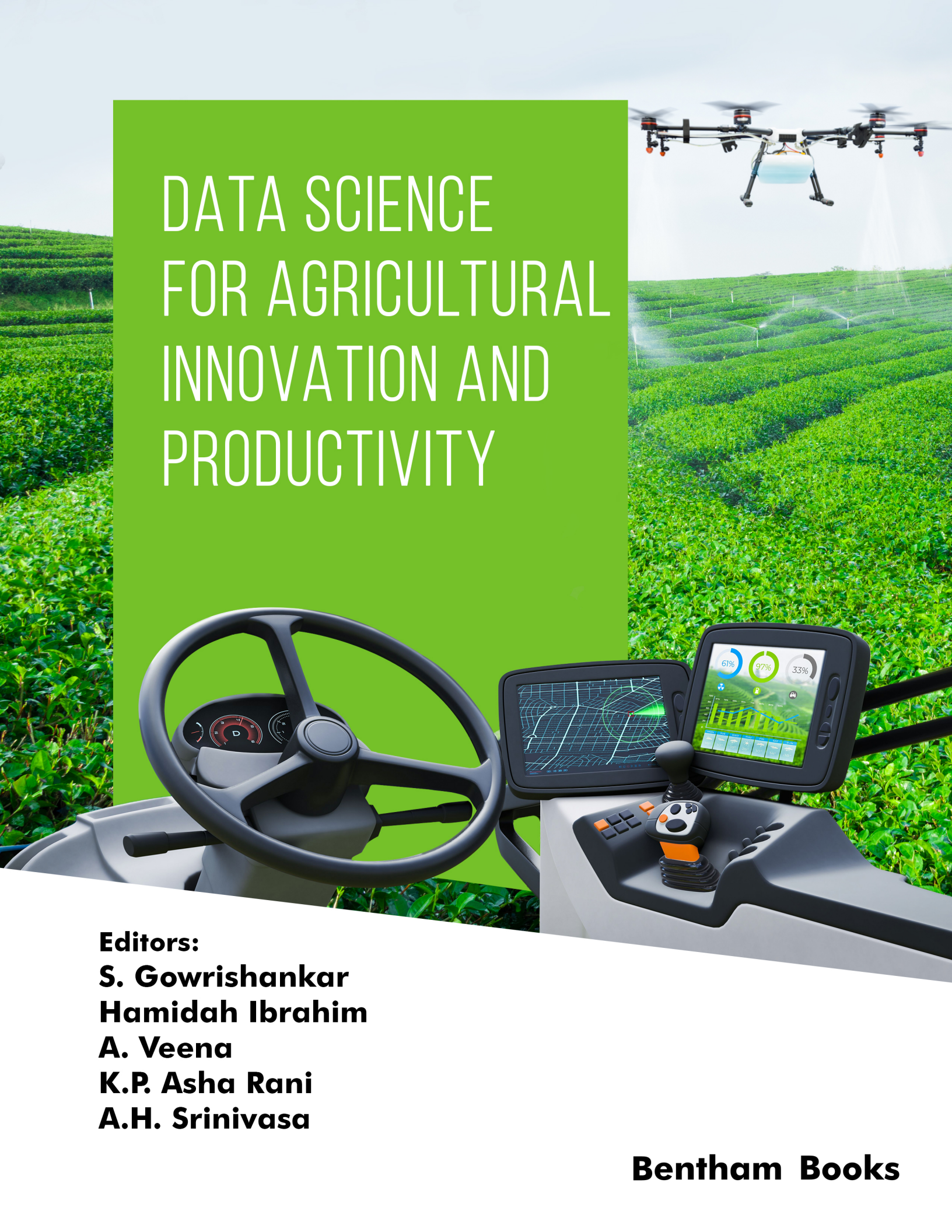




DATA SCIENCE FOR AGRICULTURAL INNOVATION AND PRODUCTIVITY

Editors:

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Bentham Books

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FOREWORD

Agriculture, which contributes 15.4% to the GDP of India, was the foundation on which we built our nation and this has undergone several development phases. Agriculture is the practice of growing the food and cash crops that humans need, and its techniques and technology have advanced quickly. The selection of farming methods depends on climate, terrain, traditions, and the financial condition of the farmer. Depending on the exposure to technology, the availability of land, capital, and skilled labor, the aforementioned techniques can be used in large-scale or small-scale farming.

Each crop needs different growth conditions, differing harvesting seasons, and distinct attention. It is hard to deny the common techniques of agriculture that farmers across the world use. These include ploughing, the use of modern machinery, fertilizers, various types of seeds, *etc.* But looming on the horizon is India's population boom, which is set to rise to 1.515 billion by 2030 from 1.417 billion in 2022. This has increased pressure on the agriculture sector.

The full potential of agricultural innovation has to be fully realised in many emerging nations. Understanding and implementing the innovation drivers and procedures that are essential for realising innovation's potential and sparking it are the keys to success. Unfortunately, the cost of the agricultural cycle, beginning from the preparation of soil to the selling of the produce, has ratcheted up, along with the risks. As this book shows, relevancy in information is key and keeping track of crops, the environment and the market may help farmers to make better decisions and ease problems related to agriculture. Technologies like IoT, Machine learning, deep learning, hydroponics, and smart farming can attain information and process it. The authors of this book present a powerful argument for the application and implementation of such aforementioned technologies that will surely help alleviate many challenges we currently face, if not outright prevent it.

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PREFACE

Agriculture can provide for one of humanity's essential needs, which is food. Around the globe, agriculture is a source of employment besides providing for humankind's basic requirements. Agriculture now entails significantly more than merely planting a seed, raising a cow, or capturing a fish. To feed a huge population, an entire environment and a spate of individuals must work together. Innovation enables us to achieve more and better with less. Innovation is driven not just by technology breakthroughs, but also by creative methods of organising farmers and linking them to the information they want. Many smallholder farmers throughout the world continue to cultivate in the same manner that their forefathers did hundreds of years ago. Traditional farming methods may continue to be effective for some, but new tactics may assist many in significantly improving yields, soil quality, and natural capital, as well as food and nutrition security. Farmers can be grouped in novel ways to ensure that information reaches them more readily and efficiently. The kind and style of the extension itself have altered significantly throughout time. For example, developments in satellite mapping and information and communication technologies (ICTs) are already altering more traditional agricultural extension activities. Farming is getting more accurate and productive as a result.

The number of farm records in electronic format is growing daily, and informatics and data analysis are essential to analyse these huge records with diverse datasets.

This book reveals the use of different sensors to collect diverse farm data, which comprise chemical/pesticide tracking, harvest and yield records, planting records, shipping records, labor tracking, weather data, *etc.* Sustainable Agriculture focuses on meeting current requirements without compromising the ability of future generations to meet their own. An agriculture system that enables farms of all sizes to be profitable and contribute to their local economies is one that is both economically and socially sustainable. A system like this would prioritise people and communities over corporate interests, support the next generation of farmers, provide everyone with access to healthy food, and support the next generation of farmers. Because of the widely varying scales, dimensions, and volumes of electronic farm data, multidisciplinary solutions are needed for visual depiction and digital characterisation. Gains in agriculture have improved thanks to developments in machine learning. By offering detailed advice and insights about the crops, machine learning is a current technology that helps farmers reduce farming losses.

Farmers, vendors, theoreticians and engineers have used various software applications and servers for these uses. Because of problems with disease identification, a lack of interoperability brought on by vendor-locked agriculture systems, and security/privacy concerns regarding data storage, sharing, and usage, the agriculture domain is well known for suffering from heterogeneous and uneven data, delayed farm communications, and disparate work flow tools.

The material in the book is presented in a way to encourage researchers to think and indicate concepts that are introduced, which can solve real-world problems in the agricultural domain. Research and extension are crucial to innovation pathways. The contents of this book focus on,

Smart Farming - The future of agricultural technology is big data collection and analysis in agriculture to improve operational efficiency and reduce labour expenses. Based on a more precise and resource-efficient strategy, smart farming has the potential to offer more

productive and sustainable agricultural output. IoT has encouraged the assumption that a smart network of sensors, actuators, cameras, robots, drones, and other connected devices would provide agriculture with new levels of control and automated decision-making, allowing for a lasting ecosystem of innovation.

Artificial Intelligence - It is progressively growing as a component of the agricultural industry's technological growth. It is playing a critical role in the agriculture sector and is altering the industry. AI protects the agriculture sector against a variety of threats, including climate change, population expansion, labour shortages, and food safety. The goal is to boost global food production and will not only help farmers improve efficiency, but they will also increase crop quantity and quality and ensure crops reach the market faster.

Machine Learning - With the emergence of IoT and other technologies, a fertile ground for real-time monitoring has emerged. Machine learning solutions in agriculture rely on real-time data to provide farmers with exponential advantages. AI and machine learning are powerful catalysts for improving remote facility security, yields, and pesticide efficacy.

Deep Learning- It is a relatively new, innovative approach for image processing and data analysis, with promising results and enormous potential. Deep learning has recently entered the agricultural sector after being effectively employed in other disciplines.

Hydroponics system - It is the cultivation of plants in a controlled setting. While indoor farming is not a new phenomenon, hydroponic farming, a more recent discovery, simplifies the growing process even more by eliminating all unneeded components of traditional farming. Small farmers, amateurs, and business companies all employ hydroponic production systems.

Robotics in Agriculture - Robotics will undoubtedly bring about an agricultural revolution. Although the road ahead is not very smooth, we must assess the feasibility, sustainability, and efficiency of providing the world's food demands. However, it will be exciting to observe how farmers, agribusinessmen, and consumers will use the potential of robotics and digital-mechanization to define the future of this sector.

Internet of Green Things - Green IoT is an evolution of IoT that reduces emissions and pollution through many elements while also having low operational costs and power usage. Green IoT is the future, especially as the world seeks new methods to combat climate change; this new domain offers several chances for enterprises.

Crop health monitoring - It encompasses the monitoring of several factors, such as temperature, humidity, precipitation, insect intrusion, and seed and soil quality, allowing for improved crop quality and health decisions. This requires rapid involvement of farm managers in cases of emergency, such as overnight freezing or pest incursions, even from remote areas where they are not accessible on-site.

Application of sensors in agriculture - Given the current circumstances and their adverse influence on traditional farming techniques, agriculture must be carried out more wisely, utilising innovative and cutting-edge technologies. It is the only method to give a solution and fulfil the world's population's infinite and expanding requirements. Farmers may now remotely record their crops and monitor their efficacy, manage agricultural pests, and take quick action to safeguard their crops from environmental threats by using smart sensors in agriculture.

Climate Adaptation Strategies - Climate change, which primarily affects hydro-meteorological threats, is a fact that is influencing the planet in a variety of ways. It manifests itself in a variety of ways, including a rise in the frequency and severity of floods, droughts, and high temperatures. Climate change has caused droughts, other extreme weather occurrences, and meteorological disasters in many nations in recent years. Effective management of climate change-induced difficulties causes localised techniques that may differ from one region of the world to the next, and even within a single country.

Web 3.0 for Farming- Web3, the third generation of the internet and simple video-based technologies in local languages, has the potential to transform agriculture. It refers to initiatives taken to develop a decentralised form of the internet based on blockchain technology and on user ownership, which has the potential to reverse old data paradigms and return power to farmers.

The precise focus of this handbook will be on the potential applications and use of data informatics in the area of the agriculture domain.

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CHAPTER 1

Digital Twin for Smart Farming

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Abstract: One of the disruptive technologies that will emerge in the 21st century is the digital twin, which is a digital copy of any physical object that may exist in any setting. Many industries heavily rely on digital twin technology to produce high-quality products that can be shipped throughout the world with no loss in efficiency. The initial efforts have been made by the agricultural sector toward the implementation of digital twin technology in farming and other types of activities. It has already begun to apply vertical farming together with other crucial cutting-edge technologies in a chosen number of smart cities.

Keywords: Disruptive technologies, Efficiency, Digital twin, Smart cities.

INTRODUCTION

Without trustworthy and up-to-date information regarding farm operations, modern agricultural production is not viable. The use of digital technology in agriculture, such as sensing and monitoring devices, sophisticated analytics, and smart equipment, is becoming more necessary. Fast-evolving technologies like the cloud, the Internet of Things, big data, machine learning, augmented reality, and robots are driving a shift in agriculture toward “smart farming” systems [1-4]. One way to look at smart farming is as the natural progression of precision agriculture [5]. In smart farming, management activities are not just dependent on accurate location data but also on context data, situational awareness and event triggers. One way to think about a smart farming system is a cyber-physical control cycle that integrates sensing and monitoring, intelligent analyses and planning, and intelligent control of farm operations for all relevant farm processes (also known as a “whole farm management perspective”).

Using digital information that is (near) real-time rather than on-site direct observation and physical labour, farmers may remotely monitor and manage

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operations in smart farming systems. Therefore, farmers are immediately notified of any issues or impending problems. One may examine a high-quality digital picture of the plant, animal or machine in question from the comfort of their workstation or smartphone to see how things are doing out in the field or stable. Simultaneously, machine learning algorithms enhance the digital view by adding object-specific evaluations and recommendations. Farmers are able to replicate both remedial and preventative activities and assess the effect of such simulations on the digital depiction. Last but not least, the selected intervention may be carried out remotely, and the farmer can utilize the digital view once again to determine whether or not the issue has been resolved as anticipated. As this smart farm management cycle grows more autonomous, the farmer will no longer need to intervene manually, which is another thing that may be anticipated. It's fair to state that everything on the farm (crop, field, cow, equipment) is gradually being virtualized and, therefore, increasingly, remote-controllable. The concept of a digital twin is an interesting metaphor that can be used to describe this development.

Even though there are different ways to define a “Digital Twin”, which will be covered later, in general, a “Digital Twin” is a digital copy of a real-world object that acts and changes in the same way in a virtual space [6, 7]. Using Digital Twins as a core tool for farm management decouples physical flows from their planning and control. A digital twin eliminates important limitations related to space, time, and human observation. The need for farmers to be physically close to their crops would be eliminated, which would make it possible to execute, monitor, manage and coordinate farming tasks remotely *via* automation. This makes it possible to decouple the physical flows of agricultural activities from the informational components of those processes. Data from sensors and satellites, for example, may provide context to a digital twin that would otherwise be impossible to get directly from the physical object.

TECHNOLOGIES USED IN SMART FARMING

While innovation and digital transformation are occurring across many sectors, they are particularly crucial for the future of the planet and the well-being of humans in agriculture. The World Economic Forum projects that the world population will reach 9.8 billion by 2050, which implies that we may need to produce twice as much food as we do now without considerably straining natural resources like land and water.

However, there are good reasons to maintain a hopeful outlook. Throughout history, however, inventive people have found ways to overcome this problem. 8,000 years ago, during the first agricultural revolution, the plough revolutionized

production. In the 1800s, developments such as the seed drill introduced a degree of mechanization to farming. The middle of the 20th century saw a number of significant advancements made in the fields of artificial fertilizer and plant science.

At this point in time, we have entered the fourth era of agriculture. The rate of innovation is over the roof, and venture capital funding is flooding in. During 2020, that is, during COVID-19, Finistere Ventures and PitchBook Data projected a 22.3% increase in funding for this sector in 2020, reaching a total of \$22.3 billion. In order to put this into perspective, the sum amount of investments made since 2010 is now \$65.4 billion.

There is clearly longer any room for speculation on the digital transformation of agriculture. It is not a hoax. In addition, it has a significant influence on the agricultural industry as a whole. Here are some instances.

- **Drones that plant rice seeds:**

In April 2020, Chinese drone company XAG demonstrated rice sowing in Guangdong. First, it asked two employees to scatter 5kg of rice seeds by wading through a flooded paddy area. It took an hour and a quarter to complete the arduous task.

Then it deployed its XAG Xplanet drone on the same duty (Fig. 1). The unmanned aircraft system flew along a path that had been pre-programmed for it and dropped rice seeds from the sky. The task was finished in one minute and one hundred and twenty seconds. Farming using intelligence 1: labour from humans 0.



Fig. (1). XAG Xplanet drone (Courtesy: <https://www.xa.com/en/xp2020>).

It is impossible to understate how much of an influence drones have had on farming. Drones improve productivity while also being safer for workers and the environment. According to Xag, compared to conventional methods, this technology may use up to 90 compared to conventional methods, this technology may use up to 90% less water and 30% less chemicals. It also has a higher degree

of precision. Using a technology known as JetSeed, it can discharge seeds at speeds of up to 18 metres per second. This prevents any seeds from being carried away by the wind. The end result is an efficiency that is 80 times greater than that of hand sowing.

The use of commercial drones is one of the areas of the Internet of Things (IoT) that is expanding at the quickest rate, and 5G will play an important part in making this expansion possible.

- **Smart agriculture and the iot: a ‘ball’ to keep grain fresh:**

A smart sensor has the potential to be a game-changing piece of technology for an industry as scattered and out of the way as farming. It has the potential to significantly cut waste while simultaneously increasing production.

One such device is GrainSage, which is manufactured by Telesense as shown in Fig. (2).

It’s a sensor that’s been inserted in a ball, and the business says it looks like something a dog might use as a chew toy. The gadget is then tossed onto the existing heap of grain by the farmers. The ball is programmed to provide information numerous times each day on the temperature and humidity levels in the building.



Fig. (2). GrainSage by Telesense to keep grain fresh (Courtesy: <https://www.futurefarming.com/smart-farming>).

The cloud receives this data wirelessly, and TeleSense’s machine learning algorithms analyse it there to find significant patterns before transmitting it to the TeleSense app.

And how that LPWAN has been developed, there is an energy-saving, Internet of

Things (IoT)-optimized connection that can link these sensors for up to ten years on a single battery charge.

- **The robot that looks after chickens:**

There's nobody else around here except us hens... not to mention a robot dubbed "The ChickenBoy" that is dangling from the ceiling as shown in Fig. (3).



Fig. (3). The ChickenBoy analysis robot (Courtesy: <https://www.robotscience.com/>).

Start-up company Faromatics, located in Barcelona, has garnered a lot of attention for its EU-funded creation: a robot that enables chicken farmers to independently monitor their flock. The device has also received a number of accolades in the field of smart farming. The rail-mounted robot moves along the ceiling and utilizes a series of sensors to monitor heat feeling, air quality, light and sound in chicken housing.

Using a cloud service, farmers may set up The ChickenBoy to notify their phones through push notifications.

- **5G Farming: helping salmon farmers to 'see' one million fish:**

One of the biggest challenges for smart farming technology so far has been connecting its sensors and tracking devices. Farms are large; they are often located in isolated areas. Therefore, establishing a connection between these things *via* 3G or 4G might be challenging. Meanwhile, only the largest and most resourceful farmers are capable of establishing Wi-Fi access over thousands of acres of land.

5G farming offers solutions to practically all of these issues (Fig. 4). Low-latency

and accessible in any location, 5G can connect 100 times more devices per square kilometer than 4g. It can transfer data at rates up to one hundred times faster than before.



Fig. (4). 5G farming (Courtesy: <https://www.cubiclecom.com/blog/5g-agriculture-smart-farming/>).

A small number of farmers handle one million fish using a centralized feeding system in this region. They use a number of cameras that are positioned close to the cages to watch the procedure. This does not always have a simple solution. The water may get cloudy at times. Sometimes cameras have problems. During the winter, Norway's days are mostly cloudy and gloomy.

When farmers' vision is impaired, they run the danger of over-or under-feeding their animals, which may lead to pollution and spillage.

The issue might be remedied with higher-resolution cameras. However, the video cannot be sent back to the central site using the current 4G networks' limited capacity. However, problems with fibre optic cables are common when travelling vast distances.

This is the motivation for the 5G agricultural experiment that is being hosted by Telenor and the Aquatech company Bluegrove. 5G is dependable and easily available, and it can handle the bandwidth demands of high-definition real-time video. For the Sinkaberg Hansen Gjerdinga use case, the applications were set up and processed on an edge server. This reduced the delay to a minimum. Bluegrove estimates that Sinkaberg Hansen might save up to 50 million NOK in annual costs as a result of the partnership.

- **Soil health in smart farming: machine learning gets its hands dirty:**

One of the most well-known uses of machine learning is found in the field of medicine. In this application, computer programmes may analyze massive data sets to look for clues that might point to the presence of illness. The same work may take a human expert years to complete.

It is very clear that the same pattern recognition applies to the technologies behind smart farming. In today's market, a variety of companies provide solutions of this sort. The first example is Pattern Ag. Machine learning is used to identify several plant diseases and pests. For instance, it is able to identify a single rootworm egg in a sample of one pound of soil.

The system is capable of both diagnosing and resolving the issue at hand. It then utilizes that information to determine which herbicides to use and how much of each to use (Fig. 5). This is one of the numerous agricultural advances that, in comparison to previous methods, is both more effective and less harmful to the environment.

In the United States, rootworm pesticides are used to protect 55% of fields, according to Pattern Ag, even though only 18% are in financial danger from these pests. In the absence of accurate data, farmers may overprotect against rootworms.

Feeding 9.8 billion mouths by 2050 is one of the largest challenges mankind faces. However, human ingenuity has historically been able to overcome obstacles of a similar kind. There is strong cause to be optimistic about the future thanks to the technological advancements that have been made in agriculture.



Fig. (5). Teralytic: Wireless NPK sensor for monitoring soil health (Coutesy: <https://www.producer.com/crops/independent-probes-take-the-measure-of-the-soil/>).

DEFINITION OF DIGITAL TWIN

The field of agriculture is one that is not only notoriously difficult but also one that is consistently subject to development. Because they are dependent on natural conditions such as weather, diseases, soil conditions, seasonability, and climate, production processes are basically dynamic [8]. In addition to this, producers are obligated to meet the strict standards set forth by consumers and society with regard to concerns of food security, food safety, sustainability, and health. These requirements can be broken down into four categories: As a result, farms must not only be highly efficient, but also meet stringent quality and environmental standards, as well as react to changing market conditions. In addition to this, it is imperative that farms operate as effectively as they possibly can. Farmers' managerial obligations are significantly put under pressure as a result [8, 9]. Timely observation of agricultural operations necessitates constant reevaluation of production strategies and rescheduling of planned activities.

DIGITAL TWIN TYPOLOGY

The portion of the product's lifespan shown in Fig. (6) and referred to as the “utilization phase” is where the majority of the focus of Digital Counterparts is directed [10]. This is the time when digital twins are linked to their corresponding physical twins in the actual world. In this stage, Digital Twins can be used to maintain track of physical objects, prescribe optimal states for those objects, forecast how those objects will change, and even make remote adjustments to the actual objects' existing conditions. Even before the stage in which they are used, Digital Twins can already be developed to characterize and reproduce the states and behaviors of their real-life twins who have not yet been born. This can be done even before the stage in which they are used. This might be accomplished prior to the stage of consumption. Last but not least, digital duplicates can be used to reconstruct the previous states of physical objects even after the initial period of their utilization has come to an end. Based on Redelinghuys *et al.*, [11], Lepenioti *et al.*, [12], we came up with the following definitions for six distinct types of digital twins:

- **Imaginary Digital Twin:** A mental representation of something that does not yet exist in the actual world; also known as a concept. It defines the information that is necessary to actualize its physical twin, including examples such as functional requirements, 3D product models, material and resource specifications, production models, and disposal and recycling specifications. In addition, it defines the information that is necessary to actualize its digital twin [13]. Imaginary twins have the extra capability of replicating the behavior of designed but as of yet unrealized items within acceptable tolerance limits. This can be done