Strengthening Smart Agriculture in Malaysia through Pervasive Computing

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***Abstract* — Global economies have been significantly impacted by the introduction of digitalisation, especially through the usage of ubiquitous computing technologies. This digital transformation has far-reaching implications for income inequality, employment, and economic development. Malaysia, actively participating in the digital economy, has employed internet-based technologies like cloud computing, big data analytics, the Internet of Things (IoT), and artificial intelligence (AI) to enhance its GDP and living standards. Smart Agriculture initiatives undertaken by the nation serve as a prime example of this paradigm shift, as they prioritise sustainable practices and urban agricultural solutions. While ubiquitous computing holds great promise for the agricultural industry in Malaysia, the country faces certain obstacles that must be overcome before its full potential can be achieved.**

Keywords* — *Smart Agriculture; Smart Farming; Ubiquitous Computing; Agriculture 4.0;

I. Introduction

The influence of digitalisation on economies worldwide has been significant, yet it has been unevenly distributed within and between economies. These results have a wide impact, affecting income and social inequality, employment, and economic development. Moreover, the rapid increase in global data transmissions, which has grown 45 times larger, shows the significant progress of digitalisation (McKinsey Global Institute , 2016). The digital economy includes a wide range of economic activities and transactions, including agriculture, that rely heavily on digital information for operation and production (Kylasapathy, et al., 2018).

Agriculture is considered one of the most essential industries, playing a pivotal role in ensuring food security (Abbasi, et al., 2022). The adoption of a digital economy, incorporating the utilisation of internet-based technologies like cloud computing, big data analytics, the Internet of Things (IoT), and artificial intelligence (AI), can substantially enhance a nation's gross domestic product (GDP) (Yin, et al., 2021). In addition, Malaysia has actively embraced this transformation, improving its citizens' living standards (Rosmani et al., 2019). Malaysia's Smart Agriculture technology development is an example of this transformation, with its primary focus on urban agricultural solutions and the aspiration of achieving sustainable agriculture goals (Wei En & Devanthran, 2020).

Ubiquitous computing holds significant potential for Malaysia's digital transformation. However, according to Kylasapathy et al. (2018), several challenges must be addressed for Malaysia to fully realise the benefits of ubiquitous computing. These challenges include a shortage of talent with the requisite skills, slow broadband speeds, and low digital adoption among businesses. Hence, it is very important to overcome these challenges to ensure Malaysia can establish itself as a pioneer in the adoption of ubiquitous computing, particularly within the agriculture industry and fully leverage the advantages of digitalisation (Kylasapathy, et al., 2018).

II. Overview of Digital Challenges for Malaysia's Agriculture Industry

A. Current Digital Challenges Faced by Malaysia

The adoption of digital technologies is essential for Malaysia's Agriculture Industry, transforming its edge in the marketplace from traditional resources to innovation and positioning itself on the digital frontier. However, this transformation poses digital challenges such as inadequate infrastructure, skill deficiencies, and security and privacy concerns (Kylasapathy et al., 2018). Moreover, the integration of IoT devices in Malaysia presents technological challenges, compatibility issues, and dependency on a centralised cloud-based business model, which may lead to additional expenses without equivalent returns (Badarudin, et al., 2018).

Digitalising agriculture presents challenges, such as investing in farmer training, ensuring device safety in harsh climates, managing large-scale deployments, selecting optimal device positions, and ensuring interoperability. Data loss, physical interference, low energy usage, and limited storage are also highlighted as potential security concerns (Farooq, et al., 2020). Thus, comprehensive planning, training, IoT infrastructure, device safety, intelligent management systems, complex algorithms, and secure communication protocols are required to handle security issues.

On the other hand, the agriculture industry in Malaysia specifically faces challenges of high investment costs, lack of skilled labour, inadequate infrastructure, and poor internet connectivity in rural areas (Lazim, et al., 2020). A recent study conducted by Abdul-Hamid et al. (2020) identified 18 critical challenges faced by businesses, including the lack of automation

system virtualisation, unclear economic benefits of digital investments, lack of process design, unstable connectivity among firms, and disruptions in employment (Abdul-Hamid, et al., 2020). Hence, it is crucial to consider these challenges as they have the potential to hinder the incorporation of digital technologies and delay the agricultural industry's evolutionary transformation in Malaysia, as shown in Fig.1.

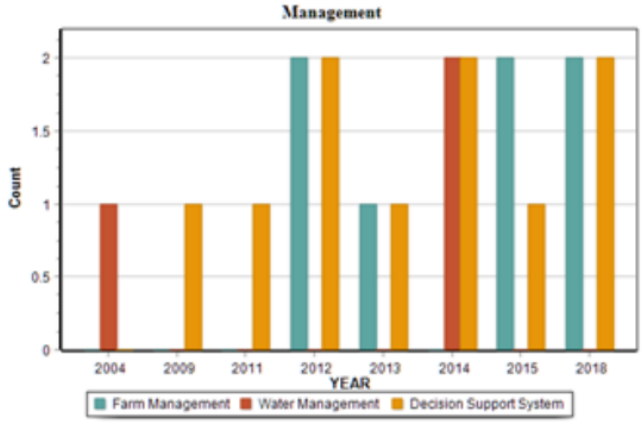

Fig. 1. Evolution of Smart Farming Management by Years (Wei En & Devanthran, 2020)

B. *Economic Impact of These Challenges*

The economic impact of the challenges faced in implementing digital technologies in Malaysia can be significant, resulting in delays and additional costs for businesses and organisations. This may hinder Malaysia's global competitiveness and impede the adoption of IoT. Moreover, relying on a centralised cloud-based business model could result in unprofitable expenses and resource waste and impact the economy (Badarudin, et al., 2018). Therefore, Malaysia must address these challenges and create a conducive environment for IoT growth to realise its economic benefits.

Agriculture is an essential industry in Malaysia's economy, employing over 1.6 million people. It is also considered a key National Key Economic Area (NKEA) due to its potential to accelerate growth and generate income for farmers (Lazim, et al., 2020). However, challenges in digitising the agriculture industry can harm the economy. Businesses that cannot afford implementing new technologies may lose a competitive edge and potential profits. Besides, these challenges can significantly impede competitiveness, limiting access to crucial information, communication, and market opportunities (Lazim, et al., 2020).

Additionally, Abdul-Hamid et al. (2020) identified challenges may impact the economy. They have the potential to impede innovation, reduce productivity, elevate costs, and disrupt production efficiency. Employment disruptions also bring social and economic costs, including rising unemployment rates and reduced consumer spending (Abdul-Hamid, et al., 2020). Hence, addressing these challenges is crucial for successfully implementing Industry 4.0 in Malaysia's agriculture sector and its long-term economic sustainability. It can also help the country realise the full potential of the economic benefits of IoT.

C. *Ubiquitous Computing Solutions for Agricultural Challenges*

Ubiquitous computing, powered by technologies like cloud computing, augmented reality, IoT, autonomous robots, and system integration, addresses agricultural challenges by improving production efficiency, reducing costs, and enhancing product quality. Examples include using IoT, AI, and big data for autonomous crop production and precision tasks with drones and unmanned tractors (Lazim, et al., 2020). System integration enables data sharing for better collaboration and decision-making. Other than that, IoT is applied throughout the agricultural production chain, focusing on precision farming, livestock management, and greenhouse monitoring using wireless sensor networks. A specific case is an IoT-based system for real-time microclimate monitoring (Farooq, et al., 2020). Collectively, these technologies address agricultural challenges and promote competitiveness, efficiency, and sustainability in Malaysia's agricultural sector.

III. Understanding Ubiquitous Computing

A. *Exploring Ubiquitous Computing: Definitions and Key Principles*

Ubiquitous computing is a revolutionary model that integrates computing devices into our environment and infrastructure, making computing power available anytime and anywhere (Azizul, et al., 2015). It aims to integrate technology in a way that is both seamless and ubiquitous, enabling individuals to perform their duties with minimal interruption (Helfer, et al., 2019). involves using sensors, cameras, and smart devices to collect and process real-time data. Ubiquitous computing offers a wealth of information on ongoing processes and paves the way for innovative decision-making strategies (Mukhametov, 2020) With its compact size and high productivity, ubiquitous computing emerges as the optimal solution for digitalising urban infrastructure.

In addition, ubiquitous computing is guided by the crucial principle of connecting physical objects for data sharing and enabling seamless device collaboration with contextual awareness. This ensures intelligent adaptation to the user's context while maintaining transparency. (Abdul Aziz & Othman , 2013) Besides, Human-Computer Interaction (HCI) is essential for designing user-friendly interfaces, and privacy and security are paramount due to the vast amount of data flowing through the system (Azizul, et al., 2015). Ubiquitous computing has the potential to transform various industries, enhancing efficiency, productivity, and sustainability. In the agricultural sector, for example, it can significantly boost production.

B. *Ubiquitous Computing Infrastructure in Malaysia*

Ubiquitous computing relies on key technologies to achieve its vision of seamlessly integrating technology into human lives. The main technologies involved in ubiquitous computing systems are cloud computing, the Internet of Things, and 5G technologies. These technologies are used to facilitate large-scale communication between devices, optimise decision-making, and improve energy efficiency and productivity (Mukhametov, 2020). The development of ubiquitous

computing in Malaysia hinges on integrating these technologies, including a robust wireless infrastructure, diverse sensors and embedded devices, cloud computing capabilities, and data analytics infrastructure (Azizul, et al., 2015).

Nevertheless, Badarudin et al., (2012) highlight recommendations to realise IoT in Malaysia, including providing financial incentives and special funds to motivate and enable IoT adoption for future development and achievements and increasing awareness through campaigns and programs (Badarudin, et al., 2018).

IV. The Economic Potential of Ubiquitous Computing in Malaysia

A. Improved Connectivity and Digital Infrastructure

Malaysia's journey to upper middle-income status has coincided with the microelectronics revolution, bringing about increased digital connectivity in the country. (World Bank, 2018) This connectivity serves as a foundation for Malaysia's digital economy, driven by robust information and communications technology (ICT) infrastructure (Osman, et al., 2014). Such enhanced digital connectivity significantly influences economic growth by expanding market reach, enhancing operational efficiency, and powering innovation (Edrak, et al., 2022).

Over recent years, Malaysia has made significant progress in advancing digital connectivity through various policies and initiatives. One such initiative is the National Digital Economy Blueprint, known as MyDIGITAL. This comprehensive plan, designed to transform Malaysia into a regional digital leader by 2030, encompasses six strategic priorities: fortifying digital infrastructure, expediting digital adoption, empowering digital talent, accelerating digital innovation, promoting digital inclusion, and ensuring sound digital governance. MyDIGITAL is poised to make a substantial positive impact on both the country's economy and society (MyGovernment, 2023)

This enhanced connectivity has facilitated the use of digital applications and fostered the development of digital talent, aligning with long-term strategies for the digital economy ecosystem. The resulting boost in connectivity has played a pivotal role in promoting technological adoption, streamlining business operations, and driving innovation (World Bank, 2018). Moreover, it has enabled the emergence of smart homes, intelligent transportation systems, and digital healthcare solutions, all contributing to the advancement of digital infrastructure (Edrak, et al., 2022).

B. Smart City Initiatives and Economic Development

Smart cities use technology to improve the quality of life for residents and efficiently use resources. According to Musa, five major smart cities focus on economic development, public safety, energy and environment, infrastructure, and transportation. Smart city initiatives contribute directly and indirectly to economic growth by offering economic opportunities in transportation, energy, water, waste management, public safety, and healthcare. However, economic development in smart cities requires government dedication, incentives, vision, and leadership (Musa, 2017).

Smart cities use advanced technologies to enhance lifestyles and support sustainable economic growth. By optimising resource management and infrastructure efficiency, they reduce costs, boost productivity, and attract businesses and talent, improving global competitiveness (Sadeq & Cevik, 2022). Smart cities play a crucial role in addressing challenges related to population growth, urbanisation, and the environment. They offer innovative solutions in urban planning, operation, networking, and management, leading to efficient resource management, reduced energy consumption, improved transportation systems, and enhanced environmental sustainability (Kolobova, et al., 2022).

In 2017, the Malaysian government launched the National Digital Infrastructure Plan (NDIP), outlining initiatives to develop Malaysia into a digital nation. The NDIP includes smart city initiatives such as developing a nationwide high-speed broadband network, deploying smart sensors and devices to collect data on city operations and infrastructure, developing smart applications to improve city services delivery, and establishing digital innovation hubs and startup accelerators (MCMC, 2023).

On the other hand, in 2019, the Ministry of Housing and Local Government (KPKT) introduced the Malaysia Smart City Framework (MSCF), built upon four pillars (MyGoverment, 2023):

1. **Empowerment**: Focus on citizen involvement
2. **Innovation**: Promote innovative technologies
3. **Sustainability**: Develop eco-friendly cities
4. **Inclusivity**: Ensure benefits for all citizens

The MSCF covers all aspects of smart city development as shown in Fig. 2, including :

- Smart Economy: Economic growth and opportunities
- Smart Environment: Sustainability and environmental protection
- Smart People: Improved quality of life, including education, healthcare, and transportation
- Smart Mobility: Enhanced transportation systems and accessibility

A key focus within Malaysian smart city development is smart agriculture, which falls under the Smart Environment framework. Smart agriculture, integrating ICT, enhances Malaysia's agriculture by improving efficiency and productivity while mitigating environmental impact. Technologies like IoT, big data, cloud storage, and mobile devices automate and streamline farm management. The growing trend in Malaysia focuses on urban farming for sustainable agriculture (Wei En & Devanthran, 2020).

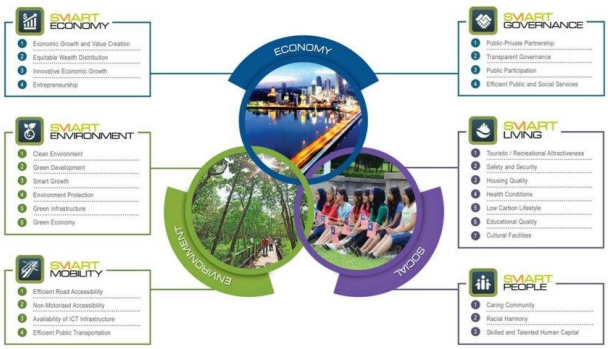

Fig. 2. Aspects of Malaysia Smart City Framework (MSCF)

One notable smart agriculture initiative in Malaysia is the Smart Paddy Field Initiative, which involves deploying a wireless sensor network system at Titi Serong. This system enables farmers to monitor water and pH levels in paddy fields, reducing their workload and enhancing crop yields remotely (Miskam, et al., 2014). Overall, smart city initiatives, including those in smart agriculture, contribute positively to the Malaysian economy by attracting foreign direct investment (FDI), generating employment, and increasing economic productivity.

C. Entrepreneurship and Digital Economy

Malaysia's

Ubiquitous computing, or the Internet of Things (IoT), is a game-changer for entrepreneurship and innovation. It enables effortless information exchange, streamlined operations, and data-driven decision-making. This empowers entrepreneurs to optimise their available resources and promote the development of innovative solutions. (Milik, et al., 2023). In addition, it also facilitates the emergence of new business opportunities and enhances productivity and efficiency across different industries. This technology enables customised user experiences and improved access control. (Friedewald & Raabe, 2011).

Adopting ubiquitous computing is pivotal in promoting long-term economic sustainability and nurturing creative thinking, ultimately leading to success. Technically, it amplifies entrepreneurial endeavours and innovative practices, facilitating entrepreneurs in effectively adjusting to dynamic business requirements, accessing worldwide markets, and fostering a climate conducive to invention and experimentation (Gkikas, 2014).

Nevertheless, ubiquitous computing is playing a major role in promoting the growth of the digital economy in Malaysia. The Malaysian government's Industry4WRD policy has facilitated the country's adoption of ubiquitous computing technology. Industry4WRD is a key component of the government's vision to transform Malaysia into a high-income, advanced economy. It aims to help Malaysian businesses become more productive, competitive, and sustainable by embracing Industry 4.0 technologies and practices and creating new jobs and opportunities in the Malaysian economy (MyGovernment, 2023).

Industry4WRD offers several key initiatives to support Malaysian businesses in their Industry 4.0 transformation, including :

- Readiness Assessment Program : Assists businesses in evaluating their current readiness and areas for improvement.
- Financial Support : Offers funds for implementing Industry 4.0 technologies.
- Skills Development Programs : Equips Malaysian workers with vital skills for Industry 4.0 success.
- Ecosystem Development : Promotes a supportive environment for Industry 4.0 innovation and growth in Malaysia.

In addition, Industry4WRD provides the digital infrastructure and technologies needed to support smart agriculture, which can help to achieve Industry4WRD's goals of increasing productivity, improving quality, and reducing costs. Smart agriculture technologies, such as hydroponics, can help the agriculture industry gain numerous benefits, including automating tasks, controlling the environment, and making better crop management decisions using real-time data about crops and the surrounding environment. Smart systems can also be used on other types of farms to check soil acidity and water level, helping farmers improve their efficiency, productivity, and sustainability (TMOne, 2020).

V. CHALLENGES AND CONSIDERATIONS

A. Ethical and Privacy Considerations in Smart Agriculture

Ubiquitous computing is the integration of computing into everyday objects and activities. It is a rapidly developing field with the potential to revolutionise many aspects of human lives. However, it is also important to consider the ethical implications of this technology before it becomes widely adopted. Due to the constant collection, storage, and processing of personal data in ubiquitous computing environments, privacy risks arise (Pasricha & Wolf, 2023). Additionally, the use of ubiquitous computing technology can lead to surveillance and loss of individual autonomy (Hilty, 2015).

Privacy-enhancing technologies and practices, such as data anonymisation, encryption, and user consent mechanisms, must be implemented to protect personal data and ensure its responsible and ethical use in ubiquitous computing. Furthermore, regulatory frameworks and policies, such as data protection laws and privacy regulations, also play a vital role in guiding the ethical use of personal data (Pasricha & Wolf, 2023). Therefore, these ethical issues highlight the need for careful consideration and responsible decision-making in developing and deploying ubiquitous computing technologies (Hilty, 2015).

Despite the increasing use of ubiquitous computing in the agricultural sector, knowing the ethical concerns associated with smart agriculture is essential. According to Zampati (2023), farmers, especially smallholders, often do not benefit from sharing and exchanging their data, leaving them feeling disempowered. Additionally, shifts in power dynamics within

the agricultural sector raise questions of fairness and equity. The implications of smart agriculture on human life and society, including the displacement of jobs, transformations in rural communities, and environmental repercussions, require ethical considerations (Burg, et al., 2019).

In response to these issues, it is important to focus on the ethical aspects of data governance, including access, control, and consent, to ensure transparency and build trust between stakeholders. On top of that, implementing farmers' rights to data in local and international laws, guidelines, and policies is crucial for protecting their privacy and ensuring data security (Zampati, 2023). Developing and deploying smart agriculture technology requires careful consideration of ethical implications, including the importance of establishing trust within data-sharing networks (Burg, et al., 2019).

B. Infrastructure and Implementation Challenges

Agriculture is a key economic sector in Malaysia, employing over 1.6 million people (Lazim et al., 2020). The adoption of ubiquitous computing technologies is crucial to foster agricultural sector growth. However, it is equally important to identify potential challenges in implementing these technologies in Malaysia's Smart Agriculture.

One challenge is the limited technological application in Malaysia's agricultural sector. This sector faces several challenges: small-scale production, limited technological adoption, dwindling arable land, environmental degradation due to climate change, rapid urbanisation, and an aging farming population. Therefore, selected technologies must suit the farms' climate, weather, and soil conditions and ensure constant production without jeopardizing the environment, biodiversity, ecosystem, and human health (Lazim et al., 2020). Another challenge is the lack of experts and professional service providers specialising in smart agriculture technology. This makes it difficult for farmers to invest in technology directly. On top of that, financial constraints pose another obstacle, as the lack of direct technology investment often stems from financial limitations (Kamarul Zaman, et al., 2022).

A multifaceted strategy is necessary to address the infrastructure and implementation challenges encountered in smart agriculture technology in Malaysia. First and foremost, there is a serious need to enhance farmers' and agricultural workers' digital literacy and skills. Training programs are essential in equipping them with the knowledge and capabilities required for effective technology utilisation. Furthermore, implementing supportive policies and incentives can act as a mechanism for the widespread adoption of ubiquitous computing in agriculture, creating a more conducive environment for innovation (Lazim et al., 2020). Additionally, fostering collaboration among farmers is essential, given the scarcity of professional service providers. Collaborative efforts enable the sharing resources and expertise, making it easier to address challenges collectively. Lastly, establishing robust communication networks and mentoring systems within the farming community can encourage motivation and facilitate knowledge sharing, fostering a culture of continuous improvement and adaptability (Kamarul Zaman, et al., 2022).

VI. Case Studies and Success Stories

A. Case Study 1 – Economic Growth and Smart Farming: Examples from Türkiye and the World

Smart agriculture techniques, such as soilless farming and drone spraying, have been implemented in Turkey, resulting in higher yields and profits from smaller agricultural areas. Smart farming has also been shown to reduce costs, fuel usage, and time, potentially saving 10% on total costs, 9% on fuel usage, and 17% on time. Increased production in the manufacturing and agriculture sectors, enabled by smart farming practices, contributes to economic growth by improving productivity, technology, and workforce quality(Amador, 2022).

B. Case Study 2 – Green Smart Agriculture

Japan and China have widely adopted information and communication technologies (ICT) and the Internet of Things (IoT) to develop precision agriculture solutions, which has boosted economic growth. These technological advancements have increased agricultural productivity, created new jobs in agricultural technology, and attracted investments in the smart agriculture sector. Smart agriculture technologies have enabled farmers in these countries to monitor and manage their crops more efficiently, reducing resource waste and optimising resource utilisation (Singh & Kaur, 2019).

C. Case Study 3 – Smart Agriculture Using the Internet of Things with Raspberry Pi

Australian dairy farmers are using IoT devices to monitor their cows' health and behavior, helping them produce more milk more efficiently. This is contributing to the economic growth of the Australian dairy industry. Besides that, smart agriculture initiatives using IoT technologies are also positively impacting the Malaysian economy. For example, the implementation of IoT-based irrigation systems has resulted in a 24.44% water savings rate per year compared to traditional irrigation systems. Additionally, IoT technologies in smart agriculture systems have helped improve crop production and reduce water wastage, leading to economic benefits (Muhammad et al., 2020).

D. Case Study 4 – Beyond Ubiquitous Computing: The Malaysian Honeybee Project For Innovative Digital Economy

The HoneyBee project in Malaysia is a digital economy initiative aiming to create a mobile platform for devices to communicate and work together securely and safely. This platform is important for building a digital economy in Malaysia and is expected to support a variety of applications in different fields, including smart agriculture. For example, the HoneyBee platform could be used to develop mobile apps for farmers to monitor crop health, control irrigation systems, and manage livestock. Overall, the HoneyBee project is a promising initiative that has the potential to accelerate Malaysia's digital transformation and support the growth of the digital economy, including the smart farming sector (Patel, et al., 2014).

E. Case Study 5 – Economic potential of rice precision farming in Malaysia: the case study of Felcra Seberang Perak

A study conducted at Felcra Seberang Perak in Malaysia evaluated the economic potential of precision farming technologies in rice cultivation. The study found that adopting precision farming technology packages, including variable rate seed and fertiliser application systems, could result in an additional net income per hectare of between MYR 1109 to MYR 1333 due to reduced production costs. Precision farming technologies showed positive monetary impacts from formal-scale and large-scale farmers in the study (Rahim, et al., 2021).

VII. CONCLUSION

Digital transformation powered by ubiquitous computing is a promising way to boost Malaysia's economy, especially in agriculture. The opportunity to capitalise is crucial to address digital challenges such as inadequate infrastructure, skill shortages, and security concerns. These challenges can affect Malaysia's global competitiveness and delay IoT adoption, ultimately hindering economic growth. As a crucial sector employing over 1.6 million people, agriculture plays an important role in the Malaysian economy. Therefore, overcoming these challenges is essential for successfully implementing Industry 4.0 in Malaysia's agriculture sector and achieving long-term economic sustainability. Ubiquitous computing and the integration of digital technologies can revolutionise this dynamic industry by increasing production efficiency and boosting competitiveness. By adopting a holistic approach and fostering innovation, Malaysia can fully exploit the economic benefits of IoT and digitalisation, positioning itself as a leader in the digital age.

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