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Innovation and Technologies Synthesis of Various Components: A Contribution to the Precision Irrigation Development for Open-Field Fruit Orchards

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***Abstract*—**Precision irrigation (PI) technology has emerged as a solution to optimize water usage in agriculture, aiming to maximize crop yields while minimizing water waste. Developing a PI for commercialization requires developers to research, synthesize, evaluate, and select appropriate technologies and make use of such information to produce innovative products. The objective of this review is to facilitate innovators by providing them with a summary of existing knowledge and the identification of gaps in research linking to the innovative development of PI. This paper reviews and synthesizes technologies and components relevant to precision irrigation, highlighting its potential benefits and challenges. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework is used for the review. As a result of this review, the different technologies have limitations and may only be suitable for specific orchards or spatial settings. The current technologies are readily available in a range of options, from affordable controllers to high-performance systems that are both reliable and precise. Furthermore, the future prospects for incorporating artificial intelligence and machine learning techniques hold promise for advancing autonomous irrigation systems.

***Keywords*—**Innovation synthesis, technology assessment, precision irrigation technologies, precision irrigation components, new product development.

I. Introduction

In the face of an increasing global population and limited freshwater resources, efficient and sustainable agricultural practices have become paramount. One of the key challenges in modern agriculture is optimizing water usage to ensure maximum crop yield while minimizing water waste. In this context, precision irrigation (PI) has emerged as a revolutionary approach, offering a promising solution to address this challenge.

PI is a cutting-edge technology that leverages advancements in sensors, data analytics, and automation to precisely deliver water to crops based on their specific needs. Unlike traditional irrigation methods that apply water uniformly across an entire field, PI enables farmers to tailor water application at a fine scale, considering various factors such as soil moisture levels, plant growth stage, and weather conditions. By providing the right amount of water to crops precisely when and where it is needed, PI optimizes resource utilization and enhances overall agricultural productivity.

Developing a new PI for commercialization requires developers to perform technology synthesis and make use of such information to select appropriate technologies and produce innovative products. This is crucial, as technology synthesis and selection greatly influence the success and competitiveness of the product in the market [1].

Nonetheless, according to the information available in the publication, there are very few papers describing the presence of irrigation technologies and components, especially for the PI application in open-field orchards.

This research synthesizes various technologies and components behind PI, highlighting its potential benefits and challenges by examining current literature and case studies. The study is intended to contribute to innovators who apply a collaborative approach to problem-solving and idea generation that involves seeking external input and resources from a diverse range of individuals and organizations.

II. Technology Assessment

Technology assessment is a critical process that involves evaluating and analyzing the impact, effectiveness, and implications of various technological advancements. It aims to provide insights and recommendations to individuals, organizations, and societies on how to best utilize, adopt, and manage technology.

The assessment process typically involves several key steps. Firstly, it requires identifying the specific technology or technologies under consideration. This could range from emerging technologies like artificial intelligence and machine learning to established ones like mobile applications or cloud computing.

Once the technology is identified, the assessment involves evaluating its potential benefits and risks. This includes considering its impact on productivity, efficiency, cost savings, and overall competitiveness. In addition, technology assessment examines the long-term sustainability of technology. This involves considering factors such as its scalability and adaptability to future needs.

Firms must acquire the right technology and go beyond to

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create unique features, improve performance, and improve customer satisfaction. The results of a technology assessment should provide valuable insights and recommendations to guide decision-making for the development of a product. In summary, technology selection impacts competitiveness, performance, time to market, cost efficiency, and scalability, increasing the chances of a successful new product.

III. Innovation Synthesis

There are many techniques that entrepreneurs can use as a foundation to bring ideas and create innovative products. Innovation synthesis is one of the powerful techniques that seek external ideas, solutions, and partnerships to spur innovation. Innovation synthesis is the process of combining existing ideas or concepts to create new and innovative solutions [2]. There are four main types of innovation synthesis comprised of invention, extension, duplication, and synthesis. It is a powerful tool for driving innovation, as it allows businesses and organizations to tap into the collective knowledge and expertise of their employees, partners, and customers. Innovation synthesis can be used to solve a wide range of problems, from developing new products and services to improving business processes. It is a valuable tool for businesses and organizations that are looking to stay ahead of the competition and drive innovation.#For instance, a large international chemical company that produces chemicals for crop protection has built an open innovation platform to collaborate with expertise globally [3]. Apple, a big tech firm, developed the iPhone by synthesis of existing ideas and concepts, such as the touchscreen, the graphical user interface, and the mobile phone [4], [5].

A key success of new product development (NPD) is technical identification and evaluation at the early stage of a project. This study provides basic information to aid in this evaluation. Additionally, experts advocate for comprehensive research, meticulous planning, and systematic task organization. Furthermore, it is imperative to actively involve stakeholders throughout project implementation and deployment. By following these well-defined steps, projects can be executed efficiently and achieve success.

IV. Overview of the Precision Irrigation Technology

A. Principle of Precision Irrigation

Precision irrigation (PI) refers to the application of water and nutrients to crops in a precise and controlled manner, optimizing resource usage and maximizing crop yield. It utilizes variable rate technology to apply precise amounts of water and nutrients to specific areas of the field based on crop requirements. This method uses cutting-edge technology including soil moisture sensors, meteorological information, and irrigation scheduling algorithms to calculate the precise water needs of crops. PI reduces water runoff and evaporation by directly supplying water to the root zone, improving crop development, and reducing the risk of diseases caused by excess moisture.

B. Evolution of Precision Irrigation

The concept of PI has been around for centuries, but it has only been in recent decades that technology has been developed to make it practical. The development of PI has been driven by several factors, including the increasing scarcity of water resources, the need to reduce the environmental impact of agriculture, and the desire to increase crop yields. Looking back and learning from the evolution of PI helps entrepreneurs understand trends of development to predict future innovations. The following section summarizes the developments of PI since 1950 [4].

1) Early Development (1950s-1979s)

The early development of PI was driven by the need to improve the efficiency of irrigation systems. In the 1950s, drip irrigation was introduced as a more efficient alternative to flood irrigation. In the 1970s, variable rate irrigation (VRI) was developed, which allowed farmers to adjust the amount of water applied to different areas of a field [1].

2) Rapid Growth (1980s-2000s)

The 1980s and 1990s saw rapid growth in the use of PI technology. This was due to a few factors, including the increasing scarcity of water resources, the need to reduce the environmental impact of agriculture, and the development of new technologies that made PI more affordable and accessible.

3) Recent Developments (2000s-present)

In recent years, there have been several new developments in PI technology. These include the use of satellite imagery and drones to monitor soil moisture, the development of new sensor technologies, and the use of artificial intelligence to optimize irrigation scheduling.

C. Common Type of Irrigation Methods

PI technologies encompass various approaches and systems. Prior to PI technologies adoption, it must examine its suitability when applied to different types of irrigation that are relevant to crop types, climates, and field conditions. The following section offers an overview of different types, including drip irrigation, sprinkler irrigation, and localized irrigation.

1) Drip Irrigation

Drip irrigation, also known as trickle irrigation, involves the delivery of water directly to the root zone of plants through a network of tubes or pipes with emitters or drippers. This method provides water slowly and continuously, reducing water loss due to evaporation and runoff.

2) Sprinkler Irrigation

Sprinkler irrigation involves the use of overhead sprinklers that spray water over the crop area. This method mimics rainfall by distributing water in the form of small droplets or fine mist. Sprinkler systems can be designed to deliver water uniformly or with variable rates based on crop needs.

3) Micro-Sprinkler Irrigation

Micro-sprinkler irrigation is similar to sprinkler irrigation but uses smaller sprinklers that emit water at a lower rate. The system can be designed to deliver water directly to the root zone or to cover a larger area, depending on crop requirements.

4) Center Pivot Irrigation

Center pivot irrigation systems consist of a central pivot point with long, rotating arms equipped with sprinklers. As the system rotates around the pivot, water is distributed over a circular area. This type of irrigation is often used for large-scale agriculture, such as field crops.

5) Lateral Move Irrigation

Lateral move irrigation systems are similar to center pivot systems but move along a straight line instead of a circular path. They typically consist of a series of pipes mounted on wheels that move water over rectangular fields.

6) Subsurface Drip Irrigation

Subsurface drip irrigation involves burying drip lines beneath the soil surface, delivering water directly to the root zone of plants. This method reduces water loss due to evaporation and minimizes contact with the foliage, potentially reducing disease risks.

D. Adaptability of Precision Irrigation for Fruit Orchard

Fruit farmers adopt the PI technology to manage farms in several methods. PI is used to monitor crop water requirements and then precisely control the amount of water irrigated to crops. The adaptability of PI lies in its ability to cater to the specific needs of different fruit varieties and orchard conditions. It takes into account factors such as soil type, plant age, weather conditions, and growth stage to determine the precise amount of water and nutrients required by each tree. This customized approach promotes healthy root development, improves nutrient uptake, and enhances overall plant vigor, leading to higher yields and better fruit quality.

Additionally, PI systems provide farmers with real-time monitoring and control capabilities. Through the use of sensors and advanced technologies, farmers can remotely monitor soil moisture levels, weather conditions, and plant health. This allows them to make timely adjustments to irrigation schedules and optimize resource usage based on actual plant needs.

The adaptability of PI also extends to its compatibility with sustainable agriculture practices [6]. By reducing water usage and minimizing nutrient runoff, PI helps conserve natural resources and mitigates environmental impacts. It also enables the efficient use of fertilizers and pesticides, reducing their potential negative effects on the environment.

1) Soil Moisture Monitoring

One of the fundamental principles of PI is accurate soil moisture monitoring. Soil moisture content plays a crucial role in determining crop water requirements. Various sensor technologies, such as tensiometers, capacitance sensors, and time-domain reflectometry, are used to measure soil moisture levels at different depths. Real-time monitoring enables farmers to apply water precisely when and where it is needed, avoiding over-irrigation or under-irrigation.

PI systems employ soil sensors, weather stations, and satellite imagery to collect data on soil moisture, temperature, humidity, and crop health. These data points are analyzed to determine the water requirements of specific areas within a field, allowing for targeted irrigation.

2) Plant Water Requirements

Understanding the water requirements of different crops is essential for PI. Crop evapotranspiration (ETc), which represents the amount of water lost through evaporation and plant transpiration, is a key parameter in determining irrigation scheduling. ETc can be estimated using weather data, crop coefficients, and reference evapotranspiration (ETo) models, such as the Penman-Monteith equation. By considering crop-specific water needs, farmers can optimize irrigation scheduling and avoid water stress or excess water application [5].

3) Crop-Specific Management

PI technology recognizes the variability in crop water requirements based on crop type, growth stage, and field conditions. By adopting crop-specific management strategies, farmers can tailor irrigation practices to meet the unique needs of different crops. This approach optimizes water use, minimizes nutrient leaching, and promotes healthy plant growth.

4) Data Collection and Analysis

Performance and accuracy of PI rely on the quality of instruments, scan rate, and method of data collection. If data can be measured and collected in real-time, it will lead to higher accuracy. However, some technologies, such as remote sensing and satellite imagery, are limited in their sampling rates, while IoT and weather stations can collect data in real-time. Advanced data analytic tools can process and interpret the gathered data, offering valuable information for irrigation decision-making. Examples include machine learning algorithms and data fusion approaches. The effectiveness of irrigation systems is then increased by using this data to enhance irrigation schedules.

5) Irrigation Efficiency and Uniformity

PI aims to maximize water-use efficiency and ensure uniform water distribution across the field. Efficient irrigation systems, such as drip irrigation and micro-sprinklers, reduce water losses due to evaporation, runoff, and deep percolation. Additionally, PI employs techniques like pressure regulation, flow control, and proper emitter placement to achieve uniform water distribution, minimizing spatial variations in soil moisture levels.

6) Irrigation Scheduling and Automation

PI scheduling is crucial for optimizing water usage and crop productivity. Advanced technologies, such as soil moisture-based sensors and weather forecasting models, enable automated irrigation scheduling. By integrating real-time data with crop water requirements, these systems can automatically trigger irrigation events, ensuring timely and accurate water application.

7) Integration of Decision Support Systems

PI systems often feature decision support systems (DSS) that provide real-time recommendations for irrigation scheduling, fertigation, and pest management. DSS utilizes data-driven models, historical data, and expert knowledge to assist farmers in making informed decisions, optimizing resource allocation, and maximizing crop yields.

V. Research Method of Technology Assessment

The sources of information for performing technology assessment are retrieved from Scopus databases, including information from a few manufacturers' datasheets.

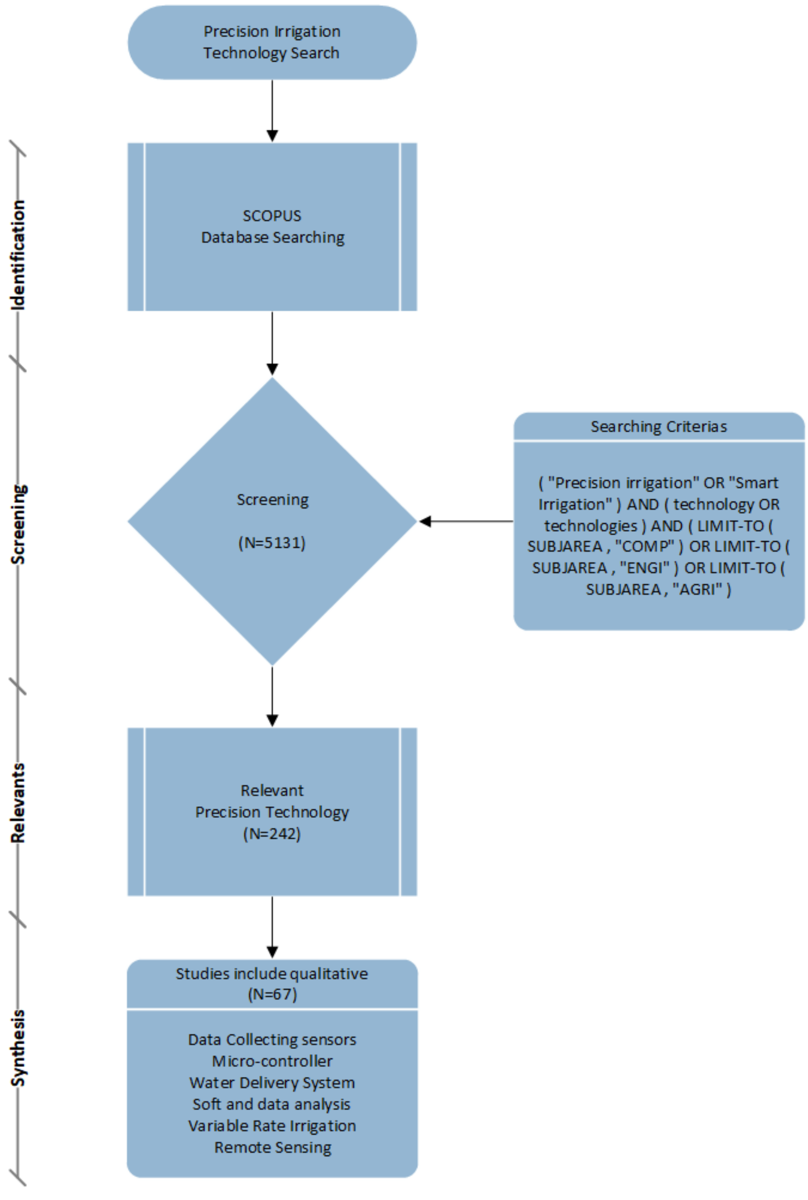

Fig. 1 Article Screening Processes

To ensure that the assessment obtains quality information, this research utilizes the PRIMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) technique [7]. The terms ("Precision irrigation" OR "Smart Irrigation") AND (technology OR technologies) AND (LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "AGRI") are used as search criteria. The initial result of the search found more than 2000 articles. The articles are passed the filter if their issued date is between 2019 and 2013, and they are cited more than 20 times. Sub-consequently, the articles will be reviewed and synthesized.

The diagram in Fig. 1 illustrates how an article passes the filter and selection. It begins with searching in journals, filtering, and selection. Finally, 67 articles were chosen for review, synthesis, and evaluation.

PI and technologies can be found in several subjects. As demonstrated in Table I as a result of searching, computer science, engineering, and agriculture and biological science are the top three areas in which this research will mostly have references.

Fig. 2 demonstrates the number of articles and other documents related to irrigation agriculture. The growth is more slope since 2019 and increased the average by 30%. Note: amount of 2023 only updates till September.

Fig. 3 shows that the trend in research has been rapid growth in the sensor network and system since 2019. This is due to emerging IoT technologies. The field of agriculture technology continues to expand and evolve, constantly incorporating new technologies and knowledge, resulting in steady growth. This trend can be attributed to the emergence and utilization of innovative technologies such as IoT, AI (artificial intelligence), and ML (machine learning), which are providing valuable insights to researchers in the field. Despite that, the published articles and documents are mainly spread into computer science (24.1%), engineering (22.4%), and agriculture science (12.5%). These are more than half of another field as shown in Fig. 4.

TABLE I
SUMMARY OF ARTICLES BY SCHOLAR

No.	Subject Area	Articles
1	Computer Science	3010
2	Engineering (IEEE)	2792
3	Agricultural and Biological Sciences	1565
4	Mathematics	698
5	Environmental Science	671
6	Physics and Astronomy	660
7	Decision Sciences	576
8	Energy	496
9	Social Sciences	367
10	Biochemistry, Genetics and Molecular Biology	318
11	Materials Science	269
12	Earth and Planetary Sciences	202
13	Chemistry	173
14	Chemical Engineering	164

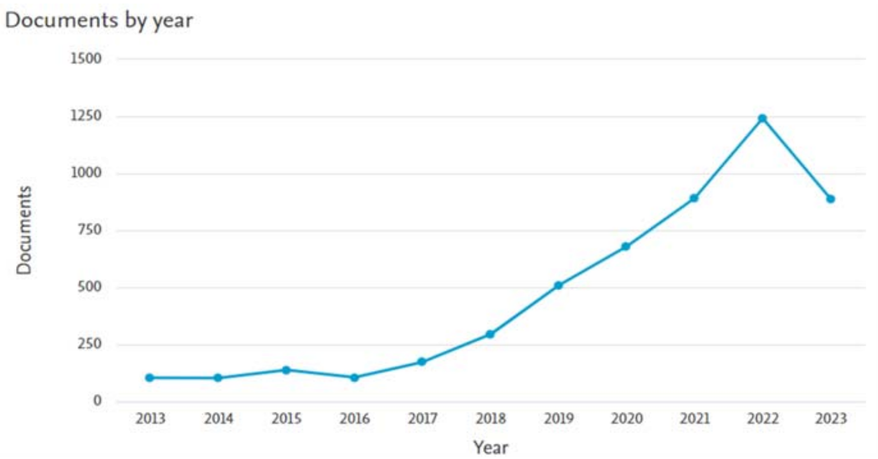

Fig. 2 Amount of Publish Documents by Year

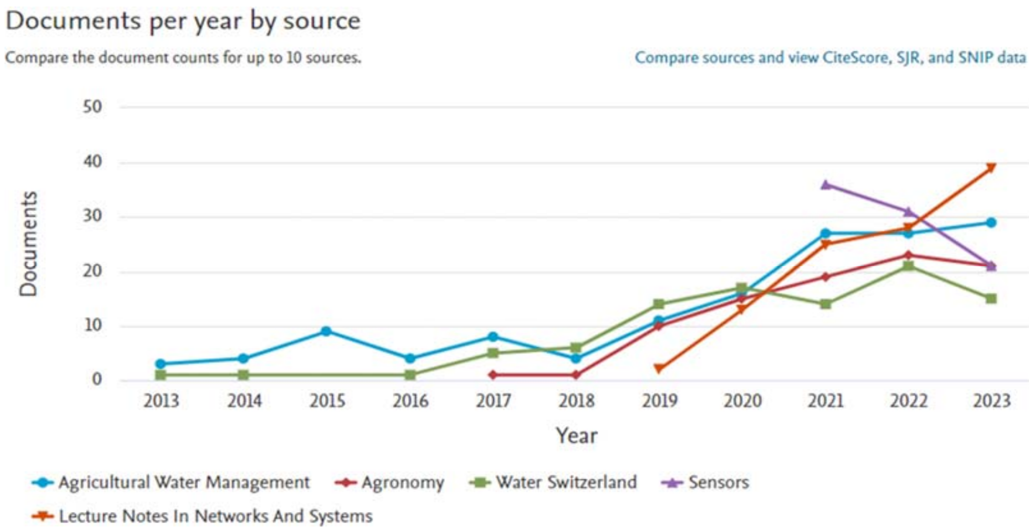

Fig. 3 Compare and view cited score

Research in the domain of agriculture technology is continuing to increase because of new emerging technologies. Predictably, new technologies and knowledge will launch and provide additional value to farmers.

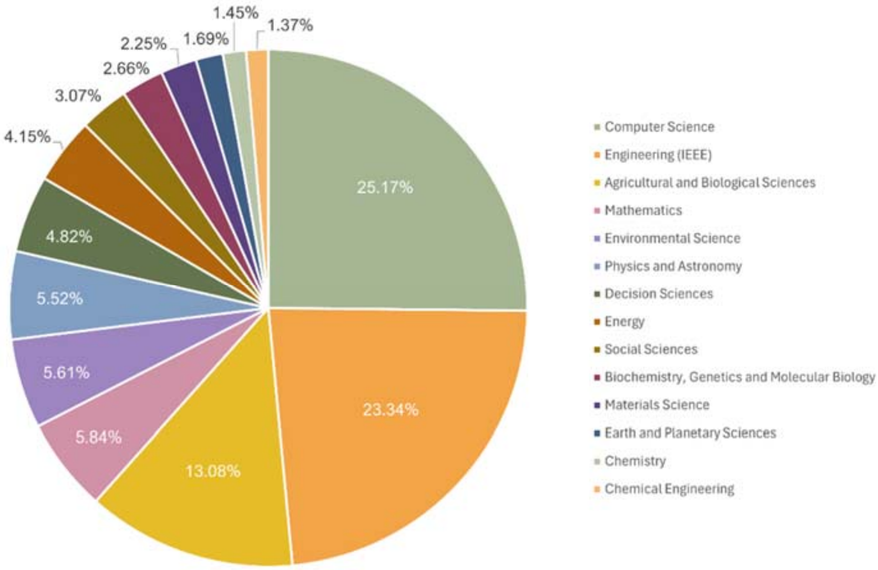

Fig. 4 Documents by subject area

VI. Precision Irrigation Components Technology Assessment

PI technology encompasses various approaches and systems. PI technology appears in a variety of forms, including the automatic regulation of irrigation using microcontrollers or programmable logic controllers, the use of IoT for data collecting, and crop growth analysis utilizing image sensing technologies. Practically, the PI concept can be applied in four applications, which include data collection, data analysis, decision-making, and precision control. This section explores the key components, including sensors, controllers, actuators, and communication systems, highlighting their roles and functionalities. The key components of PI are summarized in Table II.

TABLE II
Summary of Articles by Categories

No.	Scholars Categories	Articles
1	Internet of Things	2794
2	Sensors	1455
3	Irrigation System	922
4	Smart and precision irrigation	750
5	Machine learning	720
6	Micro-controllers	621
7	Precision agriculture	606
8	Wireless sensor network	535
9	Agricultural robots	467
10	Artificial Intelligence	253
11	Remote sensing	180
12	Unmanned Aerial Vehicle (UAV)	57

A. Data Collecting Components

These are devices that measure various parameters such as soil moisture, temperature, humidity, and weather conditions. Sensors provide real-time data that help determine the precise irrigation requirements of the plants. The data of the field orchard are collected and transmitted to a database and controller, or software platform. These data are then used for analysis, monitoring, and assisting farmers with irrigation decision making and controlling the delivery of water to the field. There are various types of sensors that developers should select to match the application and characteristics of plants, soil, and local weather. Moreover, the design of PI for open-field fruit orchards is more specific to crop size, the shape of the canopy, height, land plot space, evapotranspiration factors, and farm management.

1) Automatic Weather Sensor

An automatic weather station (AWS) is a type of weather monitoring system that is designed to collect and record various meteorological data automatically. It consists of a set of sensors and instruments that measure parameters such as temperature, humidity, wind speed and direction, atmospheric pressure, precipitation, and solar radiation. These stations continuously measure and transmit data to a central data logger or a remote server. The data can then be accessed and analyzed in real-time by meteorologists, researchers, and other stakeholders. AWS is widely used as data acquisition to calculate evapotranspiration according to Penman-Monteith equation [8]. A more detailed approach involves utilizing water balance to determine irrigation doses, while also incorporating feedback from sensors to empirically adjust crop coefficient. This combination of water balance and sensor feedback enables the calculation of irrigation volumes through water balance, while also allowing for site-specific adaptive responses to sensors.

The pricing of instruments for instant pyranometers is typically based on their performance and accuracy. Class A pyranometers are considered the highest quality and offer the most accurate measurements. They undergo rigorous calibration procedures and are built with high-quality components, resulting in superior accuracy and stability. This level of precision is essential for applications that require highly accurate solar radiation measurements, such as meteorological research, solar energy studies, and climatology. On the other hand, Class B and C pyranometers have slightly lower accuracy and may not undergo the same level of calibration and quality control as Class A instruments. These lower classes of pyranometers are still suitable for many applications such as irrigation systems where high accuracy is not a critical requirement. The wind speed measurement or anemometer is another example as they have various types of instruments such as cup anemometer, sonic anemometry, LIDAR, or SODAR [9]. The price of them is mostly upon its accuracy, data storage, and communication feature [10], [11].

The product developer may face difficulty choosing an appropriate AWS integration for their product. To ensure that the AWS has accuracy within the control range, some researchers did an accuracy comparison test before employing it in their work [12].

2) Soil Moisture Measurement

A soil moisture instrument is a device used to measure the water content in the soil. It provides valuable information about the moisture level of the soil, which is crucial for efficient irrigation and plant health. Several PI products integrated soil moisture sensors as data input. However, selection sensor technology will reflect the accuracy and reliability of the product. There are major technologies of soil moisture sensors consisting of the following.

(a) Frequency Domain Reflectometry (FDR): Uses oscillating electric current to measure the dielectric constant of soil, which is affected by water content.
(b) Time-domain reflectometry (TDR): Similar to FDR but uses a short pulse of electricity. It is more accurate but more expensive.
(c) Capacitance: Measures the capacitance of soil, which is affected by water content. It is inexpensive and easy to use but not as accurate.
(d) Microwave: Uses microwave radiation to measure the dielectric constant of soil. It is accurate and can measure soil at depth but costly.
(e) Infrared: Uses infrared radiation to measure the temperature of soil, which is affected by water content. It is inexpensive and easy to use but not as accurate.

3) Image Sensing Techniques

Not only in-situ sensors are used to measure soil moisture but also satellite image technologies are adopted in many applications. Satellite soil moisture technology uses remote sensing to measure the amount of water in the soil from space. This is done by measuring the way that microwave radiation interacts with the soil. Microwave radiation is absorbed by water, so the more water in the soil, the more microwave radiation is absorbed.

Satellite remote sensors are more favorable today because they provide information on soil moisture levels over larger areas [13]. Some soil moisture sensors are designed to be connected to automated irrigation systems, allowing for precise and efficient watering based on real-time soil moisture data. This helps to conserve water and prevent water wastage. A study demonstrates that combining the water balance method with soil moisture sensors provides a reliable approach for automated irrigation scheduling in orchards [14].

Satellite sensing of soil moisture technology has several advantages over in-situ soil moisture measurements. These advantages include:

(a) Wide spatial coverage: Satellites can measure soil moisture over large areas, such as entire countries or continents.
(b) High temporal resolution: Satellites can measure soil moisture at frequent intervals, such as daily or even hourly.
(c) Cost-effectiveness: Satellite soil moisture measurements are relatively inexpensive compared to in-situ measurements.

4) Internet of Things

IoT technologies in agriculture leverage sensors and connectivity to enhance farming practices. They enable real-time monitoring of crop health, soil moisture, and weather conditions, optimizing irrigation and reducing water waste [15]. IoT-enabled irrigation systems allow users to remotely monitor and control their irrigation systems such as changing watering schedules or turning it off/on, from anywhere using a smartphone or a computer. IoT devices can collect and transmit real-time data about various environmental factors, such as soil moisture, weather conditions, and plant health. These data can be analyzed informed irrigation decisions. Some developers have built an automatic watering system that integrates sensors, microcontrollers, and cloud platform [16]-[18] as a system.

The communication technologies of IoT devices are an important factor to consider if designed for use in the open field orchard [19]. LoRaWAN (Low Range Wide-Area Network) and NB-IoT, ZigBee, and Bluetooth are becoming increasingly popular due to their longer range and low power consumption [20], [21]. However, if IoT devices are designed to be installed in remote areas, the cellular network is recommended [22]. The number of nodes and devices in an IoT network requires design at the engineering stage otherwise the congestion of data may reduce the overall efficiency of data communication and may be difficult to expand [23].

The automatic irrigation systems based on IoT and stand-alone or application platforms are low-cost investments compared to programmable controllers, but their useful life, reliability, and accuracy are major concerns. However, it depends on irrigation application, spatial, crop characteristics and users' acceptance.

5) Unmanned Aerial Vehicles

Agriculture drone technology has brought significant advancements to modern farming practices. These drones enable precision crop monitoring, allowing farmers to quickly detect and address crop health issues. They also provide efficient field mapping capabilities, allowing for precise resource allocation [24]. With their crop spraying systems, drones minimize chemical wastage and promote targeted treatment. Additionally, agriculture drones contribute to crop assessment and yield estimation, helping farmers make informed decisions [25]-[27].

Typically, a UAV has three major parts that consist of drone, optical sensors, and software. Based on their aerodynamic characteristics, it can be divided into four categories; as multi-rotor, fixed-wing, single-rotor, and hybrid vertical take-off and landing [28]. The multi-rotor is the most flavor because of flexible control and cost saving but flying time is shorter approximately 20-40 minutes compared to other types. In applying UAV for open field orchards, the developer should evaluate what type of optical sensors should be obtained for the design application such as color (RGB), hyperspectral, thermal camera, and multispectral. There are a lot of post-processing software that are capable of being used to analyze, present UAV data, and transform it into practical or usable information. Abdulridha et al. [1] collect spectrum reflectance data from tomato plants affected by tomato yellow leaf curl using a hypersonic sensing approach. The result demonstrated accurate detection between noninfected or healthy tomato plants. The multispectral sensors can be used to record near-infrared spectrums with RGB sensors, leading to normalized difference vegetation index (NDVI) monitoring.

UAVs with thermal image sensors have been used to detect water stress or plant vegetation in fruit orchards [30], [31]. The software that is used for data analysis and visualization is an additional cost to the utilization of UAV. In this perspective, the innovator or developer should consider whether such a cost could be accepted by the farmer or buyer or not.

Despite that UAVs are efficient tools for mapping and scouting large farms, providing growers with valuable information to enhance productivity, these UAVs can be equipped with various sensors, such as RGB, multispectral, hyperspectral, thermal cameras, and LiDAR, ranging from $200 to $25,000. The cost varies by the resolution of the image sensors; the more pixels, the higher the cost [32].

B. Controllers Unit

PI systems are equipped with controllers that receive data from sensors and employ analytical algorithms to ascertain the optimal irrigation schedule. The operation of these controllers can be automated or manually configured, contingent upon the specific system design. The microcontroller has been widely utilized in smart irrigation [33]-[35].

A singular controller comprises a central processing unit (CPU), an input/output (I/O) interface, a communication module, and a graphic display unit. The CPU's architecture can be categorized into two primary classes: microcontrollers and microprocessors. Microcontrollers integrate memory, I/O capabilities, and readily available interfaces within a compact unit. Conversely, microprocessors exhibit superior computational power compared to microcontrollers but lack built-in I/O and interfaces. Microprocessors offer heightened flexibility, enabling the attachment of diverse peripheral devices, including I/O components and memory, to facilitate concurrent operation. Presently, advancements in chip manufacturing have given rise to microcontrollers combined with a CPU, a graphic user interface (GPU), an audio processor, and a singular processor within a single integrated circuit, commonly referred to as a System on a Chip (SoC). Notable SoCs such as the Raspberry PI (RPi) are constructed on the Linux operating system (OS) platform, providing compatibility with an array of programming languages, including Python, Fortran, Java, C, and C++. The RPi is Broadcom chips based on Arm's Cortex-A processor. The Arduino board is another well-known controller. Although it is not as fully featured as an RPi, it is sufficient to run a simple project like autonomous watering that is based on the moisture level of the soil.

PLC (Programmable Logic Control) is widely used in many automatic or smart irrigation [36]. It offers several advantages over microcontrollers in automation and control systems. They are robust, reliable, and designed for industrial environments. PLCs are highly scalable, making it easy to expand and modify control systems. They have user-friendly programming languages and built-in communication capabilities. PLCs also have advanced diagnostic features for efficient troubleshooting and maintenance.

The development of an intelligent irrigation control system necessitates the meticulous selection of an appropriate processor, contingent upon user requirements and production expenses. The deployment of a microcontroller is deemed suitable for rudimentary irrigation systems, primarily owing to its compatibility with relatively low data volumes and cost-effectiveness considerations. However, it is imperative to acknowledge certain trade-offs, wherein microcontrollers may exhibit limitations in terms of operational speed, resolution, and system stability when compared with PLCs. The microcontrollers resolution and stability are not as good as PLCs. PLCs offer superior performance attributes and friendly programming software, but they also have a significantly elevated cost paradigm.

C. Water Delivery System

The water delivery system is a crucial component of PI technology. It ensures that water is distributed efficiently and precisely to the plants' root zones, minimizing water wastage, and maximizing its effectiveness. Various methods are employed, such as drip irrigation, micro-sprinklers, or center pivot systems, depending on the specific needs of the crops and the field. Drip irrigation involves the use of small tubes or emitters that deliver water directly to the base of each plant, minimizing evaporation and runoff. Micro-sprinklers distribute water in a fine mist, covering a larger area while still being targeted. Center pivot systems use rotating sprinklers mounted on a moving pivot to irrigate large fields in a circular pattern. These technologies enable farmers to provide the right amount of water to the plants precisely where it is needed, promoting optimal growth, and minimizing water usage.

D. Software and Data Analysis

PI systems often rely on software applications or platforms that collect and analyze data from sensors and controllers. These applications provide insights into crop water requirements, irrigation scheduling, and overall system performance. The data from the field are collected through various techniques, including the use of IoT sensors, UAVs, and satellites. Subsequently, the data or images undergo analysis, where machine learning and AI have been widely adopted to develop numerous algorithms for analysis [37], [38].

One of the primary goals of data analysis in PI is to achieve optimal water efficiency. By examining historical data and real-time measurements, the software can identify trends and patterns, allowing for the development of customized irrigation plans and schedules. These plans take into account factors such as crop type, growth stage, weather conditions, and soil characteristics to deliver the right amount of water at the right time and in the right location.

Furthermore, data analysis enables the identification of potential issues or anomalies in the irrigation system. By monitoring variables such as soil moisture levels and flow rates, the software can detect deviations from expected values and alert farmers to possible leaks, blockages, or malfunctions. This proactive approach helps prevent water wastage and ensures the system operates efficiently. Since 2010, ML become cutting-edge technology in collaborative data analysis, performing prediction and decision-making models on PI [37]. Corbari et al. [39] computed soil water balance based on data from satellites and forecast crop water requirement. With regard to data analysis, Filgueiras et al. [40] take advantage of remote sensing and regression algorithms to predict evapotranspiration and vegetation indices [40].

Software and data analysis also facilitate record-keeping and reporting. By centralizing data collection and analysis, farmers can generate comprehensive reports on water usage, crop performance, and overall system efficiency. These reports not only provide valuable insights for farmers to optimize their irrigation practices but also serve as documentation for regulatory compliance and certification programs.

Each prediction model may not generalize and be widely applied for various crop varieties when addressing data analysis development for open-field orchards. As a result, the creation of algorithms and ML may take some time and include collecting a large amount of data. Data collection and storage are additional issues that should be taken care of early in the design process. The annual cost that consumers or farmers must pay for software platforms is a significant problem and the complexity of using them may cause them to reject the product.

E. Variable Rate Irrigation

VRI technologies have revolutionized the way water is applied in agriculture. VRI allows for precise control and adjustment of water application rates across a field, based on the varying needs of different areas. By utilizing specialized nozzles, valves, or control systems, VRI can deliver the right amount of water to each plant or crop, taking into account factors such as soil moisture levels, topography, and plant growth stage [41]. This technology enables farmers to maximize water efficiency, minimize water wastage, and improve overall crop health and productivity. By tailoring irrigation rates to specific areas, VRI helps to address areas of excess or deficit water supply, resulting in uniform crop growth and reduced water runoff. It also allows for the targeted application of fertilizers and other inputs, optimizing resource utilization and reducing environmental impact. The flexibility and precision offered by VRI technologies make them valuable tools for modern agriculture, helping farmers achieve sustainable and efficient water management practices. In the past, VRI was adopted in large-scale farming but recently VRI has been utilized in various sizes of fruit orchards. The new technologies, such as variable speed drives, help farmers adjust the pump flow rate of water transport to crops via spray nozzle or sprinkler emitter. The limitations of VRI are its high investment cost, high maintenance cost, and its inability to mobilize when used to irrigate tall trees compared to sprinkler systems. The advantages and disadvantages of VRI are summarized by O'Shaughnessy et al. [42] which shall be considered and evaluated when a new VRI product is being implemented. The traditional design of VRI appears as a large arm with a water pipe and spray nozzle installed along the arm. A new design combines automatically feeding and irrigate in a single robot [41].

Despite the efficiency gains associated with VRI, resulting in reduced time requirements for large-scale watering, it is imperative to acknowledge that the initial investment costs are somewhat elevated, accompanied by challenges about operational intricacies and maintenance. It is worth noting that VRI retains considerable prospects for technological advancement, particularly in areas such as automatic water management, spatial precision in distribution, and adaptation to a diverse range of crop varieties [43].

F. Remote Monitoring and Control

PI systems can be remotely monitored and controlled through mobile applications or web-based platforms. This enables farmers to adjust irrigation schedules and settings, even when they are not physically present on-site. Remote monitoring reveals different methods such as using UAVs, satellite, and IoTs. Many researchers propose the integration of soil moisture sensors, controllers, and computer programming for watering remote control [14], [44]. The combination of soil sensors, weather monitoring, and controllers with prediction control provides significant water efficiency [45].

Automated systems can be controlled remotely, providing farmers with convenience and flexibility. In this regard, farmers are recommended to employ appropriate technologies that fit crop variety, spatial, and farm management, including irrigation, pests, diseases, and nutrient controls [46].

VII. Challenges and Limitations

While PI technology shows great promise, it is not without challenges. This section explores the limitations and obstacles associated with its implementation, such as cost, technical complexity, maintenance requirements, and potential over-reliance on technology. PI, while optimizing water usage in agriculture, does have its limitations. One key limitation is the reliance on accuracy and accuracy of data. PI systems require real-time information about soil moisture levels, weather conditions, crop water requirements, and other variables to determine the optimal amount of water to be applied. However, obtaining these data can be challenging, especially in remote or resource-constrained areas where access to reliable sensors or weather stations may be limited. Additionally, even with access to data, the accuracy of the measurements and the reliability of the sensors can vary, leading to potential inaccuracies in irrigation scheduling. Another limitation is the initial cost and complexity of implementing the systems. The installation and maintenance of sensors, controllers, and other equipment are costly, making it less accessible to small-scale farmers or those with limited financial resources. Furthermore, the technical knowledge required to operate and troubleshoot these systems may pose a challenge for farmers with limited technological literacy. Finally, PI systems are highly dependent on a stable and uninterrupted power supply. In areas with unreliable or limited access to electricity, the operation of these systems may be hindered, leading to potential disruptions in irrigation schedules. Despite these limitations, ongoing research and development efforts aim to address these challenges and make PI more accessible, reliable, and cost-effective for farmers around the world.

VIII. Results and Discussion

As water resources become increasingly scarce and the need to reduce the environmental impact of agriculture grows, PI will become even more important. New technologies are being developed all the time that will make PI even more efficient and effective. The key trends that are shaping the evolution of PI technology are listed below:

(a) *The increasing use of sensors and data analytics:* Sensors are being used to collect data on soil moisture, weather conditions, and other factors that can affect irrigation needs. These data are then used to optimize irrigation scheduling and improve the efficiency of irrigation systems.

(b) *The growing use of automation:* Automation is being used to reduce the labor required to operate and maintain PI systems. This makes PI more affordable and accessible to farmers.

(c) *The development of new irrigation technologies:* New irrigation technologies, such as sub-surface drip irrigation and laser-controlled VRI, are being developed that offer even greater efficiency and precision.

(d) *VRI:* VRI systems divide fields into smaller management zones and adjust water application rates accordingly. This technology enables farmers to customize irrigation based on variations in soil type, topography, and crop needs, optimizing water usage and reducing wastage.

(e) Machine learning and AI will play a key role in precise water irrigation where autonomous features will be bundled into the PI system.

An innovation or new development of a PI product should address at least four major factors: technologies, commercialization, demand, and user acceptance. The products should have flexibility to operate, high reliability, scalability, and low operation and maintenance costs. For instance, if the system requires for installation many of soil moisture sensors throughout the crop area, this method could lead to an incumbrance of users to maintain it.

Table III presents an overview of the technologies commonly found in scholarly documents. Product developers in the product innovation field should carefully consider and select appropriate technologies that align with their product objectives and market strategies, with a focus on ensuring customer satisfaction. The new design must also incorporate technologies that provide a competitive advantage and align with the product's intended market positioning. For instance, if developers opt to utilize satellite technology for data collection, it is important to acknowledge that data collection may be hindered in instances where cloud coverage is extensive. Furthermore, most satellites have a limited orbit frequency of three times per day, resulting in a lower amount of data acquisition compared to alternative technologies.

TABLE III
Comparison of Technologies Components

Technology	Performance			O&M*	Cost
	Reliability	Accuracy	Speed		
Sensors					
Soil moisture	M	L	H	L	L
Weather station	H	H	M	H	H
UAV	M	M	L	H	H
Satellite	L	M	L	H	M
Thermal image	M	M	L	H	H
Communication					
LoRaWan	M	M	L	H	M
ZigBee	H	H	M	L	L
Ethernet	H	H	H	L	H
WiFi	M	H	H	M	M
GSM	M	H	M	M	H
Controllers					
Arduino	L	M	L	M	L
Ras-PI	L	M	M	M	L
PLC	H	H	H	H	H
Computer	H	H	H	L	H
Operating					
Android	M	H	L	L	L
Ras-PI	M	H	M	L	L
SCADA	H	H	H	H	H
Cloud	M	H	L	L	M

* O&M: Operation and Maintenance
L = Low, M = Medium, H = High

In cases where the design application necessitates extensive data computation, such as in machine learning, ethernet or WiFi connectivity would be a suitable choice. The selection of controllers, software, and operating systems should be based on a consideration of both the overall cost of the product and its performance. However, there are no set rules in determining these factors, as they are contingent upon the specific product objectives and market strategies.

Finally, developers must ensure that the selected technologies are compatible with the crop varieties, spatial requirements, and end-users of the product.

IX. Conclusion

The selection of components is based on the objective and market positioning of the new product. The higher product cost is the higher performance, reliability, and accuracy. Some of the technologies come with their own set of limitations; one technology may be suitable for one specific crop or area but not for another. One key limitation is the need for extensive research and development, which requires significant financial investment and time. Developing an efficient and reliable PI system involves designing and testing various components, such as sensors, controllers, and software algorithms, to ensure accurate and precise irrigation scheduling. Additionally, the product development process requires collaboration between experts from different fields, including agronomy, engineering, and software development, which can further complicate the process. Another limitation is the need for field validation and testing. It is crucial to conduct extensive field trials to evaluate the performance and effectiveness of the new PI product under different environmental conditions, soil types, and crop varieties. These trials can be time-consuming and require access to agricultural land and cooperation from farmers. Furthermore, the adoption and acceptance of a new PI product by farmers may be a challenge. Farmers might be hesitant to adopt new technologies due to factors such as cost, perceived complexity, or lack of awareness. It is important to educate and demonstrate the benefits of the new product to gain farmer acceptance and overcome any resistance. Despite these limitations, the development of new PI products is crucial for sustainable agriculture and water conservation. Continuous research, innovation, and collaboration can help overcome these limitations and lead to the development of more efficient and user-friendly PI solutions.

X. Future Research Directions

The advent of new technologies, such as machine learning, artificial intelligence, IoT, cloud computing, and communication networks, is propelling irrigation technologies to operate at a significantly accelerated pace, with improved efficiency and heightened intelligence. In the future, the integration of these technologies will further augment irrigation systems, rendering them closer to achieving complete autonomy, thereby obviating the need for human intervention in this task. This combination entails cutting-edge sensors, advanced communication capabilities, powerful processors, and cloud infrastructure. The irrigation system will be designed to operate on behalf of the owner. The prevailing trajectory of PI technology is progressing towards unmanned operation. The subsequent generation of irrigation will exhibit enhanced precision and full automation. The novel product is expected to possess heightened intelligence, serving not only as a monitoring and reporting tool but also capable of autonomously or manually adjusting water delivery in response to changes in weather conditions.

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