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Leveraging Remote Sensing, Drones, and IoT for Smart Village Agricultural Transformation-A Review

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Abstract- Although agriculture continues to be the mainstay of rural development, conventional methods frequently fall short of the demands of increased productivity, resource scarcity, and climate variability.

The Smart Village logic puts forth the integration of modern technologies, with agriculture serving as a train of entry: this study analyzes how high-end technology-a multimodal data fusion, drone monitoring, satellite remote sensing, and smart irrigation-combine to make crops intelligent and sustainable.

Drones support agricultural activities by providing high-resolution insights in a local area and thereby allowing immediate local responses, while satellite remote sensing enables us to see large and continuous areas for a given period to assess crop health and water stress. Beyond spatial, spectral, and temporal fusion, multimodal frameworks that combine data from satellite, drone, and ground-based IoT sensors increase accuracy because each platform's constraints are diminished by the other. The research presents various intelligent irrigation system deployment methods which use automated adjustments based on soil moisture and weather patterns to achieve maximum resource efficiency and water conservation. These technologies work together to optimize resource utilization while reducing labor expenses and boosting production output which strengthens climate change adaptation. Smart villages transform agriculture by integrating modern technology into rural infrastructure which enables data-driven farming methods that respect community involvement and environmental protection.

Keywords- Smart Irrigation, remote sensing, drone-based monitoring, multimodal sensing, smart village agriculture

I. INTRODUCTION

The Smart Village concept aims to improve rural areas through modern technology which creates sustainable communities and economic stability and better living conditions. The agricultural

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sector which supports rural life exists as a vital industry that digital innovation can transform completely. Traditional farming methods encounter difficulties with both efficiency and accuracy and climate variability adaptation although they possess substantial local knowledge. The situation requires modern tools which include multimodal sensing frameworks and drone-based monitoring and remote sensing and smart irrigation systems. The combination of these technologies enables rural areas to implement data-driven farming methods which boost production levels and protect environmental resources. Satellite-based remote sensing provides farmers and urban planners with the ability to observe agricultural areas from a large distance. Anderson et al. showed that satellites enable ongoing monitoring of crop health and soil wetness and water stress through spectral indicators which include NDVI and EVI and NDWI [1]. The broad-area monitoring system enables villages with limited resources to access trustworthy information about their crops and drought patterns and seasonal variations. The implementation of satellite-based crop monitoring systems enables smart villages to perform community-level planning through affordable and expandable methods which support pest management decisions and irrigation scheduling and planting strategies. The technology of drone-based crop monitoring delivers instant field data at centimeter accuracy which improves the value of satellite information. Drones that operate with RGB and multispectral and hyperspectral and thermal sensors detect pests and nutrient shortages and stress areas before humans can see them [2]. The smart village system allows smallholder farmers to use drone services through cooperative resource sharing which provides them access to advanced diagnostic tools without needing to purchase each device separately. The system gives equal access to precision agriculture technology which helps all farmers get better results and makes farming communities more resilient. The integration of multiple platforms within multimodal sensing frameworks which unite satellite data with drone and ground-based information from IoT soil probes and weather stations enables better decision-making. Yang and his team showed that multimodal technologies boost treatment accuracy and reduce uncertainty through their method which unites data fusion with machine learning algorithms to generate detailed crop condition information [3]. The new system optimizes water and fertilizer and pesticide use to produce higher crop yields and reduced expenses for farming communities. The final stage requires water management strategies to transform into operational frameworks which intelligent irrigation systems will use for ongoing management. The system uses weather information and automated valves and soil moisture sensors to deliver water at specific times for crop irrigation.

For a smart village, this means significant savings in water resources, improved crop resilience to climate change, and reduced labor requirements, all of which contribute to rural sustainability. In essence, these technologies—satellite monitoring, drone surveillance, multimodal sensing, and smart irrigation—are not isolated innovations. Together, they constitute the technological backbone of a smart agricultural ecosystem within a smart village. Through the distribution of practical information to farmers and automated resource systems and joint tool usage they create a foundation for rural development which supports sustainability and social equality. The systems operate through automatic valves and weather data and soil moisture sensors to deliver water precisely at the right moment for crop needs. The smart village approach leads to major water resource conservation and better agricultural resilience against climate change and reduced manual work which supports rural sustainability. The four technologies

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function as interconnected systems rather than separate independent inventions. The smart agricultural ecosystem of a smart village needs these components to function properly. The system establishes an equal rural development base through resource automation and farmer information access and advanced tool sharing.

II. LITERATURE REVIEW

Growing populations and dwindling arable land are putting increasing strain on the world's food supply, necessitating the development of accurate and scalable crop monitoring technologies. Agri-cameras, satellites, UAVs (drones), and smart irrigation systems are examples of remote sensing technologies that have revolutionized modern agriculture by providing high-resolution, real-time, and predictive insights into crop health. We begin our work with the Satellite-Based Crop Monitoring System. Satellite remote sensing detects electromagnetic radiation which emerges from Earth surfaces through reflection or emission. Sunlight interacts with plants by reflecting or absorbing various wavelengths based on their health status. Healthy vegetation absorbs red light because chlorophyll in plants but the leaf structure causes near-infrared (NIR) radiation to reflect. Vegetation under stress has higher red reflectance and decreased NIR reflectance [4]. Braga et al. in 2021stated that utilizing these spectrum responses, satellites provide vegetation indices that are commonly used to evaluate crop vigor, such as the Normalized Difference Vegetation Index (NDVI): (NIR−Red)/(NIR+Red)(NIR - Red) / (NIR + Red). The Enhanced Vegetation Index, or EVI, accounts for soil background and atmospheric factors. The Normalized Difference Water Index, or NDWI, measures water stress using the NIR and SWIR bands [5]. Contemporary satellites Sentinel-2 and Landsat-8/9 deliver multispectral data which provides 10 to 30 meter resolution images with 5 to 16 day revisit intervals. Modern platforms use hyperspectral sensors which record hundreds of narrow bands to study plant biochemistry at a detailed level [6]. For the mechanism of Drone-Based Crop Monitoring, high-resolution imaging at the centimeter scale is made possible by drones (UAVs), which operate at low altitudes (20–200 m). In contrast to satellites, which only use passive solar reflectance, drones are able to carry a variety of active and passive sensors, such as: RGB For the purposes of measuring plant density, canopy cover, and visual disease detection, cameras take pictures in visible light. To compute indices like as the Normalized Difference Red Edge (NDRE) and NDVI, multispectral sensors record reflectance in distinct bands, such as red, green, blue, NIR, and red-edge. By capturing hundreds of consecutive spectrum bands, hyperspectral sensors allow for fine-grained study of stress signals, pigment content, and crop nutrient status. Thermal infrared sensors aid in the detection of changes in canopy temperature caused by water stress and evapotranspiration. Laser pulses are used in LiDAR (Light Detection and Ranging) to produce three-dimensional maps of plant height and canopy structure. Nathan et al. described that drone-based monitoring usually includes the following steps in its workflow: Mission planning (GPS-guided flight paths) [7]. Data gathering (sensors take pictures at predetermined times). Processing photogrammetry (creating 3D point clouds and orthomosaics from photos). NDVI, NDWI, and chlorophyll indices are calculated. Prescription mapping: maps of variable-rate pesticide and fertilizer spraying created for precision farming. Their limited service area and need on excellent weather conditions for flying are the drawbacks, though. Using the distinct advantages of each, multimodal sensing combines satellite,

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unmanned aerial vehicle, and ground-based sensors into a single framework. High-resolution, localized stress mapping is provided by drones. Agri-cameras, Internet of Things soil probes, and weather stations are examples of ground sensors that provide continuous, real-time data at the plant and soil levels. Data fusion techniques like spatial fusion, which combine coarse but large-area satellite data with high-resolution UAV imagery for better scaling, are crucial to the multimodal monitoring mechanism [8].

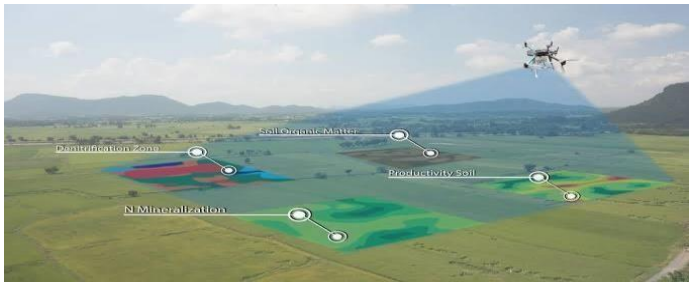

Fig.1. This figure demonstrates how drones help in surveying various parts of soil [9]

Technology	Primary Mechanism	Advantages	Limitations
Satellites	Spectral reflectance captured in visible, NIR, SWIR; vegetation indices (NDVI, EVI, NDWI)	Large-scale coverage; temporal continuity; cost-effective	Limited resolution; cloud interference
Drones	Low-altitude, high-resolution imaging with multispectral, hyperspectral, thermal, and RGB sensors	Early detection; fine spatial detail; yield prediction	Small coverage area; operational costs
Multimodal	Fusion of satellite, UAV, and ground-sensor data; ML-based analytics	Scalable, high-accuracy, holistic monitoring	Requires advanced integration systems

Describing smart irrigation system, In order to reduce waste and preserve the health of crops and landscapes, smart irrigation systems automatically adjust watering schedules and quantities based on site circumstances (soil, plants, and weather). Systems are often divided into two categories: controllers based on weather/ET and controllers based on soil moisture sensors. Ndunagu et al. said that many contemporary systems incorporate both, as well as remote sensing, edge computing, IoT connection, and artificial intelligence. Various accessories combine to create a cohesive whole. The monitoring component is made up of several sensors that serve as smart irrigation monitoring units. The primary sensors are those for soil moisture, wind speed, evaporation, leaf wetness, precipitation, snowfall, and data collection [10]. Automatic irrigation is based on a variety of control valves in the control section. Ball valves, butterfly valves, pulse valves, and other types of valves can be controlled remotely [11]. Select various water pipes and valves based on the various irrigation zones. Numerous sensors wirelessly send climatic and soil moisture data to the platform, which then evaluates and investigates the information. It determines the area and water volume that requires irrigation, then wirelessly instructs the control valve at each location. The water valve is opened or closed by the controller. Liao et al. described that smart irrigation systems consider site-specific factors like soil type, sprinkler rates, and

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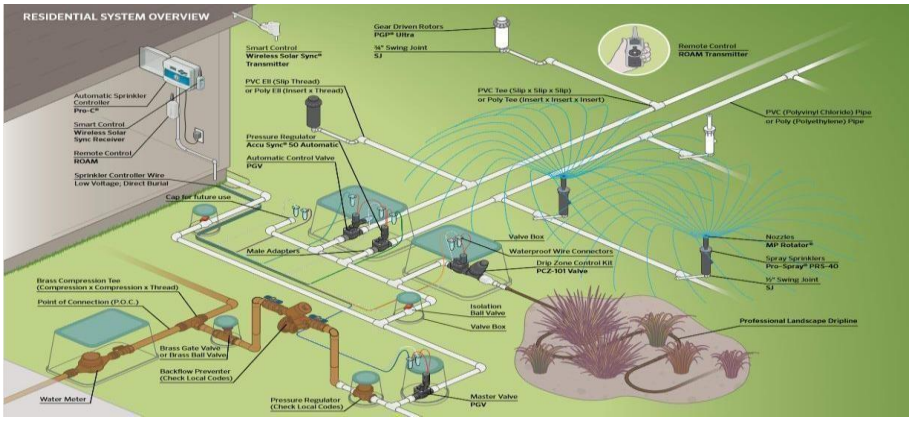
more as ambient temperatures rise or rainfall varies. We can select different soil moisture sensors based on the kind of soil [12]. When buying sensors, consumers merely need to make sure they are compatible with their systems. Evaporation sensors, on the other hand, are weather monitoring equipment [13]. The soil surface evaporation is reflected in its value. By collecting this climate-related data, irrigation time can be modified. For the purpose of precisely reflecting the change in leaf wetness, the leaf wetness sensor mimics the properties of a leaf. We can determine whether the plants are dehydrated and whether the soil needs to be watered by keeping an eye on the leaf moisture. The leaf wetness sensor reflects the evaporation of plant leaves. In case of Rain and snow sensor, when you are watering your lawn and it happens to rain, you are sure to stop watering immediately. Watering in the rain wastes water and money, and causes unnecessary runoff. Smart irrigation also has such a function. The rain and snow sensor is the basis for realizing this function. There are metal wires on the surface of the rain and snow sensor, which will conduct electricity when it encounters rain or snow. An electrical signal is sent to the management platform, and the platform notifies the controller to close the water valve in time after receiving it [14]. The cost of rain and snow sensors is very low, around $25. It also has an automatic heating function, even in the severe winter, the surface will not freeze, ensuring normal work. Rain and snow sensors are quite inexpensive, costing about $25. Additionally, it has an automatic heating feature that keeps the surface from freezing throughout the harsh winter months, guaranteeing regular operation. Year-to-year variations in precipitation and snowfall mean significant water and financial savings for irrigators. Watering during windy conditions can lessen the amount of water that absorbs into the soil and the regularity of lawn irrigation distribution. Installing wind speed sensors is necessary so that, should the wind speed above a predetermined threshold, the irrigation cycle will be stopped. We logically plan the irrigation cycle and length based on the local weather conditions, which can collectively save a significant amount of water resources.



Fig, 2. Residential irrigation system [15]

III. DISCUSSION

Smart irrigation replaces flood irrigation with the goal of conserving water. It meets plant growth requirements with minimal water. Data on soil moisture can be gathered by smart irrigation systems, which can then efficiently regulate irrigation water. Additionally, it has a circulation mechanism to conserve water. remote administration. You can perform irrigation labor and monitoring data analysis using a computer or mobile device; you don't need to physically be in the irrigation area. Simply turn on

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the phone when it's appropriate to check the plant's growth progress. Labor costs are significantly reduced because a single individual may oversee several cloud platforms simultaneously and irrigate thousands of acres of agriculture.

We establish instant modifications to the watering system through sensor data which arrives in real time. Water plants according to their growth stage through regular scheduled watering at exact intervals. Every flower will develop properly when the garden receives uniform water distribution. The cloud platform will experience immediate changes which include timed irrigation and remote irrigation and cycle irrigation and flexible switching between the three irrigation modes. Satellites enable farmers to monitor and control large areas because they show aerial views of extensive agricultural lands. Farmers receive dependable data from these systems to monitor crop health and resource usage across worldwide agricultural regions. Satellite data helps farmers analyze long-term trends and create field maps and crop classifications which supports their agricultural planning activities. Drones collect detailed field data through their high-resolution sensors which permits scientists to study specific field sections precisely. The devices function as instant data collectors that operate at high resolution to help users address emerging problems such as dry zones and pest attacks. [17]. The technology of drone data enables experts to identify precise areas which need fertilization and irrigation and insect control so they can create specific intervention strategies. The multiple sensors within multimodal remote sensing (MRS) include multispectral and hyperspectral and radar and thermal sensors which work together to produce integrated data. MRS delivers enhanced precise and thorough and reliable information about crop physiology and soil moisture and nutrient status through its method of combining multiple data sources. The system combines different sensor information to provide complete and consistent data which performs better than individual sensors when clouds block the sky. The MRS system demonstrates a complete picture of plant health and development through its ability to follow multiple agricultural progress indicators.

CONCLUSION

The development of smart communities through farming depends on modern irrigation systems and monitoring platforms as essential starting points. Remote sensing systems function through satellite technology which tracks agricultural fields to detect crop health and water stress and soil conditions yet drones deliver exact field-level information whenever required. Multimodal sensing systems which combine satellite observations with drone monitoring and ground-based IoT sensors generate precise crop and soil data for improved agricultural decisions that reduce uncertainty. The principles enable intelligent irrigation systems to operate water sustainability with effectiveness which results in waste reduction and improved crop production. The technologies use data analysis to produce automated farming systems which connect local communities to traditional manual work beyond standard manual operations. The initiatives offer three main advantages to rural communities because they defend their resources better and boost their ability to manage climate changes and produce better living conditions through increased agricultural output. The new methods show strong promise for the future but they face ongoing challenges because of their monetary needs and network requirements and technical training needs. Smart villages create sustainable farming

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systems through rural infrastructure which unites benefits for local agricultural communities with national food protection and environmental protection goals.

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