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Development of Raspberry Pi-Based Soil Moisture Monitoring System

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Abstract: The paper plays a crucial role in modern farming, enabling the monitoring of plant health and the efficient use of water. This study proposes an automated plant watering system that operates on a Raspberry Pi, utilizing soil moisture sensing, plant disease detection, and Digital Signal Processing (DSP) methods to assist individuals in making informed decisions. The system has a sensor that checks the soil's moisture level. It turns on a relay-controlled water pump when the soil is too dry and off when the soil is just right. Plant disease detection is also used to identify potential health issues in plants. This turns on the water pump as a safety measure. The Raspberry Pi is the primary computer that utilizes DSP techniques to clean up signals and identify patterns in sensor data and illness data. The system can run on battery power and operates independently, ensuring it can always perform its intended function. This smart irrigation system not only uses water more efficiently, but it also makes it easier to monitor the health of plants. This makes it a useful tool for smart farming and precision agriculture.

Keywords: Raspberry Pi; Cloud Platform; Soil Moisture Sensor; Smart Farming; Healthy Plants; DSP Techniques; Smart Irrigation; Modern Farming; Disease Detection; Digital Signal Processing; Crop Yield.

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1. Introduction

People obtain food in various ways, but practices such as wasting water and the spread of plant diseases can reduce crop productivity and increase the likelihood of crop failure in the long term. If you water your plants the old-fashioned way, they may receive too much or too little water, which is detrimental to their health. Diseases that aren't detected quickly can spread rapidly and cause significant damage. This paper proposes the use of a Raspberry Pi-based automated plant watering system that utilizes Digital Signal Processing (DSP) and algorithms to detect plant diseases, thereby addressing these issues. A soil

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moisture sensor informs the system about the soil's moisture level, and a relay-controlled water pump regulates the amount of water flowing through it. To ensure the plants receive sufficient water, the device automatically activates the pump when the soil moisture level drops below a certain threshold.

The pump is turned off, though, when the moisture level is high enough to save water. The system can also find plant diseases. The water pump turns on when a disease is found to stop it from spreading. The Raspberry Pi is the primary computing unit, responsible for collecting and analyzing data. Using DSP methods to process signals, filter them, and extract features enhances the accuracy of evaluations of plant health and irrigation management. The device is suitable for both rural and urban gardens, as it features a battery backup that allows it to run continuously. This smart irrigation system aims to enhance precision farming by reducing water waste, controlling plant diseases, and promoting environmentally friendly farming practices. Using DSP methods enhances decision-making, ensuring that resources are utilized to their fullest potential and plants thrive.

2. Literature Review

Many countries possess abundant resources, including land, rivers, groundwater, the environment, and fertilizers. In many countries, farming is a major source of income. There haven't been many shortages of resources in the recent few decades, such as river water and groundwater. Using resources inefficiently leads to increased resource consumption and a reduction in crop yield. One way to address this challenge is to develop and utilize an IoT-based smart framework for farming [1]. Traditional methods of watering plants rely on manual watering or rudimentary automated systems that follow predefined schedules, rather than what the plants need. These methods often cause the soil to break down, put stress on plants, slow their growth, and waste water by either overwatering or underwatering [2]. Most automated irrigation systems currently in use employ soil moisture sensors to control water flow; however, they lack advanced decision-making capabilities and don't take plant disease into account, which is a significant determinant of crop health. Additionally, many traditional systems don't utilize Digital Signal Processing (DSP) methods to process and filter data, which would facilitate the detection of diseases and the monitoring of soil moisture levels [3].

Additionally, many of the systems we currently have lack disease detection capabilities, which means that plant care is reactive rather than proactive, allowing diseases to spread before any action is taken to stop them. There are other IoT-based irrigation systems available, but they require constant internet connectivity, which can hinder their performance in areas with poor network coverage [4]. Additionally, they primarily rely on data on soil moisture, overlooking other environmental factors that could aid in more precise irrigation management. New precision agricultural technology utilizes sensors and AI to enhance farming practices. For instance, machine learning algorithms can be used to determine the optimal times to water by analyzing current sensor data and historical weather patterns. However, these systems are typically complex and require substantial computing power, making it challenging for small farms to utilize them [5].

Smart agriculture is making progress by combining automation, the Internet of Things, and machine learning to enhance irrigation efficiency and monitor plant health. Sagar et al. [1] and Krishna et al. [3] both showed that inexpensive, sensor-based systems may be utilized for real-time farm management. They both employed Raspberry Pi-based systems to water plants based on the soil's moisture level automatically. Krishna et al. [3] was mostly about the irrigation system that turns on when it rains, whereas Sagar et al. [1] also utilized pH sensors and image processing to obtain more accurate crop data. Kanmani et al. [2] built on this by utilizing Convolutional Neural Networks (CNNs) to find plant ailments. This adds an intelligence level that allows you to both water the plants and treat them based on their health. The system in Kanmani et al. [2] is superior to regular sensor-only models because it utilizes image analysis to make informed decisions based on the data. This enables the use of more flexible watering methods.

Manasa et al. [6] utilized different sensors for environmental monitoring, while Rasooli et al. [8] examined more integrated smart agriculture protocols. They concentrated on specific crops, such as wheat and saffron, and utilized sensor networks and the Internet of Things (IoT) to monitor the environment. This suggests that it may be possible to optimize systems for specific crops. Banerjee et al. [4] and Lizana et al. [5] investigated lightweight automation systems that utilize Arduino and GSM modules for communication and control strategy analysis on small or dispersed farms where network capabilities may be limited. Even though the systems are designed to be inexpensive and easy to access, they cannot be as powerful as those that utilize Raspberry Pi designs in Sagar et al. [1] and Krishna et al. [3]. Muthukumar et al. [7] also didn't include image processing or sickness detection in their study, as they focused on cost-effectiveness and multi-sensor monitoring.

Nagpure et al. [9] and Kumari and Kumar [10] advanced the work by utilizing IoT platforms and cloud services to collect, store, and analyze environmental data in real-time. Both systems are designed to facilitate decision-making and water management; however, Kumari and Kumar [10] was specifically developed for horticultural operations in North India, with a focus on flexibility tailored to the region's specific needs. Ultimately, the studies revealed a shift toward precision agriculture, where systems evolve from simple automated systems to comprehensive, data-driven systems that utilize energy-efficient communication technologies, environmental monitoring, image processing, and disease prediction. Despite these studies indicating some impressive progress, certain research gaps and difficulties remain. Even though systems like the ones Sagar et al. [1] and Kanmani et al. [2] talk about using CNN models and image processing to diagnose illnesses, they only use a small number of plant species or very simple datasets.

The scalability and generalizability of these methods remain a topic of debate. Additionally, there was only a brief discussion of power management and energy efficiency, and most of the solutions assumed the presence of a power source, which excluded off-grid or rural deployments from the analysis. In this case, the solution described by Lizana et al. [5], which employs GSM-based communication for automation, is a good alternative. However, it lacks the processing power required for more advanced analytics, such as DSP or AI-based diagnostics. Additionally, only a few studies, including those by Kumari and Kumar [10] and Rasooli et al. [8], have examined the application of DSP techniques for feature extraction, signal processing, or noise filtering. These approaches might easily make sensors more accurate and decisions more reliable. For smart farming solutions that can operate independently and evolve, future research should explore hybrid models that integrate cloud-based analytics with the processing power of edge devices (such as Raspberry Pi) and utilize renewable energy sources and communication protocols that can handle faults [11]; [12].

3. Proposed Methodology

The system described below proposes a Raspberry Pi-based automated plant watering system with plant disease detection capabilities, utilizing a Digital Signal Processing (DSP) approach to overcome the drawbacks of traditional and semi-automatic irrigation systems. To enhance water management and plant health, the strategy aims to leverage real-time soil monitoring, intelligent irrigation choices, and early disease diagnosis.

3.1. System Workflow

Soil moisture sensing is the first step in the system workflow. The moisture sensor continuously measures the soil's water content and sends analog signals to the Raspberry Pi for real-time processing. The automatic watering system activates a relay to turn on the water pump for effective watering when it detects the moisture level falling below a certain threshold, and turns the pump off when the ideal moisture levels are reached. To reduce plant stress and accelerate recovery, the system simultaneously diagnoses plant diseases by analyzing leaf photos to identify early signs of disease. If symptoms are found, watering is initiated beforehand. To improve the accuracy of decision-making, Digital Signal Processing (DSP) techniques are utilized to eliminate noise, condition signals, and extract salient characteristics from sensor data. To reduce plant stress and accelerate recovery, the system simultaneously diagnoses plant diseases by analyzing leaf photos to identify early signs of disease. If symptoms are found, watering is initiated beforehand. To improve the accuracy of decision-making, Digital Signal Processing (DSP) techniques are utilized to eliminate noise, condition signals, and extract salient characteristics from sensor data. The proposed design is illustrated in Figure 1 for smart agriculture.

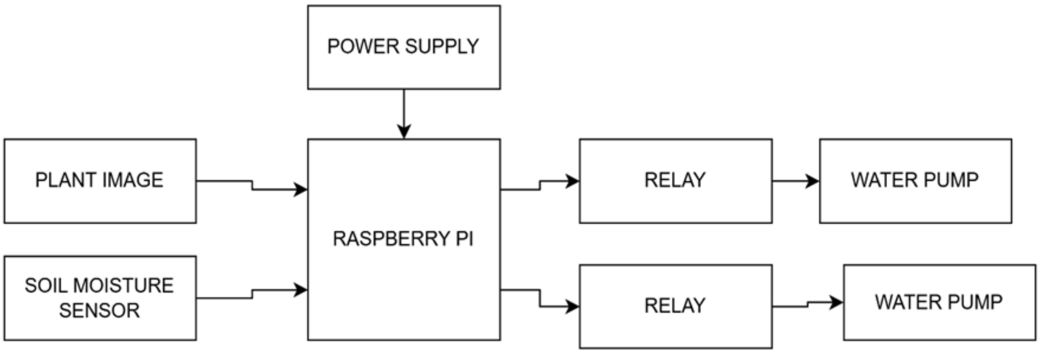

Figure 1: Block diagram of the hardware setup of the plant watering system

- **Soil Moisture Sensor (YL-69 with LM393, 3.3V–5V, analog and digital output):** This sensor continuously measures the soil's moisture content. Using a relay module, the entire system will automatically activate the water pump when the soil dries out. To prevent overwatering and water waste, the pump is turned off when the moisture level reaches an ideal level. The soil moisture sensor is depicted in Figure 2.

- **Plant Disease Detection:** Plant health is monitored through the system's plant disease detection system. To help mitigate the effects of the illness and maintain ideal hydration levels, the device activates the water pump when symptoms of sickness appear.
- **Raspberry Pi 4 Model B (Quad-Core 1.5GHz, 2/4/8 GB RAM, 40 GPIO):** The Raspberry Pi 4 was chosen due to its processing power, which is particularly useful for image-based plant disease detection and Digital Signal Processing (DSP). The Raspberry Pi manages the relay module for pumping, interprets sensor data, and makes real-time decisions. It ensures automated and effective system functioning.
- **The 5V relay module (1-Channel, max load 10A 250V AC / 10A 30V DC):** This relay is used to control the water pump based on soil moisture and plant health data.

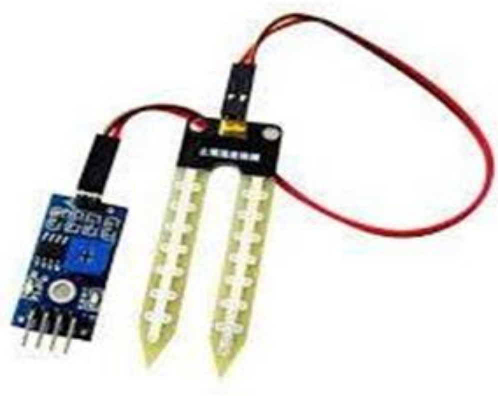

Figure 2: Soil moisture sensor (yl-69)

The Raspberry Pi serves as the main controller, processing inputs and making choices about control. To continually check soil moisture, a soil moisture sensor is inserted into the soil. The Raspberry Pi's GPIO ports receive real-time analog data from the sensor, which is then processed and compared against a set of moisture levels. To diagnose diseases, the system simultaneously receives visual input from a camera module or previously captured images. Using image processing, the Raspberry Pi analyzes the visual data to find potential illness indicators. The Raspberry Pi makes informed decisions based on both illness and moisture, triggering the relay module when it detects disease or dry soil. The relay powers the water pump that irrigates the plant. To prevent water waste, the pump is turned off when the ideal soil moisture is reached. The Raspberry Pi and pump system are equipped with a battery backup to guarantee uninterrupted operation even in the event of a power outage. For both urban and rural agricultural applications, this configuration ensures seamless integration between sensing, processing, and actuation, creating an intelligent and fully automated irrigation system.

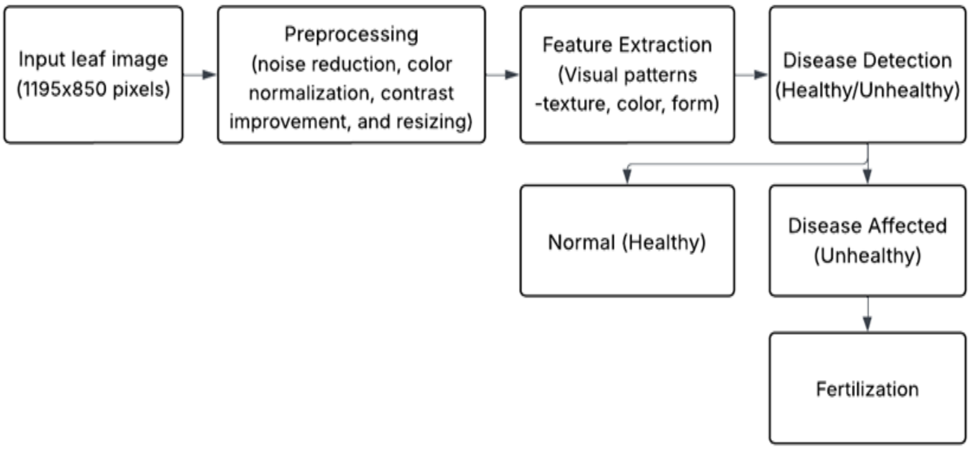

Figure 3: Software process flow diagram of the Raspberry Pi-powered automated plant watering system

The most crucial steps in the Raspberry Pi-powered irrigation system are illustrated in Figure 3's software flow diagram (image size: 1,195 x 850 pixels). The procedure begins with preprocessing soil and plant image data, which is then filtered and normalized to obtain precise findings. While sensor data highlights crucial factors such as moisture level, voltages, and signal variability, OpenCV and CNN are used to determine the texture of the leaves, color features, and the shape of lesions. When the humidity drops or it detects illness, it uses these inputs to decide whether to turn on the water pump.

- **Input / Leaf Image:** An image of a plant leaf, captured with a camera module on a smartphone or uploaded through an interface, is first sent to the system. Examining the leaf surface for visible signs of illness is the primary objective here.
- **Preprocessing:** To boost analysis accuracy, the source image is cleaned during preprocessing. Noise reduction is achieved through the application of filters such as Gaussian blur, color normalization, and contrast improvement, as well as scaling, to ensure consistent input to the CNN. These processes convert the raw image into a uniform, clean format that is ideal for accurate feature extraction.
- **Feature Extraction:** The system utilizes the leaf picture to identify unique visual patterns, including texture, color, and form, during the feature extraction stage. These characteristics indicate signs of plant disease, such as spots, blights, or discoloration. For accurate classification, extraction techniques may use color histograms, edge detection, or deep features from CNN layers.
- **Disease Detection:** The system determines whether the leaf is healthy or sick based on the retrieved characteristics and the AI model that has been developed. It serves as a choice filter; the leaf is classified as normal if there are no signs of the illness.
- **Normal:** The leaf will be considered healthy, and no further action should be taken if the illness is not discovered.
- **Disease Affected:** This block controls the status and initiates the next step for corrective action if the CNN has determined that the leaf is sick.
- **Fertilization:** Depending on the identified illness, the system recommends fertilization, promoting environmentally friendly farming practices and reducing chemical usage.

4. Result and Discussion

The Raspberry Pi-powered automated plant watering system successfully achieved its objective of automating watering through real-time environmental monitoring and cognitive decision-making. The system demonstrated efficient water management, anticipatory provision for plant health, and minimal human involvement after extensive testing in controlled and semi-field settings, making it suitable for precision agriculture in the modern era. Accurately detecting soil moisture utilizing precision sensors at various locations around the field is one of the system's best features. The sensors continuously track the soil's moisture content, and when the reading falls below a certain threshold, the system automatically activates a water pump via a relay. To prevent overwatering and submergence, and to ensure that water is used only when necessary, the pump is turned off as soon as the optimal moisture level is reached.

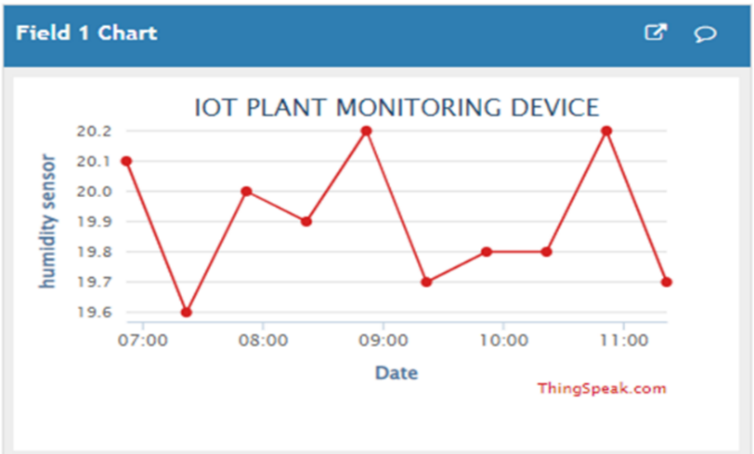

Figure 4: Humidity sensor monitoring in the IoT platform

The method integrates soil monitoring with plant disease detection. By interpreting sensor inputs and visual input, the system can identify early indicators of stress or sickness. By using this caution's preventative technique, watering may be induced as a preventive measure that promotes healthy plant development. Receiving data from sensors and controlling the system, the Raspberry Pi serves as the system's central processing unit. It employs Digital Signal Processing (DSP) techniques to appropriately analyze data, filter signals, and apply decision logic. By guaranteeing that the system responds to dynamic changes in the surroundings, it provides accuracy and dependability. Figure 4 represents the ThingSpeak output for different humidity values. The maximum value is 20.2, and the minimum recorded value is 19.6. The humidity sensor is utilized to assess atmospheric conditions and understand plant transpiration and photosynthesis rates.

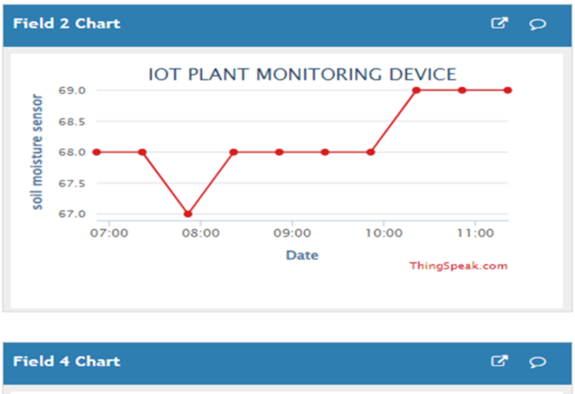

Figure 5: Soil moisture sensor monitoring in the IoT platform

The moisture content of the soil is recorded at different time instants in Figure 5. This reveals the real-time monitoring of moisture content. This avoids soil degradation and issues related to underwater and overwater conditions.

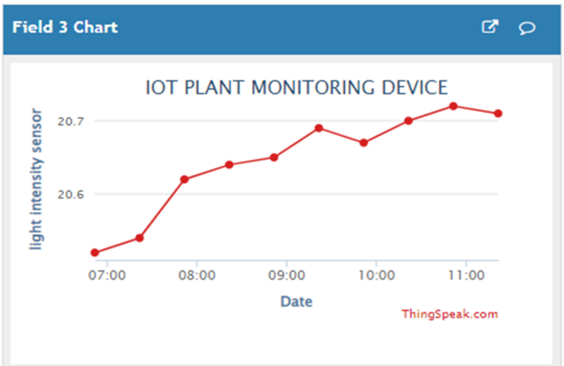

Figure 6: Light intensity monitoring in the IoT platform

The Light intensity result on the ThingSpeak platform is illustrated in Figure 6. Light sensors measure the amount of natural light in an agricultural field and adjust the artificial light levels as necessary. The right amount of light affects the amount of chlorophyll produced, as well as the size, color, and sugar content of the agricultural product.

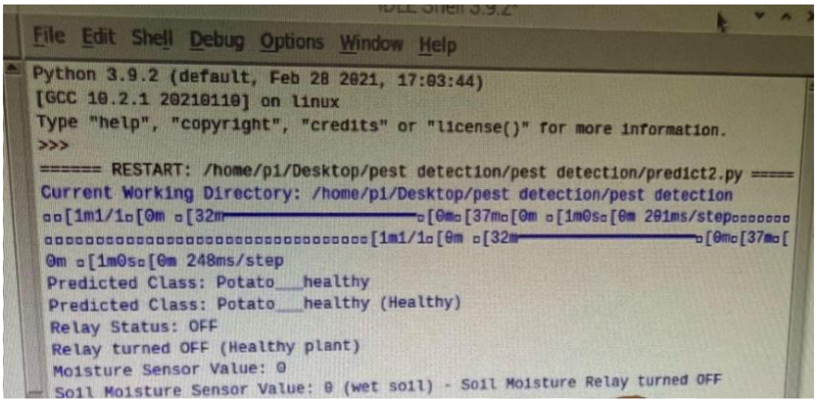

Figure 7: Soil moisture result (wet soil) and plant disease detection result (healthy)

The relay is maintained off if the soil moisture sensor detects sufficient moisture (wet soil), as shown in Figure 7. This prevents over-irrigation, saves water, and protects plant roots from waterlogging. Fertilizer or treatment is required if the plant is identified as healthy (for example, “Potato_healthy” or “Tomato_healthy”). Relays that control treatment or fertilizer systems are not in use.

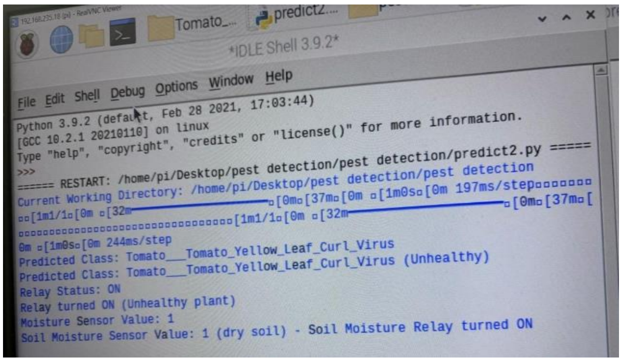

Figure 8: Soil moisture result (dry soil) and plant disease detection result (unhealthy)

The system automatically activates the soil moisture relay to initiate watering when the soil moisture sensor detects dry soil conditions, as shown in Figure 8. This ensures ideal growing conditions by providing plants with adequate water when the soil is dry. The system activates the fertilizer (ON) when the plant is recognized as unwell (for example, “Tomato_Yellow_Leaf_Curl_Virus”). To improve the health of the plant, this stage initiates corrective measures, such as applying pesticides or fertilizer.

5. Conclusion

This project's Raspberry Pi-controlled automatic watering system offers an intelligent and effective solution for precision agriculture. By combining Digital Signal Processing (DSP) algorithms, plant disease diagnosis, and soil moisture measurement, the system can identify plant health and optimize water consumption. To provide sustainable irrigation and prevent overwatering and underwatering, the water pump is automatically controlled based on the available moisture levels. The identification of plant diseases enables improved active plant care by reducing the impact of disease on agricultural output. Additionally, DSP techniques enhance sensor reading accuracy, thereby improving system reliability and decision-making. Due to the uninterruptible operation provided by the Raspberry Pi, serving as both the main controller and a secondary power source, the system can be utilized in both urban and large-scale agriculture, as well as in rural areas with inadequate power supplies. This automatic irrigation system promotes sustainable agriculture, minimizes human interference, and optimizes the use of available resources.

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Ethics and Consent Statement: The research complied with established ethical standards, and informed consent was obtained from all participants, ensuring privacy and confidentiality.

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