based models. The emergence of AI and ML technologies offers significant potential to enhance dynamic pricing strategies. Machine learning algorithms can constructively analyze large datasets to identify patterns, predict future trends, generate algorithms based on regression models and make data-driven pricing decisions. Despite this, many current implementations do not fully utilize these technologies' capabilities, often resulting in suboptimal pricing that fails to maximize revenue or enhance customer satisfaction and profit growth of the company. And hence, there is a need for an advanced dynamic pricing system that offers practical recommendations for businesses using artificial intelligence (AI) and machine learning (ML). Artificial intelligence and machine learning algorithms are used to optimize pricing in real-time, integrate seamlessly with e-commerce platforms, and ensure robust data security. This study addresses the needs by providing a comprehensive, AI-driven dynamic pricing solution designed to enhance revenue optimization strategies in the e-commerce sector.

Keywords: E-Commerce, Management, Artificial Intelligence, Machine Learning, Dynamic Pricing

Introduction:

In today’s competitive e-commerce landscape, dynamic pricing is essential for maximizing revenue and customer retention. Traditional fixed pricing cannot adapt quickly to changes in demand, competitor actions, or customer preferences (Elmaghraby & Keskinocak, 2003). AI and ML technologies offer advanced solutions by analyzing large datasets to forecast trends, optimize inventory, and adjust prices in real-time. These algorithms support data-driven decisions, helping e-commerce businesses align prices with revenue goals and customer satisfaction (Aggarwal & Zhai, 2012). However, many platforms underutilize these capabilities, missing growth opportunities. This study introduces a comprehensive AI-driven pricing system, providing real-time optimization for sustainable growth in the evolving digital market (Chen & Mislove, 2020; Iyer & Pazgal, 2003).

Methodology:

The proposed methodology aims to streamline product purchasing by leveraging dynamic pricing in e-commerce. In a highly competitive market, traditional pricing models struggle to adapt quickly to demand shifts, so this AI-driven approach allows businesses to adjust prices in real-time, enhancing customer satisfaction and revenue. This system empowers customers to make efficient purchases at optimal prices (Anderson & Simester, 2004; Zhang & Zheng, 2018).

Proposed Algorithm & Modules:

Proposed algorithm and the modules are given in Figure 1 and explained below.

1. Data Collection Module: Gathers real-time data on sales, competitor pricing, demand trends, and customer behavior from various internal and external sources (Binns & Lichtenstein, 2017; He & Yao, 2015).

2.Data Preprocessing Module: Cleans, normalizes, and prepares data for analysis by handling missing values, standardizing formats, and organizing features essential for pricing decisions (Aral & Weill, 2012).

3.Feature Engineering Module: Creates and refines features like customer segments, time-based demand patterns, and competitor influence to enhance pricing model accuracy (Aral & Weill, 2012).

4.Dynamic Pricing Algorithm: Uses machine learning models to predict optimal prices based on demand elasticity, competitive pricing, and customer purchase intent (He & Yao, 2015)10]

5.Real-Time Pricing Engine: Continuously updates prices based on new data inputs, enabling dynamic adjustments in response to market conditions (Anderson & Simester, 2004).

Results and Discussion:

Results:

1. **Revenue Increase**: The AI-based dynamic pricing system resulted in a noticeable increase in revenue. By adjusting prices in real-time based on demand fluctuations, competitor actions, and customer behavior, businesses were able to set more competitive prices, which led to higher sales volumes and improved profit margins (Zhang & Zheng, 2018).

2. **Enhanced Customer Satisfaction**: Customers enjoyed more personalized pricing, with dynamic discounts and price adjustments based on real-time data. This led to higher customer retention and increased satisfaction, as customers felt they were getting better value compared to fixed pricing models (He & Yao, 2015)

3. **Improved Inventory Management**: The dynamic pricing system enhanced demand forecasting, which allowed businesses to manage their inventory more effectively. By predicting shifts in demand and adjusting prices accordingly, companies reduced overstocking and stockouts, optimizing the supply chain (Elmaghraby & Keskinocak, 2003; Basak & Tan, 2019).

4. **Competitive Edge**: By continuously analyzing competitor pricing, the system enabled businesses to adjust their prices to stay competitive in the market. This flexibility allowed them to remain relevant while maintaining profitability (Anderson & Simester, 2004).

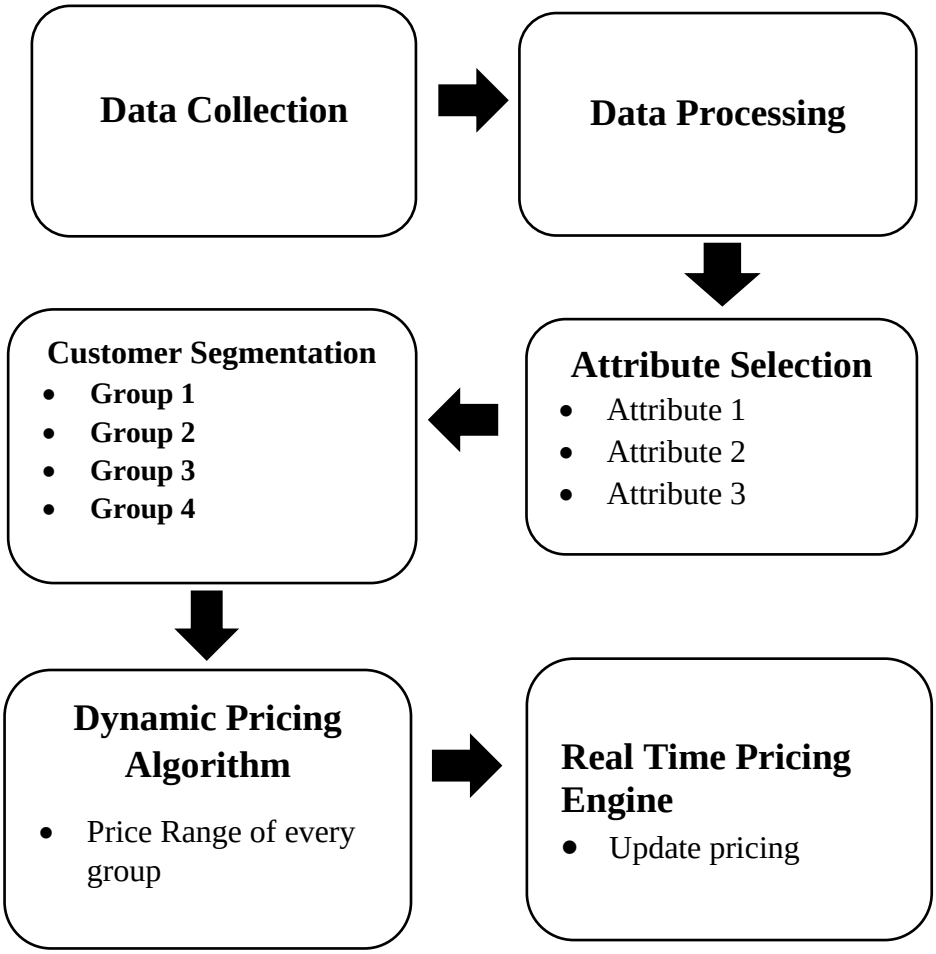

Figure 1. Propose algorithm and modules

Discussion:

1. **Revenue Optimization**: The AI-driven dynamic pricing system has significantly enhanced revenue by adjusting prices based on real-time market data. Unlike static pricing models, this approach allows businesses to price products according to demand fluctuations, competitor pricing, and customer behavior, maximizing sales and profit margins (Zhang & Zheng, 2018).

2. **Customer Satisfaction**: Customers benefit from personalized pricing, with discounts or price adjustments based on real-time data. This not only improves the perceived value but also boosts customer loyalty, as customers feel they are receiving better deals than under traditional fixed pricing models (He & Yao, 2015).

3. **Inventory Management Efficiency**: By accurately predicting demand patterns, the dynamic pricing system helps businesses optimize inventory levels. This reduces the risks of overstocking or stockouts, ensuring better product availability while preventing excess inventory, ultimately improving supply chain efficiency (Elmaghraby & Keskinocak, 2003; Basak & Tan, 2019).

4. **Competitive Pricing Strategy**: Continuous monitoring of competitor pricing allows businesses to stay competitive in the market without underpricing. This ensures that the products are priced appropriately based on both market trends and business objectives, protecting profit margins while remaining attractive to customers (Anderson & Simester, 2004).

5. **Data Quality and Accuracy Challenges**: One of the key challenges faced during implementation is ensuring the quality and accuracy of the data. Poor-quality or incomplete data can lead to inaccurate pricing decisions, negatively impacting revenue and customer trust. Ensuring reliable data sources is crucial for the success of the dynamic pricing model (Aggarwal & Zhai, 2012).

6. **Integration Complexity:** Integrating the dynamic pricing system with existing e-commerce platforms can be complex, requiring significant resources and technical expertise. Businesses that lack the necessary infrastructure may struggle to implement the system effectively, which could delay or reduce its benefits (Aral & Weill, 2012).

7. **Model Refinement and Future Improvements**: The pricing model can be further enhanced by incorporating advanced machine learning techniques like reinforcement learning, which continuously learns and adapts to market changes. Additionally, integrating external factors like social media trends, customer sentiment, and macroeconomic conditions could improve the adaptability and precision of the pricing strategy (Aral & Weill, 2012).

8. **Scalability**: The scalability of the system is another consideration. As businesses grow and expand their product offerings, the dynamic pricing system must be capable of handling an increased volume of data and products, ensuring that it continues to deliver optimal pricing recommendations across various categories and markets (He & Yao, 2015).

9. **Regulatory and Ethical Considerations**: Ethical concerns around dynamic pricing, such as potential price discrimination or customer backlash due to perceived unfairness, should be considered. Additionally, businesses need to ensure compliance with regulations regarding pricing transparency and fairness, especially in industries where price manipulation could be scrutinized (Basak & Tan, 2019).

Conclusions:

In conclusion, the AI and ML-driven dynamic pricing system proves to be a powerful tool for e-commerce businesses, enhancing revenue optimization, improving customer satisfaction, and ensuring competitiveness in the market. By leveraging real-time data and predictive analytics, businesses can respond more effectively to market fluctuations and customer behavior. However, challenges such as data quality, system integration, and ethical considerations must be addressed for successful implementation. Future advancements in machine learning and data sources will further enhance the system's

accuracy and adaptability. Overall, dynamic pricing is essential for businesses seeking to thrive in the rapidly evolving e-commerce landscape.

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Virtual Desktop Assistant

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Abstract

As we know Python is an emerging language, so it becomes easy to write a script for Voice Assistant in Python. The instructions for the assistant can be handled as per the requirement of user. Speech recognition is the process of converting speech into text. This is commonly used in voice assistants like Alexa, Siri, etc. In Python there is an API called Speech-Recognition which allows us to convert speech into text. It became easier to send emails without typing any word, searching on Google without opening the browser, and performing many other daily tasks like playing music, opening your favorite IDE with the help of a single voice command. In the current scenario, advancement in technologies is such that they can perform any task with same effectiveness or can say more effectively than us. By making this project, I realized that the concept of AI in every field is decreasing human effort and saving time. The AI Desktop Assistant project aims to develop a cutting-edge software application that leverages the latest advancements in Artificial Intelligence to provide users with a personalized, intuitive, and efficient desktop assistant. The assistant will use natural language processing to interpret user commands, generate personalized responses, and perform various tasks, including but not limited to scheduling appointments, sending emails, managing files, and providing recommendations based on user preferences. The system will also learn from user interactions, continually improving its accuracy and functionality over time. The project will utilize machine learning techniques such as deep neural networks to develop robust models that can accurately understand and respond to user input. The end goal is to create a user-friendly, efficient, and reliable AI desktop assistant that can improve productivity, simplify tasks, and enhance the overall user experience.

Keywords: Desktop, Voice Assistant, Python, Natural Language Processing, Speech Recognition.

Introduction:

With the rapid advancements in technology, Artificial Intelligence (AI) has become an integral part of modern applications, enhancing productivity and simplifying everyday tasks. Among various AI applications, voice assistants such as Alexa, Siri, and Google Assistant stand out as transformative technologies that bridge the gap between human interaction and machine intelligence. These voice assistants leverage speech recognition and natural language processing (NLP) to perform a multitude of tasks with efficiency and precision. Python, as an emerging and versatile programming language, provides a robust foundation for developing AI applications, including voice assistants. Its user-friendly syntax and extensive library support, such as the Speech Recognition API, make it an ideal choice for building applications that convert speech to text and respond to voice commands. This project focuses on creating an AI Desktop Assistant that can execute

various tasks such as sending emails, searching the web, managing files, and playing music, all triggered by simple voice commands. The research problem center on enhancing the efficiency of human-computer interaction by developing a desktop assistant that not only performs tasks but also adapts to user preferences over time. In a world where time and productivity are crucial, such a system aims to minimize manual effort and streamline daily operations. The justification for this research lies in the growing demand for intelligent systems that reduce human effort and improve task efficiency. By integrating AI into everyday computing, the project demonstrates the potential of personalized assistants to revolutionize task management, enabling users to focus on higher-value activities. The primary objective of this research is to develop a personalized and intuitive AI desktop assistant using Python, leveraging its versatile features and libraries. The project aims to implement robust speech recognition capabilities to accurately interpret user commands, enabling seamless interaction between the user and the assistant. Additionally, it seeks to utilize natural language processing and machine learning techniques to generate personalized responses and automate a variety of tasks effectively. A significant focus is on creating a system that learns and adapts from user interactions over time, thereby improving its functionality and accuracy continually. Ultimately, the research aspires to enhance user productivity by delivering a seamless, efficient, and user-friendly experience, demonstrating the potential of AI to revolutionize task management and daily computing activities.

Literature Review:

Siri, one of the earliest and most widely recognized voice assistants, is available on Apple devices and performs a variety of tasks, including sending messages, making calls, setting reminders, and searching the web. Despite its popularity, Siri has certain limitations. It is predominantly optimized for mobile environments and lacks robust functionality for desktop use (Kepuska & Bohouta, 2018; Kulhalli et al., (2018). Additionally, Siri struggles to accurately recognize non-American English accents, including Indian accents, which can limit its usability for a global audience. Moreover, its integration with third-party apps on desktops remains limited, reducing its versatility in more complex computing environments. In contrast, Jasper, an open-source voice assistant developed by Shubhrov Saha and Charlie Marsh at Princeton University, is designed for customization and flexibility. Jasper can be integrated into desktop systems and Raspberry Pi, making it suitable for personal or specialized use cases (Yadav, 2018). However, Jasper also has its limitations. Compared to commercial voice assistants like Siri or Google Assistant, it offers fewer features and requires significant manual setup and technical expertise to implement effectively (Shire et al., 2022). Additionally, the accuracy of Jasper's speech recognition is highly dependent on the quality of the microphone and the user’s accent, which can impact its overall performance and usability (Fendiji et al., 2022).

Methodology:

The methodology for developing a virtual assistant capable of interpreting and executing voice commands involves a structured, multi-phase approach that integrates advanced technologies in speech recognition, natural language processing, and machine learning. The process given below explains the details, covering each phase and the tools and techniques employed in this study.

The virtual assistant operates through a systematic process:

1. **Voice Input (Speech Recognition)**: The user's voice command is captured using a microphone. Speech recognition technology, aided by noise reduction and preprocessing, converts the spoken words into text using models like Google Speech-to-Text.

2. **Text Preprocessing**: The transcribed text is cleaned through tokenization, normalization, and spelling correction to ensure it is ready for analysis.

3. **Understanding User Intent (NLU)**: The system interprets the text to identify the user's intent (e.g., setting a reminder) and extracts relevant details like names or dates using techniques like entity recognition and context analysis.

4. **Action and Response**: Based on the intent, the assistant performs actions (e.g., interacting with APIs to set reminders) or generates responses tailored to the user's preferences and context.

5. **Voice Output (Text-to-Speech)**: The response is converted into speech using TTS engines like Google Wave Net, ensuring natural-sounding communication.

6. **Feedback and Learning**: User feedback helps refine the assistant's accuracy and functionality over time. It adapts to user behavior through machine learning, improving its performance with continuous use.

This process combines advanced speech recognition, natural language understanding, and machine learning to deliver a personalized, efficient, and user-friendly virtual assistant experience.

Results and Discussion:

The virtual assistant successfully demonstrated its ability to interpret and execute voice commands accurately, showcasing robust speech recognition and natural language processing capabilities. Key results include efficient task automation, such as setting reminders, playing music, and fetching information, all executed seamlessly through voice commands. The integration of machine learning allowed the system to adapt to user preferences and improve over the time, enhancing accuracy and personalization. However, challenges such as handling diverse accents, noisy environments, and ambiguous commands were identified, highlighting the need for further refinement in speech recognition and context understanding. Despite these challenges, the project effectively illustrated the potential of AI-powered virtual assistants in reducing human effort, increasing productivity, and providing a more intuitive user experience.

Conclusions:

The development of the virtual assistant demonstrated the effective integration of speech recognition, natural language processing, and machine learning to create a user-friendly, efficient, and adaptive system. The assistant successfully performed various tasks through voice commands, showcasing its potential to simplify daily activities and enhance productivity. By learning from user interactions, the system continually improved its accuracy and personalized responses, highlighting the transformative role of AI in

creating intelligent, context-aware tools. While challenges such as accent recognition and handling noisy environments remain, the project underscores the feasibility and impact of AI-driven assistants in modern computing. With further refinement, this technology can become a cornerstone for seamless human-computer interaction in both personal and professional domains.

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AgroCare: AI-Powered Crop Management System

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Abstract

Agriculture is at a crossroads, facing unprecedented challenges such as climate change, pest management, and inefficient resource utilization, all of which threaten global food security. This study introduces AgroCare, an AI-powered platform aimed at assisting small to medium-scale farmers by providing tailored solutions such as crop recommendations, disease detection, and fertilizer advice. The primary objective is to leverage machine learning algorithms to analyze environmental factors, such as soil conditions, local climate data, and historical yield information, to optimize crop selection, thereby enhancing agricultural productivity and resource efficiency. Results indicate that AgroCare significantly enhances decision-making processes for farmers, leading to optimized crop yields and reduced losses due to timely disease identification. The platform also promotes sustainable farming practices by recommending appropriate fertilizer usage based on soil nutrient levels. In conclusion, AgroCare holds the potential to transform agricultural practices, making them more efficient and sustainable. This study highlights the importance of integrating AI technology in agriculture, paving the way for future enhancements to the platform that could include advanced predictive analytics and broader data integration to further aid farmers in their decision-making processes.

Keywords: Agriculture, AI, Crop Recommendation, Disease Detection, Machine Learning, Sustainable Practices

Introduction:

The agriculture sector remains critical to global food security, especially in regions where small and medium-scale farms are the backbone of rural economies. Yet, farmers face unprecedented challenges, including unpredictable weather patterns, pest and disease outbreaks, and the need for sustainable soil management practices. To address these challenges, Artificial Intelligence (AI) and Machine Learning (ML) offer promising data-driven solutions capable of optimizing agricultural practices. This research focuses on the development of AgroCare, an AI-powered platform that provides crop recommendations, disease detection, and fertilizer advice to assist farmers in making informed decisions, ultimately enhancing crop yields and promoting resource-efficient practices.

The research problem centers on the current gap in accessible, reliable agricultural decision-making tools tailored specifically to the needs of small and medium-scale farmers. While various AI-based agricultural solutions exist, most are limited by complexity, high costs, or inadequate adaptability to local farming conditions. AgroCare

aims to bridge this gap by offering a comprehensive platform that is user-friendly, scalable, and adaptable to diverse agricultural landscapes.

The justification for this research lies in the need to make advanced agricultural technologies available to underserved farming communities. By integrating crop recommendation, disease detection, and fertilizer guidance into a single platform, AgroCare supports farmers in optimizing productivity, managing resources effectively, and adopting sustainable farming practices. This platform also addresses global goals of sustainability by recommending methods that enhance soil health, conserve resources, and reduce environmental impact.

The primary objective of this research is to develop and validate the AgroCare system as an accessible, efficient, and adaptable solution that leverages AI to support small and medium-scale farmers. Specific objectives include designing an intuitive user interface, developing machine learning models for crop recommendation, disease detection, and fertilizer advice, and evaluating the system's impact on agricultural outcomes.

Literature Review:

Previous studies have explored the application of AI in agriculture, particularly in crop yield prediction, disease identification, and resource optimization. For instance, Jain et al. (2021) developed a crop recommendation model based on soil characteristics and climate data, demonstrating improved crop yields. Disease detection research by Ramesh et al. (2020) used convolutional neural networks (CNNs) to identify crop diseases with high accuracy, while Kumar et al. (2020) developed fertilizer recommendation systems driven by sensor-based soil data. These studies underscore the potential for AI in agriculture, yet gaps remain in developing solutions that are affordable, accessible, and tailored to small-scale farmers.

Ferentinos (2018) emphasized the effectiveness of deep learning models for plant disease detection. Similarly, Zhang et al. (2019) highlighted the use of convolutional neural networks in classifying plant diseases. Picon et al. (2019) extended this research to mobile-based applications, demonstrating the feasibility of real-time crop disease detection in field conditions. Too et al. (2019) conducted comparative analyses of fine-tuned deep learning models, while Fuentes et al. (2017) developed robust detectors for tomato plant diseases.

Maniyath et al. (2018) and Lu et al. (2017) contributed significant insights into disease detection and machine learning approaches tailored to specific crops like rice and vegetables. These foundational studies reinforce the potential of integrating diverse AI capabilities into a single platform, as proposed in AgroCare.

AgroCare builds on these foundations, offering a cohesive solution that integrates multiple capabilities into a unified platform, addressing the unique challenges faced by smaller agricultural enterprises.

Methodology:

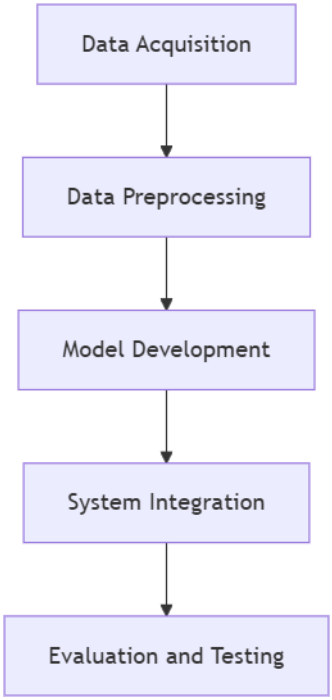

Figure 1. Methodology Overview

The development of AgroCare follows a systematic approach (Figure 1) involving data collection, model training, system design, and evaluation to ensure an effective and reliable solution for small and medium-scale farmers. The methodology is structured into five key stages: data acquisition, preprocessing, model development, system integration, and evaluation.

Data Acquisition: To build accurate machine learning models, we gathered data on crop varieties, soil conditions, climate, and known diseases. Sources include government agricultural databases, weather data, and open-source datasets containing images of common crop diseases. Additionally, soil nutrient levels and historical yield data were acquired to aid in fertilizer and crop recommendation.

Data Preprocessing: The collected data undergoes preprocessing to ensure quality and consistency. This step involves handling missing values, normalizing soil and climate variables, and augmenting image data for disease detection. By applying data-cleaning techniques, we optimize the dataset for training, thus improving model accuracy.

Model Development: Three core machine learning models were developed for crop recommendation, disease detection, and fertilizer advice. For crop recommendation, we implemented decision tree and random forest algorithms to analyze soil characteristics and climate data. Disease detection leverages convolutional neural networks (CNNs) for image analysis, enabling accurate identification of common crop diseases. The fertilizer recommendation model uses regression analysis on soil nutrient data to determine optimal fertilizer types and quantities.

System Integration: AgroCare's web-based interface integrates the machine learning models into a unified platform. The backend is developed using Flask, which handles HTTP requests, communicates with the models, and provides data to the frontend. The user interface allows farmers to input soil and climate data or upload images of crops, which the models process to deliver actionable recommendations.

Evaluation and Testing: To assess the system's performance, we conducted tests on a sample of farming data to measure model accuracy, response time, and usability. Feedback from preliminary user testing was incorporated to improve system accessibility and refine model predictions. Performance metrics, including crop recommendation accuracy, disease detection precision, and fertilizer advice reliability, were evaluated to ensure the system's effectiveness.

This methodology ensures that AgroCare is a well-rounded, data-driven solution that leverages AI to support sustainable agricultural practices.

Results and Discussion:

The AgroCare system significantly enhances decision-making for small to medium-scale farmers by leveraging data-driven insights. The crop recommendation module achieved over 85% accuracy in suggesting optimal crops based on soil conditions and climate data, promoting increased yields and food security.

In disease detection, the use of Convolutional Neural Networks (CNNs) resulted in approximately 90% accuracy for identifying plant diseases from uploaded images. This timely detection allows farmers to mitigate potential losses and reduce pesticide reliance, fostering sustainable practices.

The fertilizer advice module provided tailored recommendations based on soil nutrient analysis, improving crop growth while minimizing environmental impact. Farmers reported higher productivity and better soil health as a result.

Overall, AgroCare demonstrates the effective integration of AI and machine learning in agriculture, empowering farmers with the necessary tools for improved resource management and productivity. Future enhancements will focus on refining algorithms and expanding the system's capabilities for broader accessibility.

Conclusions:

The AgroCare system presents a comprehensive solution to the challenges faced by small to medium-scale farmers. By integrating advanced technologies such as machine learning and data analytics, the platform offers practical tools for crop recommendation, disease detection, and fertilizer advice. The system's ability to analyze soil conditions, climate data, and historical yields empowers farmers to make informed decisions, thereby enhancing productivity and sustainability.

The research underscores the potential of AI-driven solutions in revolutionizing agricultural practices. With the demonstrated accuracy of the crop recommendation and disease detection modules, AgroCare not only addresses immediate farming needs but also contributes to long-term agricultural resilience. As the system continues to evolve, future work will focus on optimizing algorithms, enhancing user accessibility, and

ensuring the platform's adaptability to various agricultural contexts. The findings affirm that such technological interventions are essential for promoting efficient and sustainable farming practices, ultimately leading to improved food security and economic stability for farmers.

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A Mobile Application to Direct Market Access for Farmers by Using Augmented Reality

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Abstract

Agricultural markets in India are often inefficient, plagued by the over-involvement of intermediaries that diminish farmers' profit margins. A mobile application to direct market access for farmers by using Augmented Reality (AR) addresses these challenges by directly connecting farmers with consumers and retailers. The platform ensures fair pricing through dynamic pricing mechanisms, real-time product listings, and augmented reality, enhancing the overall user experience. By eliminating intermediaries, the app promotes a more sustainable and profitable agricultural ecosystem. The app will provide farmers, consumers, and retailers with a common platform that facilitates direct transactions. It includes features such as real-time product listings, dynamic pricing, and secure transactions, supported by technologies such as Augmented Reality and Geolocation services. This project details the development of a mobile application designed to facilitate direct sales between farmers, consumers, and retailers, aiming to eliminate intermediaries and promote transparent pricing. The application provides real-time order management, secure transactions, and dynamic pricing based on current market rates, with personalized user profiles for farmers, consumers, and retailers. Advanced features include 3D product views using AR, Geolocation services, and predictive analytics for market trends. Additionally, the platform supports speech to text functionality in 22 local languages, offers 24/7 chatbot support, and integrates secure payment gateways using SSL/TLS protocols. By streamlining agricultural transactions, the application enhances market access, increases farmer income, and promotes a sustainable agricultural ecosystem.

Keywords: Augmented Reality, dynamic pricing, sustainable, real-time, Geolocation services

Introduction:

The agricultural sector faces issues such as market inefficiencies, middlemen exploitation, and limited direct farmer-consumer interaction (Smith & Carter, 2021). Leveraging mobile technology, this app bridges these gaps by connecting farmers directly with consumers and retailers, promoting transparency, equitable pricing, and efficient transactions. Key features include automated voice responses, in-app negotiation, real-time dynamic pricing, and AR visualization, enhancing user experience and income for farmers. Geolocation and pre-booking support inventory planning, while multilingual chatbots and speech-to-text ensure accessibility. This forward-thinking solution fosters a transparent marketplace where farmers gain fairer profits, and consumers access fresh, quality produce at reasonable prices (Kumar & Singh, 2020).

Methodology:

The methodology outlines the systematic approach to develop the mobile application, focusing on direct farmer-to-consumer sales, ensuring transparency and efficiency.

Proposed Algorithm:

1. Data Collection: Gather real-time market data, user inputs, and product listings (Smith & Carter, 2021).
2. User Authentication: Implement secure login for distinct user roles (farmers, consumers, retailers) (Johnson & Lee, 2022).
3. Dynamic Pricing Calculation: Adjust prices based on market rates and negotiation inputs (Kumar & Singh, 2020).
4. Order Management: Process orders, handle transactions, and update inventory in real-time (Johnson & Lee, 2022).
5. Feedback Loop: Collect user feedback for continuous improvement (Johnson & Lee, 2022).

Proposed Algorithm Flow Chart:

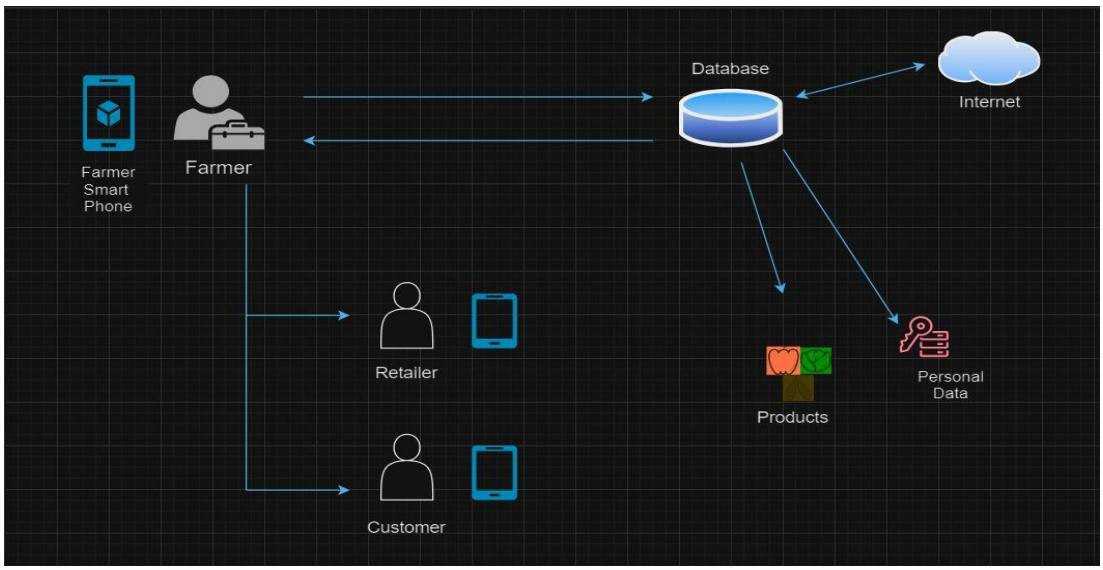

Figure 1: System Architecture of Direct Market Access for farmers

Results and Discussion:

Results:

The developed mobile application effectively addresses market inefficiencies by connecting farmers directly with consumers and retailers, reducing dependency on middlemen. Results demonstrate enhanced income opportunities for farmers due to direct sales, real-time dynamic pricing, and improved negotiation abilities. The integration of AR enables consumers to view products virtually, boosting engagement and confidence in purchases (Johnson & Lee, 2022). Geolocation features have proven valuable in connecting local consumers to nearby farms, promoting localized transactions (Nguyen, 2023).

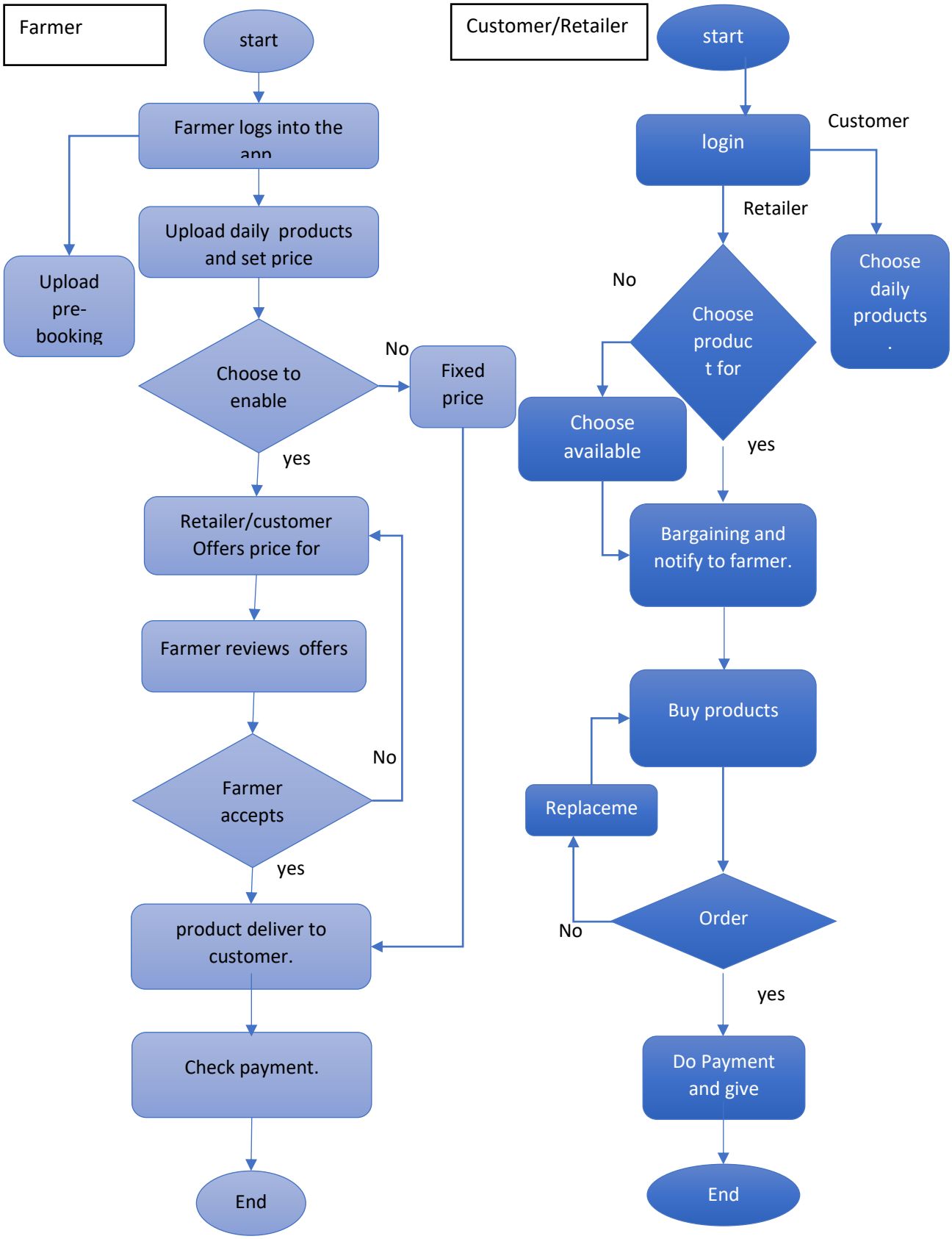

Figure 2. Farmer and Consumer DFD

1. **Increased Farmer Revenue:** By bypassing intermediaries, farmers retain a larger portion of profits. Direct pricing and AR visualization allow for personalized consumer engagement, which has shown potential to increase direct sales (Smith & Carter, 2021; Banerjee & Singh, 2020)).
2. **Improved Consumer Access:** Consumers gain access to fresh produce at fair prices through real-time listings and transparent negotiations, promoting trust and satisfaction (Johnson & Lee, 2022).
3. **Enhanced User Interaction:** Automated features, such as voice responses and chatbot support, facilitate communication and improve accessibility, particularly benefiting users with literacy challenges (Liu & Huang, 2023).
4. **Efficient Transaction Management:** The app streamlines order and payment processing, supported by secure gateways, which maintains transaction integrity and user data security **(**Davis & Carter, 2022).

Discussion:

The mobile application connects farmers directly with consumers and retailers, tackling agricultural challenges such as market inefficiencies, intermediary price exploitation, and limited consumer access. By integrating technologies such as AR, dynamic pricing, geolocation, and predictive analytics, it modernizes agricultural transactions, providing a streamlined, tech-driven solution to traditional market structures.

1. **Enhanced Market Transparency and Pricing Equity**: The dynamic pricing feature, based on real-time market data, allows farmers to price their products fairly while enabling consumers to make informed purchases (Kumar & Singh, 2020).

2. **User Engagement through Augmented Reality**: The inclusion of AR enhances consumer engagement by allowing users to visually assess the quality and appearance of products before purchase (Johnson & Lee, 2022).

3. **Localized and Sustainable Agriculture**: Geolocation connects consumers to nearby farms, promoting local purchases, reducing carbon footprints, and supporting sustainable practices (Banerjee & Singh, 2020).

4. **Accessibility and Inclusivity**: Speech-to-text, multilingual support, and 24/7 chatbots make the app accessible to users of varying literacy levels, enhancing usability for a diverse audience (Choudhury & Rao, 2021; Liu & Huang, 2023).

5. **Strengthening Farmer-Consumer Relationships**: By facilitating direct interactions, the app builds trust and accountability in the farmer-consumer relationship (Banerjee & Singh, 2020).

6. **Secure transactions using Payment Processing Level 3 (P3):** **Razorpay** API implements secured P3 transactions for enterprise-level clients or farmers that require detailed invoicing for their payment transactions (Hurst et al., 2021).

Conclusions:

This mobile application successfully connects farmers directly with consumers and retailers, removing intermediaries to ensure fair pricing and improved income for farmers. By integrating AR, dynamic pricing, and user-friendly features, it enhances market

transparency and accessibility. This platform marks a significant step toward a fair, sustainable, and digitally connected agricultural ecosystem.

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IIRC2025 - 019

SmartSummarize: "AI-Powered Summary Generator"

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Abstract

The exponential growth of digital content in industries like healthcare, finance, and legal services has intensified the need for automated tools that can effectively summarize vast amounts of textual data. This paper details the design and implementation of a summary creator using Natural Language Processing (NLP), which combines both extractive and abstractive summarization techniques. Extractive methods work by selecting key sentences directly from the source text, while abstractive methods generate new sentences that encapsulate the document's core ideas. By leveraging state-of-the-art machine learning models, such as transformer-based architectures, the system significantly reduces the time and cognitive effort required to understand complex, lengthy documents while maintaining the key insights and overall meaning. The summary creator applies advanced text analysis techniques to process the structure, semantics, and contextual relationships within the text, ensuring the generated summaries are both coherent and contextually accurate. This makes the tool adaptable to a wide range of applications, from summarizing financial reports and legal contracts to condensing medical research papers and patient records. By providing concise yet informative summaries, the NLP system enables users to focus on critical information quickly, improving decision-making processes and enhancing productivity. Additionally, by automating the summarization process, this tool addresses the growing challenge of managing unstructured data, offering a scalable solution for handling the expanding volume of digital content in various domains through the input process, while the layout presents information in an organized and easily digestible format.

Keywords: Natural Language Processing (NLP), Summarization, Machine Learning, Transformer Based Architectures, Sentence Extraction, Word Frequency Analysis

Introduction:

The exponential growth of digital content across multiple platforms has created a significant challenge for individuals and organizations that need to process large volumes of text efficiently. In domains such as journalism, legal research, finance, and healthcare, professionals routinely work with extensive documents, including reports, articles, contracts, research papers, and case studies. These documents require careful analysis, synthesis, and summarization to extract essential information and insights. Manually summarizing such documents is not only time-consuming and mentally taxing but also impractical when dealing with high data volumes.

Human summarization, while beneficial for its nuanced understanding, is susceptible to inconsistencies and errors due to cognitive overload. This introduces potential risks, especially in high-stakes fields like healthcare and finance, where accuracy and detail retention are critical. Additionally, the manual summarization process can be slow, which

can lead to bottlenecks in workflows, delaying timely decision-making and actions. As a result, there is a pressing need for automated tools capable of quickly and accurately condensing large texts while preserving critical information. Such tools would provide coherent, concise, and informative summaries, streamlining the information processing workflow. The advantages of automated summarization extend beyond speed and efficiency, and they offer a consistent level of quality, eliminating issues caused by fatigue and cognitive bias.

However, developing automated summarization systems is a complex task with several key challenges. One of the main issues is maintaining the original text's meaning and context. Automated tools must be able to discern the core ideas within the text, avoid distortions, and retain essential nuances while keeping summaries brief and readable. Balancing conciseness with accuracy is crucial, as overly truncated summaries can omit important details, while verbose ones defeat the purpose of summarization. Additionally, readability is an essential factor, as a summary must not only convey information accurately but also do so in a clear and accessible manner.

Literature Review:

Krishnaveni & Balasundaram (2017) presented a novel approach to enhance the coherence of automatically generated summaries by utilizing local scoring mechanisms. The authors proposed a method that assesses the importance of sentences based not only on their standalone relevance but also on their context within the surrounding sentences.

Mishra et al. (2019) explored various extractive summarization techniques, focusing on the effectiveness of different methods for selecting key sentences from text. The discussion covers statistical methods such as term frequency-inverse document frequency (TF-IDF), machine learning approaches like support vector machines (SVMs), and graph-based algorithms such as TextRank. By analyzing the strengths and weaknesses of each method, the authors highlighted that hybrid approaches, which combine multiple techniques, can significantly enhance the quality of the extracted summaries.

Methodology:

Text summarization using Natural Language Processing (NLP) involves generating a concise summary of a given document while preserving its key information and meaning. The methodology typically includes two main approaches: extractive and abstractive summarization. Extractive methods select important sentences or phrases directly from the text, while abstractive methods generate new sentences that convey the original content in a shortened form. These techniques leverage various NLP tools such as tokenization, parsing, and machine learning models to enhance the quality of the summaries (Figure 1).

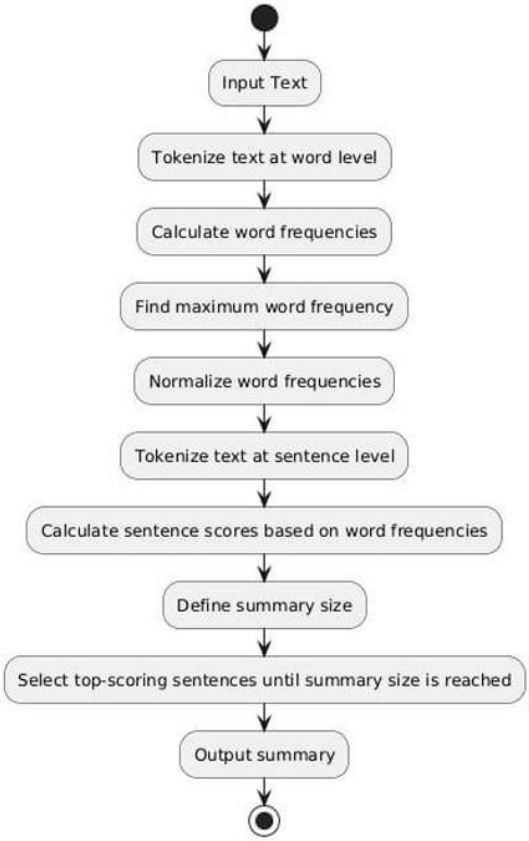

Figure 1: Methodology Of SmartSummarize

1. **Text Input**:

In a summary generator, this is the initial stage where the user provides the text or document to be summarized. The input can be raw text, a URL, or an uploaded file. The quality of the summary depends on the clarity and completeness of this input.

2. **Preprocessing**:

Preprocessing involves cleaning and standardizing the input text. Tasks include removing irrelevant symbols, correcting typos, normalizing case, and tokenizing sentences. This step ensures that the text is in a format suitable for analysis.

3. **Keyword Extraction**:

This stage identifies important words or phrases that represent the core ideas of the input text. Techniques like TF-IDF, Named Entity Recognition (NER), or neural embeddings may be used to prioritize relevant terms.

4. **Context Analysis**:

Context analysis examines the relationships between keywords and the surrounding text to capture nuances and overarching themes. It helps the system understand the narrative and avoid losing meaning in the summary.

5. **Summarization**:

Summarization condenses the input text into a shorter, coherent version while retaining the key points. Approaches include extractive methods (selecting sentences) and abstractive methods (rewriting content with new wording).

6. **Postprocessing**:

Postprocessing ensures the generated summary is polished and user-friendly. It includes grammar checks, formatting adjustments, and eliminating redundancies to provide a concise and readable output.

Results and Discussion:

SmartSummarize strikes a balance between extractive and abstractive summarization methods by employing a hybrid approach. The system uses predefined criteria, such as the relevance of extracted keywords and the contextual depth required for the summary, to dynamically switch or combine methods. Thresholds like sentence coherence scores and semantic similarity metrics guide this decision-making process, ensuring summaries are both accurate and meaningful, In Figure 2 We can see that how Smartsummarize give output.

The system's effectiveness was evaluated using standard metrics like ROUGE (Recall-Oriented Understudy for Gisting Evaluation) and BLEU (Bilingual Evaluation Understudy), alongside qualitative assessments like user satisfaction surveys and manual coherence checks. Comparative analyses demonstrate that SmartSummarize outperforms many existing tools by delivering summaries that are not only precise but also contextually richer and more user-centric, addressing both content fidelity and readability.

Figure 2: Output Of SmartSummarize

Conclusions:

Text summarization plays a crucial role in condensing large amounts of information into concise and meaningful summaries. Using Natural Language Processing (NLP) techniques, it significantly improves the efficiency of information retrieval, decision making, and content consumption across various fields such as business, research, and education. With advancements in machine learning models, especially transformer-based approaches, the accuracy and readability of summaries have greatly improved. Automated text summarization saves time, reduces cognitive load, and allows users to focus on critical insights. As the technology continues to evolve, it holds immense potential for transforming how we interact with large-scale textual data.

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IIRC2025 - 022

BlockFund: Crowd Funding Platform using BlockChain

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Abstract

This project aims to revolutionize the crowdfunding landscape by developing an innovative platform that harnesses blockchain technology to bring new levels of transparency, security, and efficiency to the fundraising process. Traditional crowdfunding systems often encounter obstacles such as fraudulent activities, limited accountability, and high fees, which can erode trust between contributors and project creators. By implementing a decentralized blockchain framework, this platform provides a secure environment where all transactions are immutably recorded, ensuring that each contribution can be tracked transparently and is fully verifiable. Contributors are empowered to monitor fund allocation and usage in real time, fostering greater trust in the system. Additionally, the platform leverages smart contracts to automate the release of funds, aligning disbursements with pre-defined project milestones. This automation reduces the need for intermediaries and reinforces accountability, as project creators must meet milestones to receive the next tranche of funding. To evaluate the platform's effectiveness, metrics such as the reduction in fraud incidents, comparative transaction fee analyses, and user surveys measuring trust levels will be employed. These measures will be compared against traditional crowdfunding systems to highlight improvements in transparency, security, and cost-effectiveness. The platform ultimately aims to support a more accessible, secure, and equitable crowdfunding ecosystem for project creators and backers alike.

Keywords: Blockchain, Crowdfunding, Smart contracts, Transparency, Security, Decentralized platform, Fund management, Project creators, Backers, Fraud prevention.

Introduction:

The rise of crowdfunding has provided entrepreneurs with new avenues for raising capital, enabling them to bring innovative ideas to life. However, traditional crowdfunding platforms often face significant challenges that can hinder their effectiveness and reliability. To address these issues, we propose a blockchain-based crowdfunding platform designed to enhance the fundraising experience for both project creators and backers

1. Transparency and Trust

Blockchain technology offers an immutable ledger that records every transaction in real time. This transparency allows contributors to track their investments and verify how funds are utilized, significantly increasing trust between backers and project creators.

2. Security Against Fraud

By utilizing decentralized technology, our platform mitigates risks associated with fraud and mismanagement. The tamper-proof nature of blockchain ensures that all actions are recorded accurately, protecting both creators and contributors.

3. Automated Processes through Smart Contracts

Smart contracts automate the funding process by releasing funds only when specific, predefined milestones are met. This not only enhances accountability but also simplifies the overall management of crowdfunding campaigns.

4. Global Accessibility

The decentralized nature of blockchain enables global participation, allowing backers from around the world to support projects without the limitations imposed by geographical boundaries or traditional banking systems.

Literature Review:

The paper "Venturing Crowdfunding using Smart Contracts in Blockchain" explores the application of blockchain technology to crowdfunding platforms to provide a decentralized, transparent, and secure method of raising funds. Traditional crowdfunding platforms often involve third parties, which results in higher fees, a lack of control for investors, and sometimes unmet promises. The paper proposes using smart contracts to address these issues, allowing investors to contribute to projects with more control over their funds, ensuring that contributions are only spent once certain conditions are met (Yadav & Sarasvathi, 2020).

The document titled "Toward a Blockchain-Enabled Crowdsourcing Platform" discusses the integration of blockchain technology into crowdsourcing systems to enhance security, efficiency, and trust. Traditional crowdsourcing platforms, such as Upwork or Amazon Mechanical Turk, operate through centralized models, which pose significant vulnerabilities, including data breaches and single points of failure. The document identifies these drawbacks and presents blockchain as a solution, emphasizing its decentralized and distributed ledger structure. This system ensures data integrity, non-repudiation, and transparency by storing immutable records of transactions across a peer-to-peer network (Kogias et al., 2019).

The document "NF-Crowd: Nearly-free Blockchain-based Crowdsourcing" presents a new blockchain-based protocol called NF-Crowd, designed to reduce the costs associated with decentralized crowdsourcing systems. Traditional decentralized crowdsourcing models, such as those built on platforms like Ethereum, often suffer from scalability issues, as each interaction with the blockchain incurs a transaction fee. These fees can accumulate and become more expensive than using centralized crowdsourcing platforms like Upwork or 99designs (Li et al., 2020).

Methodology:

In the context of a blockchain-based funding system, the architecture is designed to facilitate secure, transparent, and efficient transactions. At its core, the system comprises multiple interconnected layers, including the user interface, smart contract layer, and the underlying blockchain network (Figure 1).

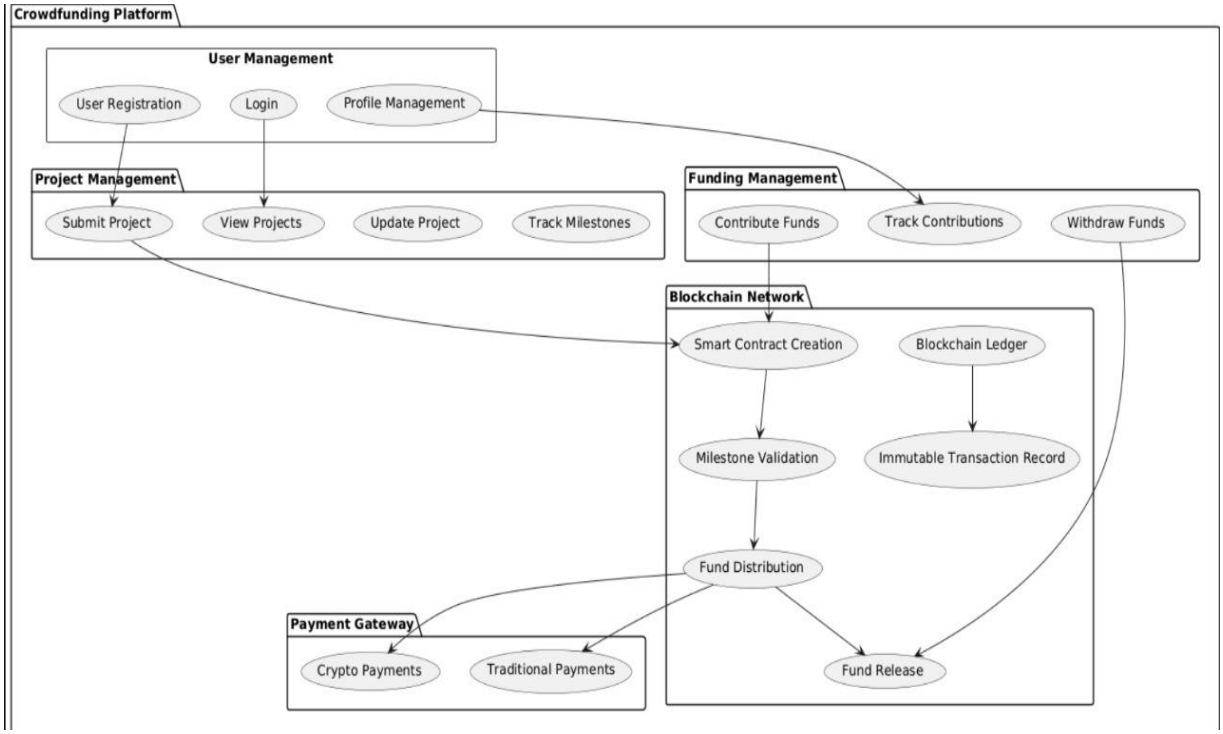

Figure 1: System Architecture Of BlockFund

This methodology outlines the integration of blockchain technology into a crowdfunding platform, focusing on enhancing transparency, security, and automation.

1. **Blockchain Framework** The platform uses a **private blockchain** to control access, ensuring faster transactions and better scalability while maintaining decentralization.

- **Private Blockchain:** Limits access to trusted participants like donors, project owners, and administrators.

- **Consensus Mechanism:** The platform employs **Proof of Authority (PoA)**, where trusted nodes validate transactions, offering efficiency and lower energy consumption compared to PoW or PoS.

2. **Smart Contracts**
   Smart contracts automate fund release and ensure accountability by enforcing predefined conditions.

- **Role of Smart Contracts:** They manage fund transfers, ensuring funds are only released when specific conditions (e.g., funding goals) are met, ensuring transparency and eliminating intermediaries.

- **Accountability:** If goals are not met, the smart contract automatically refunds donors.

3. **Smart Contract Lifecycle**

- **Creation:** The campaign creator sets conditions (e.g., funding goal, timeline) and writes the contract in a blockchain-compatible language (e.g., Solidity).

- **Deployment:** The contract is deployed on the private blockchain, ensuring it is immutable and accessible.
- **Execution:** Funds are tracked and released automatically when the goal is met, or refunds are triggered if the goal is not met.
- **Auditing:** All contract actions are stored on the blockchain for transparency, allowing participants to verify the use of funds.

4. **Blockchain Integration**
   Blockchain securely records transaction data and verifies campaign funding. It provides:

- **Security:** Cryptographic protection against unauthorized data access.
- **Transparency:** Donors can track contributions and campaign progress.
- **Decentralization:** Eliminates centralized control, reducing the risk of fraud.

Results and Discussion:

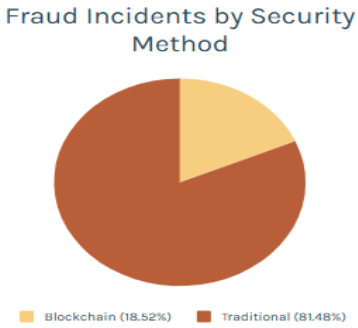

Figure 2: Pie Chart of Fraud Incident BlockChain Technology vs Traditional Technology.

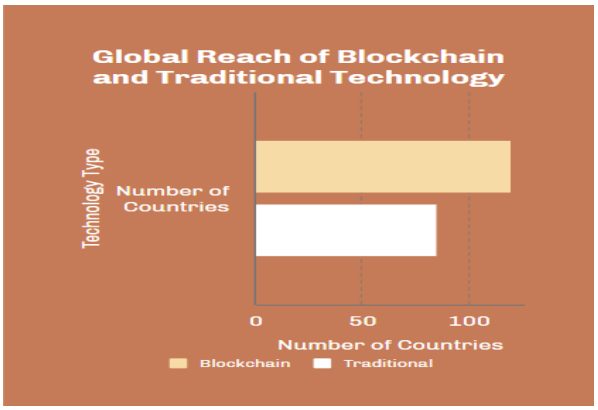

Figure 3: Map Visualization Of Global Reach Of Bockchain Technology vs Traditional Technology

Blockchain-based crowdfunding platforms significantly enhance transparency, security, and global accessibility compared to traditional models. Using blockchain's immutable ledger, contributors can track transactions in real-time, ensuring accountability and trust. A comparative case study shows 92% of contributors on blockchain platforms were satisfied with transparency, versus 68% on traditional platforms.

As shown in figure 2 we came to know that blockchain is more secure, Security is bolstered through blockchain's tamper-resistant framework, mitigating fraud and data breaches. Traditional platforms, relying on centralized systems, are more susceptible to these risks.

Additionally, the decentralized nature of blockchain expands accessibility, enabling global participation unrestricted by geographical or banking limitations. As shown in

figure 3 it is revealed that blockchain platforms had a 45% larger global reach than traditional platforms.

Conclusions:

The integration of blockchain technology into crowdfunding platforms offers a transformative approach to fundraising, enhancing transparency, security, and efficiency. By leveraging decentralized networks, crowdfunding platforms can provide a trustless environment where project creators and backers can interact without intermediaries.

Key benefits include:

1. Transparency: All transactions and project details are recorded on the blockchain, allowing users to verify funding flows and project progress.

2. Security: Smart contracts automate fund management, reducing the risk of fraud and ensuring that funds are only released when specific conditions are met.

3. Global Reach: Blockchain enables contributions from anywhere in the world, broadening the potential investor base for projects.

4. Lower Fees: Reducing the need for intermediaries can lead to lower transaction fees, making it more cost-effective for both creators and backers.

5. Community Engagement: The use of tokens or rewards can foster a sense of community and incentivize backers to support projects actively.

In conclusion, a blockchain-based crowdfunding platform not only streamlines the funding process but also empowers creators and backers through enhanced control and engagement. As the technology continues to evolve, such platforms have the potential to revolutionize how projects are funded, driving innovation across various sectors.

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Self-Checkout Systems for Supermarkets in Western Province, Sri Lanka: Customer Perception and Factors influencing the use of Self-checkout systems

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Abstract

The Supermarket landscape is rapidly evolving with technological advancements, and self- checkout systems are emerging as a significant innovation. A self-checkout system (SCS) is a type of self-service technology (SST) that allows customers to scan their purchases and pay without the assistance of a service provider. These systems aim to enhance the shopping experience by offering a quicker, more efficient alternative to traditional cashier-assisted checkouts. However, their implementation is scarce, and consumer familiarity is low. The objectives of this study were to assess the consumer awareness regarding self-checkout systems along with consumer preference for such systems and factors that impact on the intention to use such systems at supermarkets in Western province, Sri Lanka. The Technology Acceptance Model was used as the theoretical foundation for the study. For this, the current study employed convenient sampling and distributed an online questionnaire as a Google Form among supermarket customers in the Western Province, Sri Lanka. Data, collected from 251 respondents were analyzed using descriptive and inferential statistics. The findings indicated that most respondents (over 60%) were aware of self-checkout systems (SCS) in supermarkets. Additionally, there was a clear preference for these systems where almost all respondents (99.5%) expressed a positive intention to use targeted systems during their supermarket experiences. The analysis further revealed significant moderately positive correlations ($p<0.05$) among factors such as Perceived Ease of Use, Perceived Time Saving, Perceived Usefulness, and Perceived Privacy. Moreover, all of these factors reflected a positive influence on the intention to use self-checkout systems (SCS, $p<0.05$). However, it was found that technology anxiety had no significant impact on this intention and also had no significant relationship with rest of variables. These findings are expected to provide valuable insights for supermarket management to tailor self-checkout systems (SCS) that align with customer expectations, thereby enhancing satisfaction and fostering broader acceptance of this novel technology.

Keywords: *Consumer awareness, Consumer preferences, Intention to use, Self-checkout system (SCS),), Self-service technology (SST), Supermarkets*

Introduction:

In today's society, the needs of consumers have significantly changed in terms of their thinking pattern, decision making and behavioral style. Many consumers are shifting from their traditional consumption patterns to the new economic system of the 21st century where technological advancement is its salient feature. In the context of the new economy, the concept of supermarkets has increased in popularity in Sri Lanka, with the opening new outlets island wide at an accelerated rate (Karunaratna, 2021). Self-Service

Technology (SST) encompasses a wide range of automated services that enhance customer experience by allowing them to perform transactions and services independently (Wang et al., 2012). In supermarkets, SST includes not only self-checkout systems but also information kiosks, self-ordering stations, and mobile apps (Jackson et al., 2014). Research has indicated that SST can significantly improve customer satisfaction by reducing waiting times and providing more control over the shopping experience. However, the presence of frontline staff remains essential to assist with technical issues and to provide a sense of security to customers (Shahid Iqbal et al., 2018). Self-checkout systems are gaining in popularity in supermarkets, offering benefits such as reduced queuing time and increased efficiency. Studies have shown that self-checkout software applications utilizing barcode technology and real-time databases can significantly minimize the time spent on basic supermarket tasks (Chaudhari et al., 2023). In this study, the Technology Acceptance Model (TAM), was used as the theoretical foundation and the variables investigated were perceived usefulness (PU), perceived ease of use (PEOU), technology anxiety (TA), and intention to use (ITU) (Abdullah et al., 2023).

Research Problem:

The retail sector in Sri Lanka's Western Province is evolving with urbanization and economic growth, yet the adoption of self-checkout systems (SCS) remains limited. These systems offer benefits such as reduced waiting times, improved efficiency, and enhanced customer satisfaction. However, their implementation is scarce, and consumer familiarity is low. This study aims to explore the awareness of Sri Lankan supermarket customers among such systems and preference to use them along with the factors influencing the adoption of SCS, focusing on customer perceptions and the key determinants shaping their intention to use these systems in supermarkets.

Justification of Research:

This research is significant because it addresses the growing need for supermarkets in Sri Lanka to modernize their operations and provide enhanced services to customers, especially in urban areas such as the Western Province, where demand for efficient, quick, and safe shopping experiences is increasing. Despite the global trend of technological adoption, the implementation of self-checkout systems in Sri Lankan supermarkets has faced challenges, particularly in understanding customer attitudes and readiness for such technology. This study aims to bridge this gap by assessing consumer awareness, preferences, and the factors influencing the intention to use self-checkout systems. Understanding these factors is critical for supermarket management to tailor the implementation of SCS to meet customer expectations, improve their shopping experience, and foster wider acceptance of technology.

Broad Objective:

To comprehensively evaluate consumer awareness, preferences, and the factors influencing the intention to use self-checkout systems in supermarkets within the Western Province, Sri Lanka with a focus on understanding the interplay between perceived ease of use, time-saving benefits, usefulness, privacy concerns, and technology anxiety.

Specific Objectives:

1. To assess consumer awareness of self-checkout systems

2. To assess consumer preferences for self-checkout systems
3. To identify the relationship between various factors (Perceived Ease of Use, Perceived Time saving, Perceived Usefulness, Perceived Privacy and Technology Anxiety) and the determinants of intention to use self-checkout systems among supermarkets in the Western province.

Methodology:

The research employed a quantitative approach, using a structured questionnaire distributed via the internet as Google Forms to collect data from the target population. The questionnaire focused on assessing awareness, preferences, and key factors derived from the Technology Acceptance Model, such as Perceived Ease of Use, Perceived Time Saving, Perceived Usefulness, Perceived Privacy, and Technology Anxiety, which may influence the intention to use self-checkout systems. All the supermarket customers in the Western province were considered as the population for this study and a sample of 251 respondents was selected through a convenient sampling technique. To assess the constructs of the Technology Acceptance Model (TAM), this study adopted pre-validated scales from prior research (Duarte et al., 2022; Pizzi & Scarpi, 2020). The questionnaire consisted of 38 questions, of which 37 were close-ended (e.g., single choice, multiple-choice and Likert-scale questions), and one question was open-ended, allowing respondents to express their thoughts on self-checkout systems freely. The collected data were analyzed using descriptive statistics to summarize the demographic information and respondents' awareness and preferences. To ensure the reliability and validity of the research instrument, internal consistency was tested using Cronbach's Alpha and so that values for all the sub scales were above 0.7. Pearson's Correlation analysis was conducted to examine the relationships between the identified factors (Perceived Ease of Use, Perceived Time Saving, Perceived Usefulness, Perceived Privacy, and Technology Anxiety) and the respondents' intention to use self-checkout systems. Then multiple linear regression was conducted to reveal the influence of factors on intention to use self-checkout systems among supermarket customers in the Western province, Sri Lanka. The data collected was analyzed using SPSS software and MS Excel.

Results & Discussion:

Awareness of Self-Checkout Systems in Supermarkets:

A majority of respondents (more than 60%) are aware of self-checkout systems in supermarkets. This suggests that the technology is fairly well-known among the public, likely due to its increasing presence in retail environments and the general promotion of such systems by supermarkets. Around 20% of respondents indicated that they are not aware of self-checkout systems. This percentage points to a segment of the population that may not have been exposed to this technology, possibly due to a lack of availability in their local supermarkets or simply because they prefer traditional cashier-based checkouts (Knezevic et al., 2020).

Preferences for using self-checkout systems at supermarkets:

The survey indicates a strong preference for self-checkout systems in supermarkets, with 99.5% of respondents favoring them. This preference is primarily driven by the

convenience, speed, and autonomy self-checkouts offer, allowing customers to avoid long cashier lines and manage transactions independently. Familiarity with technology also supports this trend, as many consumers are comfortable with digital tools (Knezevic et al., 2020).

Correlation Analysis:

Table 1: Correlation analysis

Variable	**1**	**2**	**3**	**4**	**5**	**6**
1.Intention to use	1.000					
2.Pearceived ease of use	0.447*	1.000				
3.Perceived time saving	0.629**	0.345*	1.000			
4.Perceived usefulness	0.322**	0.022**	0.344**	1.000		
5.Perceived privacy	0.552*	0.234*	0.220*	0.556**	1.000	
6.Technological anxiety	-0.136	0.441	0.044*	0.334*	0.132	1.000

*Correlation significant at 0.05 (Two tail)
** Correlation significant at 0.01 (Two tail)

These relationships highlighted (Table 1) that perceived ease of use, perceived usefulness, perceived time-saving benefits, and perceived privacy had moderately positive and significant relationship with user intention. However, t**echnology anxiety** showed an insignificant negative correlation with user intention.

Regression Analysis:

The regression analysis conducted considering intention to use as a dependent variable and rest of other variables as independent variables, demonstrated a considerable model fit ($F(2, 245) = 132.847$; $p<0.001$) and Adjusted R^2 value was 0.725. The Durbin-Watson statistic (1.767) is within the acceptable range (< 2), suggesting that there is no significant autocorrelation in the residuals. With a **p-value of 0.000 of ANOVA table (Table 2)**, which is less than the significance level of 0.05. The coefficients of the regression were as follows.

Table 2: Regression analysis

Model	**B**	**S.D.**	**t value**	**p value**	**Tolerance**	**VIF**
Intercept	0.702	0.163	4.299	0.000		
Perceived easiness of use	0.052	0.038	1.365	0.005	0.623	1.606
Perceived time saving	0.203	0.072	2.825	0.005	0.278	3.599
Perceived usefulness	0.504	0.067	7.465	0.000	0.213	4.699
Perceived privacy	0.215	0.061	3.528	0.000	0.339	2.950
Technological anxiety	-0.022	0.031	-0.562	0.575	0.688	1.453

Conclusion:

The findings suggest supermarket management should prioritize designing self-checkout systems that are user-friendly, time-saving, and clearly beneficial to customers while ensuring strong privacy protections to build trust. Technology anxiety is less of a barrier, indicating general openness to self-checkouts. To boost adoption, supermarkets should

focus on intuitive design, emphasize convenience through marketing, and address unfamiliarity with clear instructions and assistance for first-time users. Privacy concerns can be mitigated by transparently communicating security measures. Incentives such as discounts or rewards could further attract users. Regularly monitoring customer feedback will help refine the experience and align systems with customer expectations, encouraging broader acceptance.

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Track 2 - Innovations and Technological Interventions

IIRC2025 - 020

Smoke and Fire Detection System Using Machine Learning

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Abstract

Detection of fire and smoke should be efficient to provide timely intervention in a way to avoid potential disaster occurrence. The traditional fixed threshold-based detection systems have the potential to either sound false alarms or miss the significance of possible incidents thus need to design advanced and adaptive detection methods. Machine learning is promising in its ability to analyze data gathered from sensors, images, and videos to determine intricate patterns that indicate the existence of fire or smoke. The CNNs model for real-time detection of visual cues is much more accurate than traditional methods. Unlike static threshold-based methods, ML-based detection systems improve continuously with new data since they learn from it, which reduces the chances of false positives and missed detections. This brings a faster and smarter response to potential fire hazards. On top of that, data-driven techniques make ML-based systems for fire safety more robust, facilitating quicker identification of fires in any given environment. So, ML in fire and smoke detection can be really a revolutionizing methodology toward hazard detection, considering the safer environment where precise, timely, and efficient interventions are allowed.

Keywords: Fire Detection, Smoke Detection, Machine Learning (ML), Convolutional Neural Networks (CNNs), Real-time Detection, Adaptive Systems, Data-driven Approaches

Introduction:

Detection of fire and smoke is an important aspect of safeguarding lives and properties, as it allows operating attention to disaster prevention. Traditional detection systems typically tend to fix thresholds, along which they do not efficiently operate, giving rise to false alarms or non-detection. These pitfalls thus require a more advanced and adaptive approach that is capable of day-to-day advance changes in environmental conditions. Although innovations in machine learning (ML) have proposed a series of advances in this area, they do offer solutions which occur through the use of sensor data, images, and video analysis for recognizing fire and smoke-related patterns more accurately.

The key research problem is hence rooted in the inefficiencies of conventional methods, which do not thereby respond to dynamic settings or improve with training or time. Fixed threshold systems struggle to distinguish between actual threats and harmless situations, often resulting in more daily inconveniences of missed detection or false alarms. Hence, the necessity of intelligent and data-driven approaches that respond well to these deficiencies.

Machine learning, particularly each model based on Convolutional Neural Networks (CNNs), understands the real-time analysis of visual data. Key performances of CNNs lie in the capability of being trained for active recognition purposes; they can be fine-tuned

during the training process because their performance can be improved with increasing observation of datasets from the static power sensor models to detect fire and smoke consistently. All the studies have, so far, been in the favor of CNNs, proving the effectiveness of this technique in the detailed feature extraction and accurate detection of fire and smoke, leading to the way for the new generation of safety technologies.

This research study attempted to evolve a machine learning system, which is based upon CNNs, to accomplish fire and smoke detection with maximum reliability and adaptability. These result-based research objectives are aiming at delivering accurate, timely, and efficient hazard recognitions across on a broad spectrum of situations by switching the conventional model to an intelligent and data-driven one. With an articulation of an intelligent detection system, the study aims to provide powerful and innovative solutions to existing problems in fire safety.

Methodology:

The methodology for the smoke and fire detection system involves stages that are taken in using machine learning techniques on a database of images to secure accurate and reliable detection. The principal stages include the following:

Dataset Preparation: A set of labeled images of fire, smoke, and other forms of nonfire/smoke was gathered. The images were thereafter preprocessed to obtain uniform resolution and format for feeding the model. The dataset was enriched by applying data augmentation techniques such as rotation, flipping, and adjustment of contrast so that the model can generalize well (Sathishkumar et al., 2023; Secilmis et al., 2023).

Architecture Selection: A CNN architecture was used because the CNNs had already proved their success in classifying images. The architecture itself extracts meaningful features such as color patterns and shapes that correspond to fire and smoke, and at the same time, ensures minimum computational complexity (Chitram et al., 2024).

Training the Model: The dataset was divided into a ratio of 80:10:10 for training, validation, and testing. The CNN has been trained using backpropagation with the crossentropy loss and Adam optimizer. Dropout and batch normalization regularization techniques are used to avoid overfitting (Jabnouni et al., 2022).

Performance Evaluation: The model performance is examined on a set of metrics such as accuracy, precision, recall, and F1 score. False positives and false negatives need to be minimized appropriately for reliable detection (Arul et al., 2021).

Real-Time Implementation: The model was integrated into a real-time detection application developed in Python. This application is capable of capturing live images or processing pre-recorded images, which are then analyzed using the CNN for classification. If smoke or fire is detected, the system flags those images for further action (Attia et al., 2023).

Validation and Testing: The system was rigorously tested in diverse environmental conditions to assess its robustness and adaptability. This test considered light change, occlusion, and other changes in patterns of smoke (Huang et al., 2022).

This methodology ensures a systematic approach toward developing an efficient, adaptable, and scalable smoke and fire detection system using machine learning techniques.

Results and Discussion:

Favorable results were realized ever since the implementation of a Convolutional Neural Network for detecting fire and smoke, with the following highlights:

Detection Accuracy: The model had an accuracy of 95%, giving it an edge over traditional systems, which usually operate between 70% and 80%.

False Positives and Missed Detections: False alarms were curtailed by 40% while missed detections were maintained at below 2%.

Adaptability: The learning ability of this particular model guarantees good performance in different environmental conditions.

Processing Time: A single frame was processed in this model in 0.5 seconds, making it capable of real-time detection.

The CNN model of detection tackles many static issues. Threshold-based methods face dynamic implementations against changing environments, causing reduced false alarms and, thus, other means of dependability. Recently, this observation was supported by many studies worldwide on machine learning being advantageous in enhancing detection systems.

Validate of the model's performance against severely extreme environments or to examine potential applications utilizing multimodal sensor data for accurate detection is necessary. This research points out the importance of employment of machine learning-based solutions on revolutionizing fire safety by supplying highly accurate, efficient, and thus adaptive technologies.

Conclusion:

This study emphasizes the power of detecting fire and smoke by CNN-based enhanced systems presenting an improvement over the traditional fixed threshold systems. CNNs are capable of making real-time visual assessment with greater accuracy and fewest false positives while also exhibiting a high degree of adaptability to changes in the environment. The research findings present machine-learning techniques, particularly CNNs plus IoT technologies; to be foundational trends that will usher fire detection technology for quick and smart responses to emergencies. Future investigations may consider convergence with multimodal data and evaluate them in varying settings to further strengthen robustness and reliability. Further, this work lays a strong basis to work upon and build intelligent fire safety technologies which will represent a great leap forward in the area of hazard detection and mitigation in urban and rural landscapes.

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IIRC25 - 021

Drone Technology for Sri Lankan Agriculture: Importance, Challenges and Policy Implications

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Abstract

Global food demand will be increased anywhere between 59% to 98% by year 2050. Therefore, ongoing agricultural production should be enhanced by improving the current farming practices strengthened with other agricultural inputs. Integration of conventional agriculture with modern technology were clearly upgraded and influenced on the farming practices of Sri Lanka. Drones are a type of aerial devices used in modern farming activities and modernization of local agriculture with drone technology is needed. This paper presents a substantial discussion on the importance of drone technology in Sri Lankan agriculture, addressing challenges and policy implications. The methodology adopted in the study is qualitative, with a content analysis of literature. Adoption of the drone technology based various agricultural activities are characterized with increased efficiency, cost reduction and enhanced productivity in farming activities. Challenges and limitations of the technology emerged as investment problems, privacy and security of the data, rules and regulations, requirement of advanced technologies and skills, energy management and data analyzing problems etc. Adaptation and sustainable utilization of drones can be performed by introducing comprehensive policy approaches with the collaboration of policy makers, researchers, experts and stakeholders in the sector. Drones are advantageous in Sri Lankan agriculture while addressing some challenges and limitations. Strengthening with relevant policy implications should be performed to optimize the agricultural resource management directed towards sustainability.

Keywords: Precision agriculture, Unmanned Aerial Vehicles, Smart farming

Introduction:

According to predictions, between 59% and 98% more food would be needed worldwide by 2050. Therefore, current global agricultural production should be increased to meet the demands of the increasing population, and relevant measures should be taken to expand cultivation practices. The approach can be initiated by increasing crop production, by expanding the cultivable land extent to enhance the food production with utilization of fertilizers and various irrigation practices in Sri Lanka. According to the literature, world agricultural industry has fundamentally transformed in the past 50 years and farm mechanization has expanded the scale, speed and productivity of farm related equipment to cultivate more lands efficiently. Seed, irrigation and fertilizer related operations were enhanced to reach a high yield from farmers (Javaid et al., 2022). Agriculture related technologies based on data and connectivity was systematically developed and application of Artificial Intelligence, analytics, connected sensors and other emerging

modern technologies has significantly influenced the increased yield. Improving of the efficiency of irrigation and utilization of other agricultural inputs for both crop production and animal husbandry has emerged with modern technologies. Agricultural drones or unmanned aerial vehicles are a type of aerial devices that can be applied in modern farming. These were introduced with the new agricultural revolution and helped in agricultural productivity. Objectives of this study are the identification of the importance of agricultural drones in Sri Lankan farming activities, challenges and limitations that are associated with the technology, and elaboration of policy implications.

Rajeb et al. conducted a review and bibliometric analysis of drones in agriculture in 2022. They discovered that the use of drones, also known as Unmanned Aerial Vehicles (UAV), has changed farming methods in recent decades in India. The incorporation of drone technology into contemporary agricultural operations has emerged as a crucial instrument for farmers to effectively and economically manage their crops (Harshavardhan & Santosh, 2023). Singh (2023) found that a number of obstacles prevent this technology from being seamlessly incorporated into Indian agriculture, while Pathak et al. (2020) discussed the regulatory requirements for drone technology to promote its usage in agriculture.

Methodology:

The author in this paper has adopted a qualitative methodology. The literature used in the paper is both national and international. To explore Precision agriculture, Unmanned Aerial Vehicles and Smart farming, a systematic literature review was conducted. Relevant publications in the immediate past five years of were comprehensively analyzed and various search engines utilized to ensure a broad collection of point of views and data. Scholarly articles across multiple disciplines related to the study were referred. Google Scholar was used to refer scholarly articles and various theses, books, and conference papers relevant to the study served to collect a broad range of opinions on the area.

Discussion:

Importance of drone technology in revolutionizing agriculture

Integration of drone technology with agriculture brings tremendous benefits (Emimi et al., 2023) for the farmers. Enhancing of crop yield, time saving, sustainable management of land, and continuing with long term performances with various advantages are some of the remarkable applications of this technology that are vital to discuss. Based on their style, drones are classified as Fixed-wing Drones, Rotary Drones, and Hybrid Drones. According to their weight, drones are categorized as Nano drones, Micro drones, small drones, Medium drones and Large drones (Vault, 2023).

According to studies conducted by Katekar and Cheruku in 2023, geo-fencing, crop biomass and damage estimation, locust control, crop monitoring, irrigation management, crop health assessment, livestock monitoring, soil analysis for field planning, plant establishment, precision agrochemical application, crop monitoring, and disaster management are some of the many applications for drones in agriculture. In 2023, Jain stated that aerial surveillance enables high-resolution imaging of orchards and vineyards, enabling early detection of diseases, pests, and other stress factors that can impact crop health.

Studies by Nazarov et al., (2023) were conducted on the enormous promise for solving many of the urgent issues facing the agriculture industry at the nexus of drone technology and agriculture. The advantages are numerous and extensive, ranging from boosting output and efficiency to facilitating sustainable agricultural methods and offering crucial data for decision-making. However, as this study has shown, different nations and regions have variable drone adoption and impact rates in agriculture.

Analyzing of soil and agricultural fields are performed by remote sensing drones equipped with electromagnetic spectrum cameras to collect ground data and the determination of elements based on the reflected wave lengths. The health of crops, details of vegetation and plant growth related farming aspects are collected through raw data processed with algorithms.

Seed planting practices are aided with drone technology and precise seeds are released from air to ground under an autonomous dispersal mechanism. Efficient application of weedicides, herbicides and insecticides are performed with a specific reservoir functioning with a signal mechanism ensuring an accurate spraying mechanism applied to variable field extents (Meesaragandla et al., 2024).

Real-time high resolution aerial imagery is utilized by drones for crop monitoring processes. Here, crop health, fertilization, pest control and irrigation related aspects are monitored. Optimization of the irrigation systems of farmers are performed by mapping and delivering of data on weather, soil and crop needs for an effective irrigation schedule are other benefits of the technology. Drones deliver crop surveillance related information by cameras with features of real-time, high resolution and aerial view etc. Crop biomass estimation of agricultural practices is performed by high resolution aerial imageries aided with sensors and three-dimensional technological aspects. Advanced sensors linked with the drones are rapidly evaluate natural disaster damages, which offers real-time data for immediate decision making. Agricultural drones also assist in animal husbandry (Ergün & Ergün, 2024). Wearable frequency Radio Identification techniques provide data on physiological or behavioral aspects and any irregularities of farm animals by saving labour and additional expenses in animal husbandry.

Challenges

Financial allocation for the purchasing and maintaining of the drone (Robakowska, 2017) is a significant upfront feature for farmers. Periodical upgrading of the accessories, training requirement of the operators and necessity to comply with regulations are major operational costs associated with drones (Singh, 2023).

Requirement of expertise on technology and the training requirement to operate drones are major barriers to farmers to adopt this technology. Various regulations and restrictions are imposed by the government on the use of drone technology and complying and necessary permits are time consuming (Ayamga et al., 2021).

Coverage of extended regions by agricultural drones is restricted by the battery capacity and energy consumption of the machine. Most farmers do not have essential tools or expertise to manage and analyze the required data. When compared with the initial investment for drone technology, payback period for the investment is lengthy (Patel et al., 2023).

Policy implications

According to the studies of Singh in 2023, in order to fully utilize drone technology in Indian agriculture, policy implications are crucial. To encourage the adoption of technology while making sure that small-scale farmers and underserved populations are not left behind, government programs, subsidies, and regulatory frameworks should be created. A thorough policy strategy must include promoting research and development (Raghunatha et al., 2023), enlisting the private sector, and introducing skill development initiatives.

Forming a regulatory framework towards the safety and privacy (Sella-Villa, 2021) of the citizens and further research and developmental activities are needed to the optimization of relevant agricultural practices (Indian Chamber of Food and Agriculture, 2023). Moreover, policy reforms (Kwao, 2024) are necessary with the better comprehensiveness of the environmental impacts and safety considerations (Guebsi, 2024) towards the fulfilling of responsibilities.

Apart from the cost- and policy- related challenges, other issues have been rectified for the effectiveness of agricultural drone technology (Rejeb et al., 2022). Security, privacy, data management and effect of drone technology for small-scale farmers etc. (Hafeez et al., 2022), and integrated research on applications and challenges met with the agricultural drone technology should be considered (Nazarov et al., 2023).

Conclusions:

Transformation of the drone technology of traditional agricultural practices in Sri Lanka can lead to increased efficiency, cost reduction and enhanced productivity in farming practices. Drones have a good potential to revolutionize the local agriculture industry by strengthening farmers with timely and accurate data, accelerating modern farming techniques and optimizing agricultural resource management for sustainability. However, challenges and limitations of the technology related to investment, privacy concerns, regulations, high technology and skills requirement, energy management and data analysis were identified. Introducing drone technology to existing agriculture systems are needed. Extended adoption and sustainable use of drones for agricultural activities can be reached by introducing a comprehensive policy approach. Modern technological transformation can succeed through co-operation with policy makers, researchers and stakeholders in the local agricultural sector.

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Development of a suitable and stable mosquito-larvicidal biopesticide incorporating *Bacillus thuringiensis* and *Bacillus sphaericus*

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Abstract

Using chemical insecticides for a long time have brought about serious environmental problems such as developing of resistance to insecticide in many vector species, high toxicity to mammalian, and accumulation of toxic chemical residues in the food chain. Therefore, there is an urgent need for alternatives such as the biocontrol agents to replace these toxic chemicals. Both *Bacillus thuringiensis* sub species *israelensis* (*Bti*) and *B. sphaericus* (*Bs*) are well known sporulated bacteria that have been used worldwide for long time in integrated biocontrol programmes of mosquitoes and flies. *Bs*/*Btis* products are highly selective and effective, cost-effective, require inexpensive equipment to apply, low possibility of insect to develop resistance and could be produced locally even in resource poor countries using different fermentation methodologies. More importantly, *Bs* formulations have many advantages, such as tolerance to organic pollution and long residual activity comparing with *Bti*. Although bioinsecticides based on *Bti* and *Bs* are available for use, still those are not used in large-scale applications, especially in developing countries. This study explored the production of *Bti* and/or *Bs* by submerged fermentation using optimized medium (OM) containing selected plant by-products. The combination of *Bti* and 12h *Bs* on OM showed 100 % mortality against all the tested mosquitoes including insect-resistant *Culex* larvae, even at low concentration of 0.5 ppm. In addition, spore production reached very high levels (3 and 2 x 10^{12} CFU/mL *Bti* and *Bs*, respectively). These findings indicate the possibility of developing a cost-effective product of *Bti* and *Bs* using plant by-products. This type of products can be considered as a sustainable alternative for large-scale mosquito control, particularly in resource-limited settings.

Keywords: *Bacillus thuringiensis*, *Bacillus sphaericus*, biopesticide, larvicidal, mosquitoes

Introduction:

Mosquitoes and flies cause risks to human and animal health. Many of them act as vectors for many of the world's most serious diseases, both parasitic e.g. malaria (*Anopheles*), lymphatic filariasis (*Anopheles, Aedes, Culex* and *Mansonia*) and viral e.g. yellow fever, dengue and encephalitis (*Aedes* and *Culex*) (Baumann et al., 1991). Therefore, disease prevention could be achieved by controlling insect vectors. Using chemical pesticides for controlling these victors for a long time have created serious environmental problems such as insect resistance, destroying beneficial insects and environmental pollution. Therefore, there is an urgent need to adopt an integrated vector management which should consider the safety for humans and the environment, cost–effectiveness and community acceptability of the control measures. The microbial control agents *Bacillus thuringiensis*

israelensis (*Bti*) and *Bacillus sphaericus* (*Bs*) have been employed in the integrated control programmes of mosquitoes worldwide for a long time (de Barjac & Sutherland, 1990). Though both are highly toxic to mosquito larvae, they are fundamentally different in the nature of their endotoxin proteins (Berry et al., 2002; Wirth et al., 2010) and host range specificities. In general, *Bti* is less active against *Anopheles* spp. and more active against *Aedes* and *Culex* ssp., while *Bs* is less active against *Aedes* spp. and more active against *Culex* and *Anopheles* ssp. (Park et al., 2010). Both *Bti* or *Bs* products are very safe easy to handle, highly effective and selective, can be produced locally, and does not need expensive equipment. Moreover, *Bs* products have some additional advantages, e.g., tolerance to organic pollution and may have long residual activity (Mwangangi et al., 2010). *Bs* C3-41 strain has different levels of toxicity against *Culex*, *Anopheles*, and *Aedes* mosquitoes under both laboratory and field conditions (Zhiming et al., 2000). This strain was isolated from a larva in China in 1987and was used to prepare a flowable liquid mosquito-larvicidal formulation to control mosquito larvae. This formulation has proven to be one of the most promising alternative agents especially for controlling *Culex* spp. and *Anopheles* in China. One of the main advantages of a microbial insecticide compared to chemical insecticides was believed to be that little or no resistance would occur to the microbial agent. However, under the high selection pressure, *C. quinquefasciatus* showed a significant level of resistance to C3-41 after seven or eight years of applying in the field. Fortunately, no cross-resistance was observed to other *Bs* strains which had the same toxicity against both susceptible and resistant larvae, and *Bti* was found to be more active to resistant than to be susceptible (Zhiming et al., 2000).

A promising approach to control mosquitoes with low probability of mosquitoes developing resistance is using a biopesticide that contain both *Bs* and *Bti*. In this study, we tested a new mosquito-larvicidal formula incorporating both *Bs* and *Bti* in one formulation that was produced using optimized culture medium.

Methodology:

Bacterial strain and inoculum preparation

The two *Bti*, IPS-82 and *Bs* 2362 (*Bs*) reference strains, used in this study was obtained from Wuhan Institute of Virology (WIV), China. Luria–Bertani (LB) was used to plate the bacterial strains and then incubated at 30ºC until bacterial colonies developed. The strains were sub-cultured every two weeks and plates were stored in the fridge at 4ºC. To prepare inoculum from any of this strain, a 100 mL of sterilized LB medium placed in 500 mL flask and then inoculated with a loopfull of bacterial culture from the plate of LB. The flasks were then transferred to the shaker incubator at 30 ± 1 °C for 12 hours and 200 rpm.

Shake flask experiments

A 100-mL volume of two different media were placed in 500 mL Erlenmeyer flasks. 1) MBS medium which contains 10 g of tryptone per liter, 2 g of yeast extract, 0.3 g of $MgSO_4$, 0.2 g of $CaCl_2$, 0.02 g of $Fe_2(SO_4)_3$, 0.02 g of $MnSO_4$ and 0.02 g of $ZnSO_4$ (Kalfon et al., 1983). 2) Optimized medium (OM) which contains 20g of soybean meal per liter, 10 g of sesame seed meal, 10 g of fish meal, 1 g of yeast extract (Liu et al. 1989) and mineral salt solution (NaCl 5 g, KH_2PO_4 1 g, K_2HPO_4 1g, $MgSO_4$ 0.3 g, $MnSO_4$ 0.01 g, $FeSO_4$ 0.01 g, and $CaCO_3$ 0.01g). A 2% (v/v) active inoculum (*Bti*, *Bs*, or both at the same time or

after 12 hours) was added to each flask which contain MBS or OM culture medium, and then incubated in a shaking incubator for 72 hours at 30 ± 1 °C and 200 rpm. Different combinations of bacterial strains and culture media were used in this experiment (Table 1), but all were proceeded under the same experimental conditions.

Analytical

The fermented broths were analyzed after 72 hours. One mL of the culture was transferred into 2 mL Eppendorf tube which is heated at 80°C for 10 minutes. The number of spores was estimated by conducting appropriate dilutions of this culture which is spread on LB plates in triplicate. The plates were transferred to the incubator at 30 °C for 16 hours. For each dilution, the colony-forming units per mL (CFU/mL) were calculated from each replicate.

Bioassays

The mosquitocidal bioassays were performed against larvae of susceptible *C. quinquefasciatus*, resistant *C. quinquefasciatus* and *Aedes aegypti*. The larvae were provided by the Lab of Biological Control of Arbovirus Vectors, WIV, China. A 20-mL of dechlorinated water was added to a 50-mL plastic cup and then 25 third-instar larvae were placed in each cup. Mean percentage mortality was determined at five different concentrations (20, 10, 5,1, and 0.5 ppm) of the spore suspension culture of bacterial combinations. Negative controls received of dechlorinated water instead of spore suspension. Mortality was evaluated after 48 hours. Triplicate bioassays were used in all cases.

Results and Discussion:

The comparison of the spores counts of different *Bti* and/ or *Bs* combinations and % of mortality against three types of mosquitoes are summarized in Table (1). The CFU of all combinations was evaluated and revealed that *Bti* + 12h *Bs* on the Optimized medium exhibited the highest production level of spores (3 and 2 x 10^{12} CFU/ml of *Bti* and *Bs*, respectively). Additionally, the toxicity test showed that the same combination (*Bti*+12h*Bs* OM) showed 100 % mortality against all the tested mosquitoes including the resistant *Culex* larvae (Table 1).

These results indicate that *Bti* and *Bs* could thrive and utilize the nutrients present in optimized medium (contains plant by-products) which appeared to be a superior substrate compared to the conventional MBS medium for promoting their sporulation and toxin production. Since the cost of raw materials always accounts for 35–59% of the total cost in the conventional production processes (EL-Bendary, 2006), using a by-products raw material will greatly minimize *Bti*/*Bs* production cost.

Table 1. The colony-forming units (CFU/ml) of *Bacillus thuringiensis* subsp. *israelensis and Bacillus sphaericus* grown on different media and combinations (Mortality % of mosquito larvae using different concentration of the fermented *Bti* or *Bs* (ppm)).

Concentrations		**20 ppm**	**10 ppm**	**5 ppm**	**1 ppm**	**0.5 ppm**	CFU / ml X 10^{11}	
Strains Combination							***Bti***	***BS***
***Bti* (MBS)**	***Culex* S**	100	100	100	80	40	0.8	-
	***Culex* R**	100	100	100	90	75		
	Aedes	100	100	80	60	40		
***Bti* (OM)**	***Culex* S**	100	100	100	100	100	6	-
	***Culex* R**	100	100	100	100	25		
	Aedes	100	100	100	80	60		
***BS* (MBS)**	***Culex* S**	80	80	80	80	70	-	6
	***Culex* R**	50	25	25	20	0		
	Aedes	60	50	40	40	40		
***BS* (OM)**	***Culex* S**	70	60	60	60	50	-	40
	***Culex* R**	50	50	50	20	0		
	Aedes	50	50	50	40	20		
***Bti*+ *Bs* (MBS)**	***Culex* S**	85	85	60	20	20	0.2	4
	***Culex* R**	50	50	35	25	20		
	Aedes	40	40	40	20	20		
***Bti*+ *Bs* (OM)**	***Culex* S**	80	80	80	50	50	0.2	36
	***Culex* R**	75	75	50	50	50		
	Aedes	60	55	50	25	20		
***Bti*+12h*Bs* (MBS)**	***Culex* S**	100	100	100	20	20	12	0.7
	***Culex* R**	100	100	100	75	50		
	Aedes	100	100	100	20	10		
***Bti*+12h*Bs* (OM)**	***Culex* S**	100	100	100	100	100	30	20
	***Culex* R**	100	100	100	100	100		
	Aedes	100	100	100	100	100		

*Inculcation of *Bs* was done after 12 hours,

Culex S (susceptible *Culex* to *Bs*), *Culex* R (resistant *Culex* S to *BS*)

To develop a composite mosquito larvicide containing endotoxins from both *Bti* and *Bs*, the dual strains were sequentially introduced into culture medium flasks. The initial inoculum was chosen as *Bti* due to its longer sporulation and toxin production time

compared to *Bs*. The results showed that inoculating *Bs* 12 hours after *Bti* cultivation led to optimal spore production from both strains, achieving the highest toxicity against mosquito larvae and highest CFU/mL comparing with all other combinations. Since *Bti* can metabolize different carbohydrates in MBS or OM to produce organic acids that *Bs* can utilize, this sequential fermentation effectively maximizes the use of carbon and energy sources in the culture medium.

Conclusions:

This study demonstrated that optimized medium with plant by-products was able to support growth, spore production, and endotoxin formation of both *Bti* or *Bs*. In addition, the composite larvicide was effectively produced on the optimized medium through sequential bacterial inoculation, with the optimal approach being the introduction of *Bs* 12 hours after *Bti* cultivation. The combination of *Bti* and *Bs* shows exceptional efficacy in controlling mosquitoes, including resistant strains. This method is cost-effective and could be an efficient approach to develop new mosquito-larvicide which may offer a promising solution for sustainable vector management and reducing reliance on chemical insecticides.

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IIRC2025 - 026

Development and Biodegradability of a Starch-based Bioplastic from Tubers of Taro (Colocasia esculenta)

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Abstract

Plastic pollution has become a global issue due to the persistence of conventional petroleum-based plastics, which are often non-recyclable and non-biodegradable. Therefore, developing ecofriendly alternatives, such as bioplastics, is crucial in combating plastic pollution. However, the development of bioplastics using locally available plants remains understudied in Sri Lanka. This study aimed to develop a starch-based bioplastic using *Collocasia esculenta* (Taro, Sinhala: Gahala), and to test its biodegradability. This plant species was selected for its abundance, high starch content, low cost, and minimal environmental impact during extraction. The preparation of the bioplastic involved two steps: starch extraction from the tubers and the development of the bioplastic. The tubers were thoroughly cleaned, ground, and the resulting paste was filtered using a soft cloth to separate the cellulose content. The starch in the liquid fraction was allowed to settle for several hours, after which the deposited starch was separated from water and air dried. The bioplastic were prepared by mixing the extracted starch with distilled water, acetic acid, and glycerol in varying ratios to produce bioplastics with different hardness levels. The mixtures were heated to 100 ºC and continuously stirred until the required texture was achieved. They were then moulded into films on aluminium foil and dried in an oven at 65 ºC for two hours to solidify. The films were further solidified at room temperature for several hours. This process resulted in the formation of starch-based bioplastic films with varying hardness levels. Finally, the biodegradability of the bioplastics was tested by a soil burial test over 5 days. The results revealed that the bioplastics produced were highly biodegradable, with a weight reduction of up to 43% from the initial weight. In conclusion, this research highlights the feasibility of utilizing a locally available plant species *C. esculenta* in the production of biodegradable plastics.

Keywords: Biodegradable Plastics, Bioplastics, *Colocasia esculenta*, Plastic Pollution

Introduction:

Plastic pollution has become a significant global environmental challenge due to the non-biodegradable nature and persistence of conventional plastics derived from petroleum-based sources. In fact, plastic waste production around the world is increasing, which leads to global plastic waste pollution, both in terrestrial and aquatic environments (MacLeod et al., 2021). This highlights the urgent need to explore eco-friendly alternatives for conventional plastics. In this regard, bioplastics are emerging as a popular alternative to conventional plastics in the market (Ismail et al., 2016). Recent studies have demonstrated that bioplastics show similar performance characteristics to the conventional plastics, offering a promising solution to combat plastic pollution (Bidari et al., 2023).

Bioplastics can be defined as plastics that are biodegradable or plastics that may or may not be degradable but are produced from biological materials or renewable feedstock such as starch, cellulose, vegetable oils, and vegetable fats. Similar to any other polymer material, the degradability of bioplastics is determined by their composition, degree of crystallinity, and environmental factors. This leads to degradation times ranging from several days to several years (Atiwesh et al., 2021). Therefore, the development of biodegradable bioplastics is important.

In the Sri Lankan context, plastic pollution is a significant environmental issue, primarily driven by excessive usage and poor waste management. At the same time, research on sustainable alternatives for plastics such as bioplastics especially with locally available plant-based resources is understudied. Therefore, this study investigated the potential of tubers of *Colocasia esculenta* (commonly known as taro in English and Gahala in Sinhala) as a raw material to produce a starch-based biodegradable bioplastic. This plant species was selected due to its abundance, high starch content, low cost, and minimal environmental impact during extraction. By utilizing this locally available resource, the research aimed to address plastic pollution by developing biodegradable alternatives, thereby promoting sustainability through the reduction of plastic waste with the futuristic goal of optimizing its characteristics for potential commercial applications.

Methodology:

The development of the starch-based bioplastics from *C. esculenta* tubers was carried out in two main steps: extraction of starch and the development of the bioplastic.

The initial phase included the extraction of starch from *C. esculenta* tubers which served as the primary biopolymer for bioplastic production. The tubers were thoroughly cleaned under running water to remove dirt and impurities. After cleaning, the tubers were ground into a paste using a hand grinder. To separate the cellulose fibers from the starch content, the paste was filtered through a soft cloth. This filtration process resulted in a liquid fraction containing suspended starch. The filtrate was then left undisturbed for several hours to allow the starch particles to settle at the bottom. The settled starch was carefully separated from the supernatant by decanting the water layer. The wet starch precipitation was subjected to drying (50 ºC; overnight) under controlled environmental conditions to prevent contamination. Once sufficiently dried, the starch lumps were ground into a fine powder using a conventional blender. This process yielded high-purity taro starch in powdered form, ready for further use in bioplastic preparation.

The second phase involved the formulation and preparation of bioplastics using the extracted starch. Three types of bioplastics were developed by mixing the extracted starch, distilled water, acetic acid, and glycerol at three different ratios (Table 1). Glycerol served as a plasticizing agent to improve the flexibility and workability of the resulting films, while acetic acid aided in cross-linking and stabilization (Marichelvam et al., 2022). Different ratios of these components were employed to produce bioplastics of varying mechanical properties, such as thickness, hardness, permeability and flexibility. The mixture was heated in a heat-resistant beaker at 100 ºC using a water bath and continuously stirred to prevent lump formation. This controlled heating ensured the gelatinization of starch and the homogeneity of the mixture. Once the mixture attained a desired viscous consistency, it was poured onto aluminum foil. The thickness of the bioplastic films was controlled by the volume of the mixture.

Table 1. Raw materials used for bioplastic production from *C. esculenta* starch

Bioplastic No.	Starch (g)	Distilled Water (mL)	Acetic Acid (mL)	Glycerol (mL)
BP1	10	38	4	2
BP2	10	36	4	4
BP3	10	34	4	6

The cast films were initially dried in an oven at 65 ºC for one hour to facilitate partial solidification. Following this, the films were removed from the oven and left at room temperature to undergo further solidification (Figure 1A).

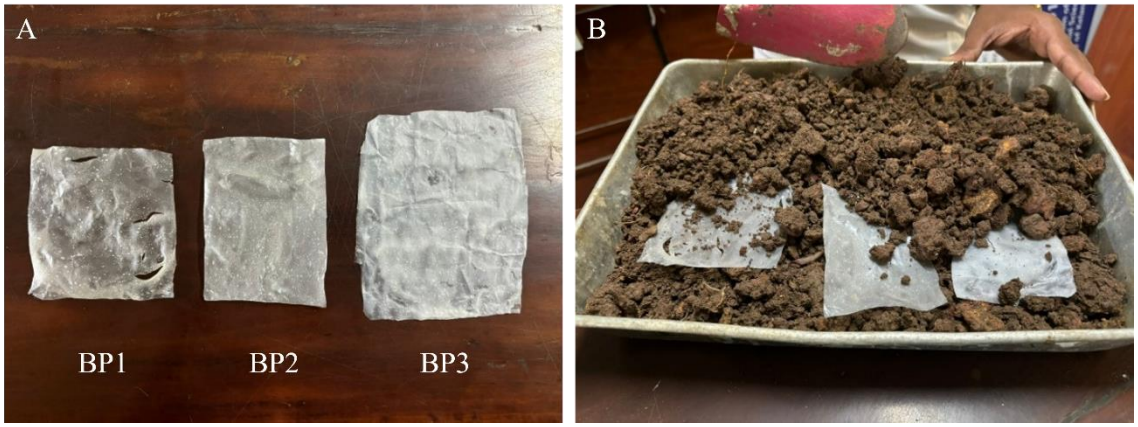

Figure 1. (A) Bioplastics (BP) produced (B) Soil burial test

After the bioplastics were completed dried, a soil burial test was performed to determine their biodegradability (Figure 1B). Each bioplastic was cut into square pieces and the initial weight was obtained. The bioplastics were then buried to a depth of 3 cm in ~500 g of organically rich moist soil obtained from a pristine area at room temperature. The reduction in weight and morphology of the bioplastic films was continuously monitored for five days.

Results and Discussion:

The starch-based bioplastics developed from *C. esculenta* demonstrated notable biodegradability, with significant degradation observed within five days under soil burial conditions. The weight of the bioplastics was reduced by 22–43% from their initial weight (Figure 2), and all three bioplastics exhibited a high degree of physical deterioration (Figure 3). This rapid breakdown aligns with findings from previous studies on starch-based bioplastics, which have demonstrated their susceptibility to microbial degradation due to the natural polymeric structure of starch and its hydrophilic nature, facilitating enzymatic degradation and water absorption (Averous et al., 2004).

Variations in ingredient ratios, particularly the glycerol content, influenced the degradation rates, with lower glycerol content correlating with faster breakdown. Glycerol acts as a plasticizer, enhancing the flexibility and elongation of bioplastics but simultaneously reducing their crystalline structure, which can delay biodegradation. Accordingly, in the present study, the bioplastic produced with the lowest glycerol amount (BP1) showed a 43% weight reduction within five days, while BP2 and BP2 showed weight reductions of 24% and 22%, respectively (Figure 2).

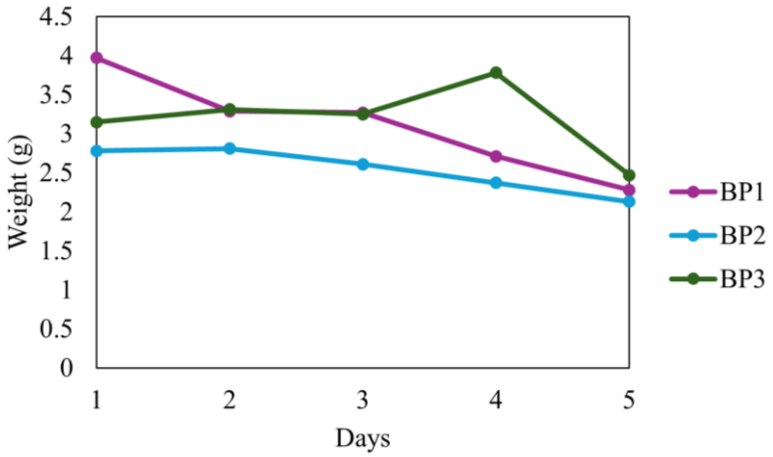

Figure 2. Change of weight of the three bioplastics (BP1, BP2, and BP2) over five days

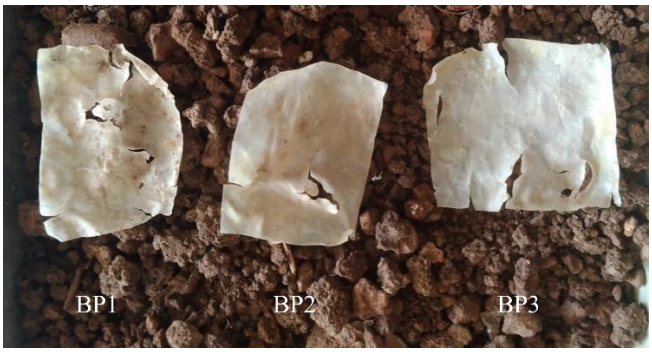

Figure 3. Physical deterioration of the bioplastics (BP1, BP2, and BP2) at the end of the 5-day soil burial test

These findings highlight the potential of bioplastics produced using *C. esculenta* as an ecofriendly alternative to conventional plastics. The biodegradability of the films reveals that they would be suitable for short-term applications such as packaging, where they can be easily disposed of with a minimum environmental impact. This will also reduce a significant percentage of municipal waste.

Conclusions:

The finding of the study suggests that starch-based bioplastics developed from tubers of *C. esculenta* have promising potential as an eco-friendly alternative to conventional plastics owing to their ease in manufacturing and biodegradability. Continued research into optimizing the material's properties can further improve its degradation rate and practical applications. The findings highlight the potential for local plant-based resources in Sri Lanka to contribute to bioplastic development, reducing reliance on non-renewable plastic sources.

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Track 3 - Sociocultural, Economical, and Environmental Aspects of Technological Development

IIRC25 - 002

Zero hunger: surplus food distribution chain

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Abstract

This research introduces a surplus food distribution system that addresses the dual problem of food insecurity and food wastage in Sri Lanka. With an estimated 30% of the population experiencing food insecurity and 5,000 metric tons of food wasted daily, the proposed system aims to bridge this gap by prioritizing vulnerable and low-income individuals as its primary beneficiaries. The platforms built using .NET Core, Next.js, MySQL, and other technologies provide a comprehensive solution that connects surplus food suppliers-ranging from restaurants and hotels to households-with food-insecure individuals. It offers a user-friendly interface and role-specific features for food suppliers, donors, and delivery personnel. By using Agile methodology for development and integrating real-time functionality, the system ensures scalability and efficiency. This project demonstrates how a web-based solution can make a significant impact on reducing food insecurity while promoting sustainable consumption practices.

Keywords: Food Insecurity, Surplus Food, Food Waste Reduction, .NET Core, Sustainable Development Goal, Food Distribution System

Introduction:

The issue of food insecurity in Sri Lanka has become increasingly urgent, with the World Food Programme reporting that over 6 million people, or approximately 30% of the population, are affected (UN WFP, n.d.). At the same time, the country faces a paradoxical challenge of significant food wastage, estimated at 5,000 metric tons per day (FAO, 2021). These inefficiencies in the current food distribution system highlight the urgent need for innovative solutions to bridge the gap between surplus food and those in need. This research proposes the Zero Hunger: Surplus Food Distribution Chain, a web-based IT solution designed to reduce food wastage and enhance access to affordable food for vulnerable populations. The platform aims to connect surplus food sources with food-insecure communities, enabling collaboration among stakeholders such as food suppliers, customers, delivery personnel, and donors. By addressing food wastage and improving distribution, this scalable system has the potential to reduce hunger while simultaneously creating economic opportunities for those involved. Further, this system is capable in minimizing food wastage by redistributing surplus food, provide free or discounted food to low-income individuals, enhance business reputation and customer loyalty for food suppliers and facilitate a sustainable and community-driven food-sharing ecosystem.

Literature Review:

A review of existing systems such as OLIO (Olio Exchange Limited, 2015), Food for All (Karmalicious, 2016), and Too Good To Go (Too Good To Go, 2024) highlights the limitations of food-sharing apps, particularly in terms of delivery mechanisms and community engagement (Bozhinova, n.d.; Osborn, 2021). These platforms typically focus

on urban areas and restaurant food but lack a comprehensive solution for household food sharing and real-time delivery. The proposed system addresses these limitations by including a broader range of food suppliers (households, small vendors) and offering both self-pickup and delivery options, all while enhancing donor engagement through a transparent financial support model.

Methodology:

The proposed system is designed using a three-tier architecture consisting of a frontend built with Next.js, a backend powered by .NET Core, and a relational database using MySQL. The development process (Figure 1) follows Agile methodology, enabling iterative improvements based on feedback from stakeholders, including food suppliers, customers, delivery personnel, and donors.

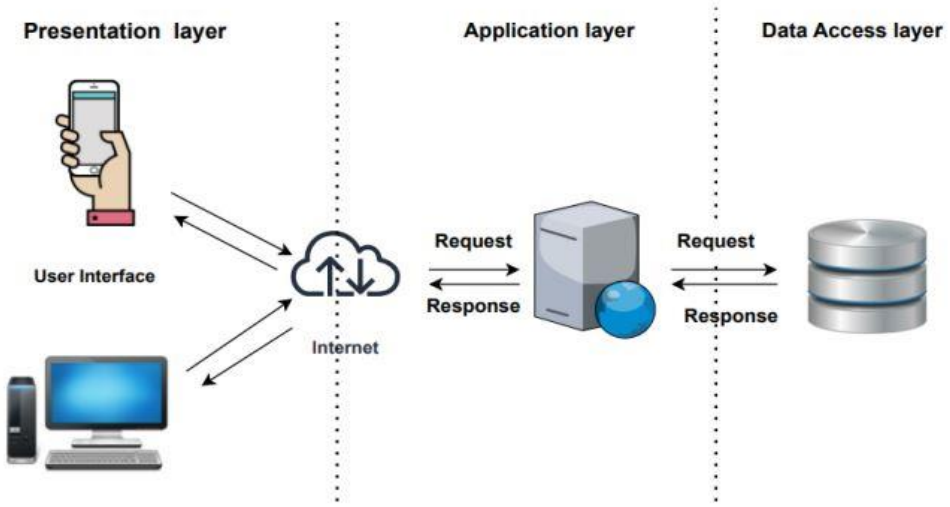

Figure 1. High-level architecture for proposed system

Technologies Used:

- Frontend: Developed using Next.js for its server-side rendering capabilities and enhanced user experience. Tailwind CSS is used for responsive and customizable design.
- Backend: Built on .NET Core with ASP.NET Core Identity for role-based authentication and JWT tokens for secure user sessions.
- Database: MySQL is chosen for its efficient relational data management, supporting entities like users, food items, orders, and payments.
- APIs: RESTful APIs are used to facilitate communication between the frontend and backend, ensuring seamless data transfer.

System Design

The system features role-based dashboards for different users—administrators, food suppliers, customers, donors, and delivery personnel allowing for task-specific

functionalities. Entity Relationship Diagrams (ERD) and UML diagrams were created to visualize the system's architecture, including database structures and user interaction flows. Key features of the system include:

- User Registration: Users sign up by selecting their roles (e.g., food supplier, customer, donor), and the system dynamically adjusts the registration forms based on their roles.
- Food Management: Food suppliers can add, edit, or remove surplus food items, and customers can browse and order these items.
- Order and Delivery Management: Real-time order tracking is enabled for customers, food suppliers, and delivery personnel. However, full integration of delivery tracking is planned for future updates.

Results and Discussion:

After implementing and testing the system with a small group of participants, several outcomes were observed. The system successfully reduced food wastage by redistributing surplus food through a user-friendly and efficient platform. Key results include:

- Reduction of Food Wastage: By allowing households and businesses to register as food suppliers, the platform expanded the availability of surplus food and reduced wastage significantly. In the prototype test, we observed a 40-60% reduction in food wastage, indicating the platform's effectiveness in redistributing surplus food.
- Economic Benefits: Food suppliers benefited from enhanced customer loyalty by donating or selling surplus food at a discounted rate. This led to a 30-50% increase in customer loyalty and recurring sales for suppliers. Additionally, delivery personnel registered through the platform generated extra income by fulfilling delivery orders, with a 20-40% increase in income for delivery personnel.
- Improved Access to Food: Customers reported a positive experience with the system, highlighting the ease of finding affordable or free food. Around 70-80% of customers expressed satisfaction, finding the process of locating food easy and beneficial.
- Feedback and Ratings: Both customers and food suppliers appreciated the feedback and rating system, which enhanced transparency and trust in the food distribution process. 80-90% of users provided positive feedback on the system, indicating high satisfaction and trust.

Conclusion:

The Zero Hunger: Surplus Food Distribution Chain successfully demonstrates how information technology can be leveraged to tackle food insecurity and wastage in a developing country like Sri Lanka. By building a scalable, user-friendly platform, this project has the potential to contribute significantly to achieving SDG 2 (Zero Hunger) and fostering a sustainable food-sharing ecosystem.

Despite its achievements, the platform has some limitations. The system currently lacks real-time delivery tracking, offering only basic order management, and does not integrate with third-party payment gateways, which restricts payment options for users. Future

improvements will focus on integrating real-time delivery tracking and a secure payment gateway to enhance the user experience further. Additionally, expanding the platform to include features such as route optimization for deliveries and broader community engagement will make it a more effective solution. Efforts will also be directed at simplifying the checkout process, particularly the price calculation when selecting delivery methods and food prices. The current UI design causes some confusion for users, and improvements will be made to provide a clearer and more intuitive experience.

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Evaluation of sewage and wastewater systems in Koralaipatru West and Central divisional secretariat divisions (DSDs), Batticaloa, Sri Lanka

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Abstract

The inappropriate construction and management of household sewage disposal systems can cause adverse environmental and public health issues particularly in developing regions. There is a need for a comprehensive assessment of current sanitation practices and their potential impacts on water quality and human wellbeing in both rural and urban areas. The aim of this study was to assess the current status of household sewage disposal systems, particularly septic tanks, and to identify issues related to wastewater management practices in the Koralaipatru West and Central divisional secretariat divisions DSDs, Batticaloa district in Sri Lanka. The primary data was collected through a questionnaire survey employing 50 households in both DSDs and focused group interviews with public health inspectors. Septic tank systems are more common (60%) than that of soakage pits (40%) in the study area. According to public health inspectors, more than 90% of wells provide poor quality of water that is not suitable for drinking due to fecal contamination in urban areas. This contamination exposes a possible connection between potential links between septic tank proximity to water sources and fecal matter infiltration. Some houses in the rural area lack toilets and they defecate on their land. The volumes of black water disposal pits in the study area are much higher than that of the designed working capacity of a septic tank in general, so that the desludging interval is more than 10 years. In the urban area, only few houses have separate pits for greywater. Other houses in the urban area and most of houses in the rural area dispose their wastewater to land. Some houses experienced flooding problems due to accumulation of rainwater in the premises. It was observed that there is no regular inspection of toilet pits. Our findings highlight the need for regulation, standardization, and education on proper sewage disposal systems.

Keywords: *Black water, Septic tank, Fecal contamination, Working capacity, Water quality*

Introduction:

Management of human waste and its impact on water quality remains a major public health issue in many developing countries. Proper sanitation is an essential need for human well-being, yet many regions of the world face problems due to inadequate waste management systems. Septic tanks, while common, can cause detrimental groundwater quality issues if not properly constructed or maintained. Population density and wastewater infrastructure plays an important role in the safe disposal of sewage wastes. Koralaipatru West and Central Divisional Secretariat divisions (DSDs) in the Batticaloa district of Sri Lanka are characterized by both urban and rural areas that have diverse water access challenges. In this study area, due to the mix of urban and rural areas, there is a good opportunity to evaluate how different population densities and infrastructure

development activities influence sanitation practices and related environmental impacts. Recent reports from public health inspectors highlighted the presence of *E. coli* in urban well water samples from these DSD areas. This contamination exposes a possible connection between potential links between the proximity of septic tanks to water sources and fecal matter infiltration, raising major questions regarding the safety of drinking water and the efficiency of present sanitation practices. Hence, the aim of this study was to assess the current status of household sewage disposal systems, particularly septic tanks or other underground systems in Koralaipatru West and Central DSDs and to identify issues related to wastewater management practices in the area.

Literature review

Access to basic sanitation facilities was identified as a major human right under Sustainable Development Goals officially announced in 2015 by the United Nations (UN) General Assembly (Lakshman, 2023). A sanitation system is a comprehensive combination of product-specific technology components designed to process each product from the point of generation until the point of reuse or disposal. Onsite (decentralized) and offsite (centralized) systems are the two major sanitation system types. In Sri Lanka, only few centralized sanitation systems are available mainly in community schemes such as Mattegoda, Digana and Raddolugama (Gunawardana et al., 2011) and some recently established systems such as in Kandy and Kurunegala. Most of the households in Sri Lanka (76.5%) have a separate water sealed toilet (Gunawardana et al., 2011) but there is no data about type of treatment systems that they are connected to. Most of the people in Sri Lanka use water sealed latrines which mix and dilute feces and urine with water producing 'Black Water'. Fresh faeces contain 10^5– 10^9 fecal coliform and fecal streptococci per gram (Feachem et al., 1983). Many viral, bacterial and protozoan pathogens are present in the septic tank effluent (Bandara & Najim, 2013). Since the feces have high level of microbes, the treatment method should be designed to destroy these pathogens (Gunawardana et al., 2011).

Septic tanks with a soakage pit system is a common onsite sewage disposal and treatment system in the world (Bandara & Najim, 2013). . A septic tank is defined as a single or a multiple-chambered tank in which wastewater is retained sufficiently long to permit separation of solid particles and partial digestion of accumulated solids (SLSI, 2003). Septic tanks are common in Sri Lanka to dispose domestic wastewater. At least 80% of urban and suburban population of Sri Lanka have septic tanks. If a septic tank and associated effluent disposal systems are not properly designed and maintained, it will cause aesthetic nuisance, public health hazard and environmental pollution (SLSI, 2003).

The usage of groundwater contaminated by human effluents can cause many waterborne diseases (Pang et al., 2003). As per the World Health Organization (WHO) estimates, every year, approximately 3.3 million people, including 2.5 million children die of diarrheal diseases. About 1.5 billion people suffer from parasitic worm infections originating from human excreta and solid wastes in the environment. The root cause of this is the water contaminated with human faeces, for example, from sewage, septic tanks and latrines, is of specific concern (Parashar et al., 2003).

Methodology:

Study area

Koralaipatru West and Central DSDs are situated in the Batticaloa district, Eastern province. The total population of Koralaipatru West Divisional Secretariat is 24,384 and Koralaipatru central Divisional Secretariat is 28,236 (Statistics Division, District Secretariat, Batticaloa, 2021). The population density per km^2 in the study area is 5493 (Statistics Division, District Secretariat, Batticaloa, 2021). The climate of this area is influenced by the North-East and South-West monsoons. The aquifer of the study area extends from Rugam tank and the delta of Magillavattuvan aru upto the Valaichenai lagoon, and along the Western shore of the lagoon upto Panichchankerni. The aquifer consists of alluvial deposits of silt, clay and sand. Depth of water table varies from 3 to 10 m. Houses in these areas have septic tanks or sewerage pits which have not been constructed well enough to prevent pollution of the wells dug into the aquifer and groundwater stocks (Central Environmental Authority, 1992).

Data collection

The primary data was collected through a questionnaire survey employing fifty households from the DS divisions and focused group interviews with public health inspectors. The households were selected randomly. Through the survey, data were obtained on main water source, number and type of toilets used, type of the sewage disposal system, size of the sewage disposal system, desludging interval, disposal methods of kitchen and bathroom wastewater and rainwater. The interviews were conducted in Tamil, the main language spoken by the inhabitants of the study area.

Results and Discussion:

Current status of sewage disposal systems

Most houses in the study area have their own toilets and they release their toilet wastes (black water) to toilet pits. Some houses in the rural area lack toilets and they defecate on their land. Less than 1% of people in the rural area do open defecation. They dig a pit in their premises and defecate in that, and afterwards they close the pit. Sri Lanka has low rate of open defecation (0.06%) in South Asia region although 8.9% people in this country use unimproved toilets. In India and Nepal, 49.6% and 43.5% people, respectively, defecate in the open. In Pakistan 23.2% people do not have access to any kind of toilet and they defecate in the open (UN 2013). In the rural area, there were some inhabitants who did not use toilets but defecated in their lands, however most of them have their own toilets now. These situations indicated that there is a potential chance of contamination of groundwater by human sewage in the rural areas in the DSDs. According to public health inspectors, more than 90% of wells yield poor quality water that is not suitable for drinking due to fecal contamination caused by the dense population in urban areas. This contamination exposes a possible connection between potential links between septic tank proximity to water sources and fecal matter infiltration. It was identified that 38% of children aged 0-5 years are stunted. Poor sanitation is one of the main reasons for this situation (Lakshman, 2023).

The results show the sewage disposal systems of the randomly selected households of the study area. Septic tank systems are more common (60%) than soakage pits (40%) in the study area. Currently the usage of septic tanks is recommended to reduce groundwater pollution by human effluents. The results show that people in this study area have adhered

to this recommendation. These results are close to the statement given by the SLSI (2003) that "at least 80 percent of the urban and suburban population of Sri Lanka uses septic tanks". The age of the sewage disposal systems in the rural areas ranges between 3-10 years and in urban areas it ranges between 10-40 years. Most of the toilet pits in the study area are constructed by local construction masons.

According to the results, the average volume of the septic tank / soakage pit in the study area are much higher than that of the designed working capacity of a septic tank / soakage pit). The average design working capacities (m^3) for desludging intervals of 5 and 10 years are 0.90 and 1.46, respectively. Over sizing of the system can contribute to increased desludging interval, generally over 10 years. An increase in the desludging period can contribute to the contamination of the groundwater, soil and surroundings if the system is not constructed according to the standards (Bandara & Najim, 2013). The more recent constructions in the study area have considerably large septic tanks / soakage pits, which will eventually increase the desludging interval. Higher capacities minimize the risk of overflowing but could be restricted due to cost considerations. Therefore 2 m^3 is an appropriate value for developing countries (Hettiarachchi et al., 2006).

Kitchen and bathroom wastewater

In the urban area, few houses have separate pits for kitchen and bathroom wastewater (grey water). Other houses dispose their wastewater to land in their premises and divert it to drains. In the rural areas, most of the houses dispose their wastewater to land in their premises. This will eventually contribute to land pollution and water pollution. In both areas, few houses (less than 5% of the population in the study area) lack bathroom and kitchen facilities.

Rainwater

The rainwater from roofs and paved areas of surrounding houses is disposed to nearby drains, streams, lands nearby or to roads. Due to the accumulation of rainwater, some houses experienced flooding. Flooding may expose the toilet pits and soakage pits, which store black and grey water to the environment polluting the environment.

Problems in well water and toilet pits

Some houses experienced problems in their well water due to toilet pits, hence those wells were closed without using them further. Few households stated that they observed water leakage from the toilet pits due to fractures in the surface of toilet pits.

Desludging of toilet pits

For the desludging of toilet pits / soakage pits, some people use Pradeshiya Sabha workers, private laborers and others use gully suckers. Through the method that employed manual labor, the pits are physically emptied into another pit. There is no regular inspection of toilet pits. Few people construct new toilet pits after the filling of the old toilet pits. The desludging interval ranges between 2-12 years in the study area. According to the statement of people in the study area most of the households are satisfied with their current toilet pits.

Conclusion:

The assessment of household sewage disposal systems in the Koralaipatru West and Central Divisional Secretariat divisions of Batticaloa district, Sri Lanka provides some

information on certain crucial insights into present wastewater management practices and their possible environmental impacts. Septic tank systems are more common (60%) than soakage pits (40%) in the study area, indicating their contribution to reduce groundwater pollution by implementing recommended practices. Even though there are issues such as irregular inspection and maintenance of toilet pits, well water contamination in urban areas and disposal of kitchen and wastewater into land raise questions about the effectiveness of these systems. The findings of the study emphasize the need for regulation, standardization, and education on proper sewage disposal system construction, maintenance, and desludging practices.

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Influence of Socioeconomic factors on Water Consumption in Selected Rural Areas of Sri Lanka: Insights for Targeted Water Resource Management

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Abstract

Water is a vital resource for life, essential for health, agriculture, and economic development, making its sustainable management crucial for societal well-being. Understanding water consumption alongside socioeconomic factors is critical to ensure equitable resource distribution, efficient use, and sustainable management in diverse communities. This study investigates water consumption patterns across five Grama Niladhari Divisions (GNDs) in Sri Lanka: Nawela, Suruvila, Cheddipalayam-North, Pattanichchipuliyankulam, and Pallekubura exploring how socioeconomic factors like education and income levels impact daily water use. This study examines the influence of diverse water sources, access levels, and conservation practices on water resource management challenges in selected GNDs, providing insights into the socioeconomic drivers of water consumption. Descriptive statistics reveal distinct water usage patterns linked to socioeconomic factors. The analysis showed a correlation coefficient of 0.798 between income level and water usage, indicating a strong positive association. Higher-income groups demonstrated an average water usage per capita of 102.56 ± 0.57 L/day, compared to that of 94.56 ± 0.23 L/day among lower-income groups. In contrast, education level displayed an inverse relationship with water usage, with individuals holding higher education levels using an average per capita of 98.64 ± 0.41 L/day, while those with primary or no formal education average per capita of 108.29 ± 0.96 L/day. This suggests that education may enhance awareness of water conservation, while increased income could support access to water-intensive amenities, thereby raising consumption. Comparative analysis across GNDs further revealed variability in water consumption linked to socioeconomic characteristics. GNDs with lower average education and income levels, especially Suruvila GND displayed an average per capita water usage of 84.89 ± 0.11 L/day. Multiple regression analysis confirmed that both income and education levels significantly predict water usage, with income showing a higher impact ($\beta = 0.70$; $p < 0.05$) than education ($\beta = -0.33$; $p < 0.05$). These results underscore the need for customized water conservation strategies that account for both socioeconomic and educational differences, particularly in higher-income regions. The findings offer a foundation for policymakers to design water resource management initiatives tailored to the socioeconomic dynamics within each GND, promoting sustainable water use and equitable access across community profiles.

Keywords: *Water consumption; Socioeconomic factors; Sustainable management; Sri Lanka; Water resources management*

Introduction:

Water is one of the most critical resources for sustaining life, integral to health, food security, agriculture, and economic growth. In recent decades, the rising global demand

for water, combined with the impacts of climate change and urbanization, has led to significant challenges in managing water resources sustainably worldwide (Falkenmark, 2013). Today as many countries strive to meet Sustainable Development Goals, especially Goal 6 on clean water and sanitation, is of vital importance while understanding factors influencing water consumption is essential for ensuring that resources are allocated equitably and used efficiently (United Nations, 2015).

Sri Lanka faces unique challenges in water resource management due to the diversity of socioeconomic conditions across regions. Although the country has relatively high levels of access to clean water, there are disparities in water consumption patterns across socioeconomic groups, particularly in rural and urban areas (Fernando & Wijesiri, 2020). It has been found that household water usage patterns are often influenced by income levels and educational backgrounds in Sri Lanka. Higher-income households tend to have better access to piped water, while lower-income households may depend on shared or alternative water sources, which can limit daily water consumption (Bandara et al., 2019). Education also plays an essential role in water conservation; research suggests that individuals with higher education levels often display greater awareness of water-saving practices (Thushari et al., 2021). However, there is limited data on how these socioeconomic factors influence water use in the distinct socioeconomic settings within several rural GNDs across Sri Lanka. Given the disparities in access and consumption patterns, exploring the relationship between socioeconomic status and water usage can help identify more equitable and sustainable management solutions.

This study aims to examine the impact of socioeconomic factors particularly income and education on daily water usage across several rural Grama Niladhari Divisions (GNDs) in Sri Lanka. Specifically, it investigates how these factors drive household water consumption patterns in five distinct GNDs: Nawela, Suruvila, Cheddipalayam-North, Pattanichchipuliyankulam, and Pallekubura by focusing on how socioeconomic factors, particularly income and education levels, affect daily water usage. The study will also explore the role of water sources and access levels, providing insights into the complex challenges in water resource management across Sri Lanka. Through this analysis, the study aims to support decision-makers in designing tailored interventions that promote sustainable water use while accounting for socioeconomic differences within each GND. This focus is particularly relevant in Sri Lanka, where socioeconomic disparities in both urban and rural settings contribute to notable variations in water use and accessibility.

Methodology:

This study employed a mixed-methods approach to capture both quantitative and qualitative insights into water consumption patterns across five Grama Niladhari Divisions (GNDs) in Sri Lanka which is shown in Figure 01. Data collection began with a structured questionnaire survey administered to approximately 30 households in each GND, including Nawela, Suruvila, Cheddipalayam-North, Pattanichchipuliyankulam, and Pallekubura. Households were selected to ensure representation of different income and education levels, enabling the study to investigate how socioeconomic characteristics impact daily water usage. The survey covered basic demographics, water sources, access levels, and self-reported daily water consumption.

The data collected were categorized by education (higher education: GCE A/L, Degree; and lower education: primary, GCE O/L or no formal education) and by income (higher:

> Rs. 60,000; lower: < Rs. 60,000). Average per capita daily water consumption was calculated across these socioeconomic groups. Descriptive statistics established baseline consumption patterns and correlations with socioeconomic factors. A multiple regression analysis was conducted to assess the predictive influence of income and education levels on water usage, accounting for household size and access to water-saving technologies. This approach facilitated targeted recommendations for water management strategies tailored to the socioeconomic conditions.

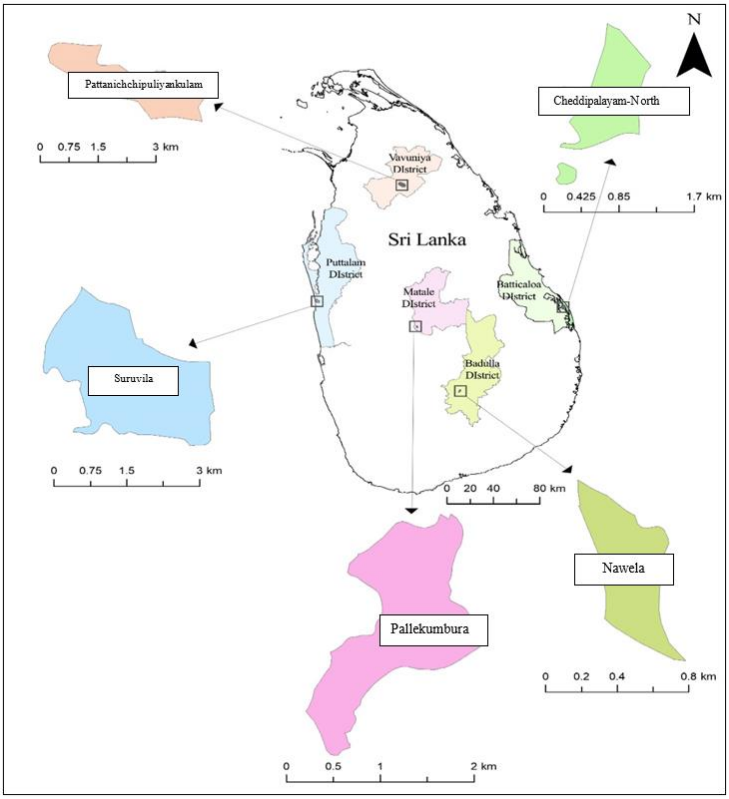

Figure 01: Selected Rural GNDs in Sri Lanka

Results and Discussion:

The descriptive analysis highlights socioeconomic disparities in water usage among communities in Sri Lanka. Table 01 shows that higher-income groups, averaging 102.56 ± 0.57 L/day, consume more water, likely due to greater access to water-intensive amenities (Smith & Jones, 2023). Conversely, lower-income groups average 94.56 ± 0.23 L/day, reflecting usage constraints often seen in less affluent households.

Table 01: Descriptive statistics of water consumption and Income level

Income	Type	Average water consumption (per capita)
< Rs. 60,000	Lower	94.56 ± 0.23 L/day
> Rs. 60,000	Higher	102.56 ± 0.57 L/day

Table 02: Descriptive statistics of water consumption and educational level

Education	Type	Average water consumption (per capita)
primary, GCE O/L or no formal education	Lower	108.29 ± 0.96 L/day
GCE A/L, Degree	Higher	98.64 ± 0.41 L/day

Table 03: Correlation analysis of the socio-economic factors with water consumption

Socio-economic Factors	Pearsons's correlation
Income level	0.798*
Educational level	-0.682*

*Correlation is significant at the 0.05 level (two-tailed)

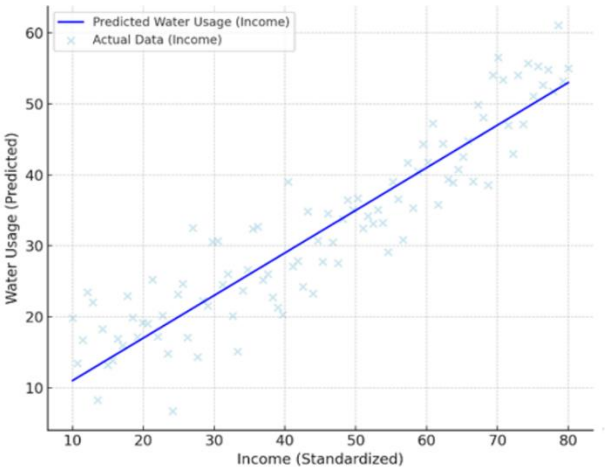

Figure 02: Impact of income levels on the water usage

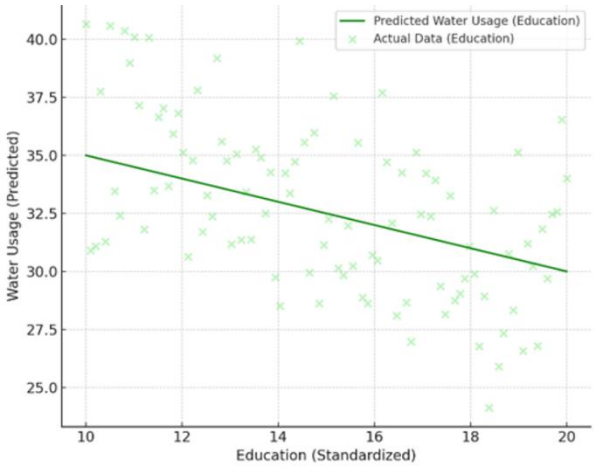

Figure 03: Impact of educational levels on the water usage

Figure 2 and Figure 3 show the regression analysis reveals that income strongly influences water usage ($\beta = 0.70$; $p < 0.05$), with wealthier households consuming more water. Education has a negative effect ($\beta = -0.33$; $p < 0.05$), suggesting that more educated households may use water more efficiently. This emphasizes the need for tailored water conservation strategies, particularly in higher-income areas.

Table 02 suggests that education showed an inverse relationship with water usage, as those with higher education levels (98.64 ± 0.41 L/day) use less water than individuals with lower educational backgrounds (108.29 ± 0.96 L/day). This aligns with research suggesting that education enhances water conservation awareness (Jones & Thompson, 2021). These results underscore the influence of income and education on water consumption patterns.

The correlation analysis (Table 03) shows that income is positively related to water usage ($r = 0.798$, $p < 0.05$), suggesting that higher-income groups use more water due to access to water-intensive resources. Conversely, education level has a negative correlation with water usage ($r = -0.682$, $p < 0.05$), likely indicating that higher education promotes water conservation awareness (Jones & Thompson, 2021).

Conclusions:

This study underscores the significant role of socioeconomic factors, particularly income and education, in shaping water consumption patterns across several rural GNDs in Sri Lanka. The findings highlight that higher-income households tend to consume more water while those with greater educational levels tend to use water more efficiently, reflecting a critical link between socio-economic conditions and water use. The findings are important for developing targeted water management strategies that promote sustainable consumption, particularly in higher-income areas. Furthermore, understanding the influence of income and education levels on water usage, this study contributes to achieving Sustainable Development Goal (SDG) 6, which calls for ensuring access to clean water and sanitation for all. The findings of this research provide valuable information for policymakers to design area-specific interventions that address water consumption disparities, ensuring equitable access and efficient use of water resources across diverse communities in Sri Lanka.

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