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Design and Implementation of a Solar-Powered Automatic Plant Irrigation System in Kampung Gisi, Bintan Regency, Riau Islands

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Abstract Agricultural sustainability is essential for rural communities, particularly in Kampung Gisi, where celery cultivation is a major source of household income. However, farmers continue to rely on manual irrigation, which is labor intensive, time consuming, and often inefficient in terms of water use. This study aimed to design and implement a solar powered automatic irrigation system that improves water efficiency while reducing farmers' workload. The approach addressed these challenges by developing an autonomous system powered by solar energy and guided by soil moisture sensing to optimize water delivery. The proposed system integrates a solar panel, an ESP32 microcontroller, a soil moisture sensor, a relay module, and a DC pump to enable irrigation decisions based on real time soil moisture data. Implementation and testing were conducted in Kampung Gisi, Bintan Regency, Riau Islands. Data collection included site visits and semi structured interviews with local farmers to document existing irrigation practices and constraints. Field trials indicated that the system effectively automated irrigation, and the results showed an approximately 30% reduction in water use compared with manual watering. Prior to deployment, farmers typically spent several hours per day irrigating, whereas the automated system substantially reduced time requirements, allowing farmers to allocate effort to other farm activities. Farmers also reported more stable soil moisture conditions, which supported healthier crop development and improved yields. Overall, the findings demonstrate that the system can enhance irrigation efficiency, reduce labor demands, and support more sustainable agricultural practices. Community participation was critical, as farmers developed technical familiarity and a sense of ownership, which supports long term system viability. These results underscore the role of appropriate technology in strengthening farming communities, and they suggest that future work should prioritize accessibility and scalability to support broader adoption.

1. INTRODUCTION

Agriculture plays a vital role in sustaining livelihoods worldwide, particularly in rural areas where farming is often the primary source of income (Kumar et al., 2023). In Kampung Gisi, located in Bintan Regency, Riau Islands, agricultural and plantation activities dominate the local economy (Samin et al., 2024). Among the crops cultivated in the area, celery has emerged as a key commodity because of its strong market value and the region's favorable growing conditions (Andaya, 2021). With abundant sunlight, relatively stable humidity, and fertile soil,

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Kampung Gisi offers an environment well suited to agricultural production.

Beyond generating income for individual farmers, agriculture in Kampung Gisi strengthens the local economy by supporting related sectors, such as transportation, local markets, and agricultural input suppliers (Amri & Rianto, 2021). Celery cultivation, in particular, has become central to the community's farming activities, contributing substantially to household income (Ahmadzai et al., 2021). This success underscores both the region's potential for agricultural innovation and the importance of sustainable practices that can maintain productivity over time. As demand for high quality produce grows, farmers face increasing pressure to adopt modern techniques that support consistent yields while reducing environmental impacts (Supandi et al., 2024).

A major constraint for celery farmers in the area is the labor intensive nature of manual irrigation. For growers managing larger plots, watering is time consuming and physically demanding, which limits the time available for other aspects of crop management (Van de Zande, 2023; Van de Zande et al., 2024). Manual irrigation can also lead to inefficient water use, either because crops receive more water than necessary or because they receive too little, both of which can reduce plant health and overall yield (Chauhan & Kumar, 2023; Shrestha et al., 2023). These challenges motivate the development of an automatic irrigation approach that can deliver water more precisely while reducing the daily burden on farmers. A practical solution is an automated system that combines renewable energy, such as solar power, with sensing technologies, such as soil moisture sensors, to regulate irrigation based on actual field conditions.

This study focuses on the design and implementation of a solar powered automatic irrigation system tailored to the needs of celery farmers in Kampung Gisi. The system integrates solar energy with microcontroller based control to operate autonomously, adjusting irrigation decisions according to measured soil moisture levels to deliver water only when needed. This strategy supports environmental sustainability by relying on renewable energy, and it promotes resource efficiency by reducing unnecessary water use. Accordingly, the objectives of this research are to demonstrate the functionality and practical advantages of the proposed system, and to evaluate its effects on water efficiency and farming productivity. By offering a user friendly and cost effective approach, the initiative aims to help farmers in Kampung Gisi address irrigation constraints while improving the sustainability of their agricultural practices.

2. METHOD

The methodology addressed key limitations of manual irrigation, including high labor requirements, inefficient water use, and inconsistent soil moisture. To overcome these constraints, the system was designed to operate autonomously using solar energy and soil moisture sensing, which together enable optimized water delivery based on field conditions.

2.1 Location, time, and duration

Our field implementation was conducted in Kampung Gisi, Desa Tembeling, Kecamatan Teluk Bintan, Bintan Regency, Riau Islands. As shown in Figure 1, Kampung Gisi is a rural area characterized by fertile agricultural land.

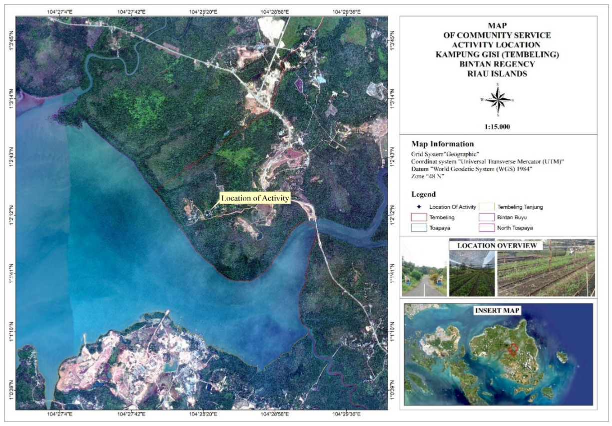

Figure 1 . Geographical location of Kampung Gisi, a rural area with fertile agricultural land

The study site comprises celery farms managed at medium to large scales, making it well suited for evaluating system performance under real farming conditions. Local characteristics, including climate and soil properties, were incorporated into the system design and operating strategy to support reliable performance in the field.

2.2 Data collection techniques

Data collection began with site visits and interviews with local celery farmers to document existing irrigation practices, identify constraints, and clarify user requirements. Direct observations of irrigation activities revealed recurring inefficiencies in manual watering, including overwatering, uneven distribution, and time constraints, particularly among farmers managing larger areas. These findings informed the system's functional requirements and design specifications.

System tools and components were selected to balance reliability and cost effectiveness. The primary components included a solar panel, a DC pump, a soil moisture sensor, an ESP32 microcontroller, and a rechargeable battery. Each component was assessed for compatibility and durability under local environmental conditions. System validity and reliability were supported through repeated bench and field testing, which was used to confirm consistent component operation and stable system performance.

2.3 Design of the system

The solar powered automatic irrigation system design is shown in Figure 2. The system uses a solar panel to capture and convert sunlight into electrical energy (Hao et al., 2022), and this energy is stored in a rechargeable battery to support continuous operation. A soil moisture sensor measures soil moisture in real time and sends readings to an ESP32 microcontroller. The microcontroller evaluates the readings to determine whether irrigation is required, and when soil moisture falls below the defined threshold, it activates a DC pump through a relay module to deliver water to the crop area. This control logic reduces water losses by preventing unnecessary watering, and it supports efficient energy use while maintaining soil moisture within the target range. The design also prioritizes user friendly operation and durability for outdoor deployment.

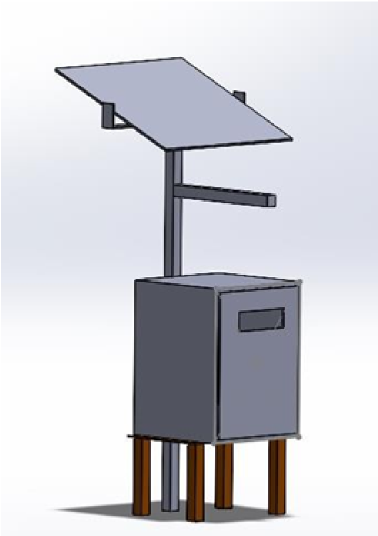

Figure 2 . The design of the solar-powered automatic irrigation system

2.4 Data analysis techniques

System performance was evaluated through field trials on selected plantation plots. Key indicators, including soil moisture levels, total water use, and system energy consumption, were monitored throughout the trials. Performance under the automated system was compared with manual irrigation to quantify changes in water efficiency and reductions in labor demand. Appropriate statistical methods were applied to analyze the collected data, support interpretation of observed differences, and validate the effectiveness of the proposed system.

3. RESULT AND DISCUSSION

3.1 Performance of the solar-powered automatic irrigation system

The solar powered automatic irrigation system was successfully designed and implemented, and it addressed key challenges experienced by celery farmers in Kampung Gisi. System performance was evaluated through field trials, which indicated reliable operation and effective automation of the irrigation process.

As shown in Figure 3, the system block diagram summarizes the integration of the main components, including the solar panel, ESP32 microcontroller, soil moisture sensor, relay switch, and DC pump. The system continuously monitors soil moisture and activates the DC pump when moisture falls below a predetermined threshold. All operating energy is supplied by the solar panel, which supports sustainability and reduces reliance on conventional power sources.

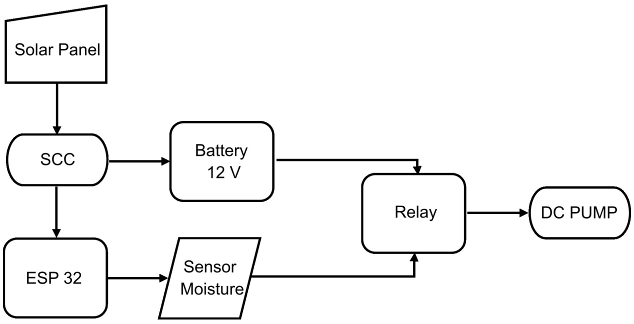

Figure 3 . Electrical block diagram of the solar-powered automatic irrigation system

Figure 4 presents the field implementation in Kampung Gisi. The system was installed in a community test plot and operated consistently under varying environmental conditions. Farmers participated directly in the installation process and received guidance on system operation and maintenance, which supported practical skill development as well as a sense of ownership.

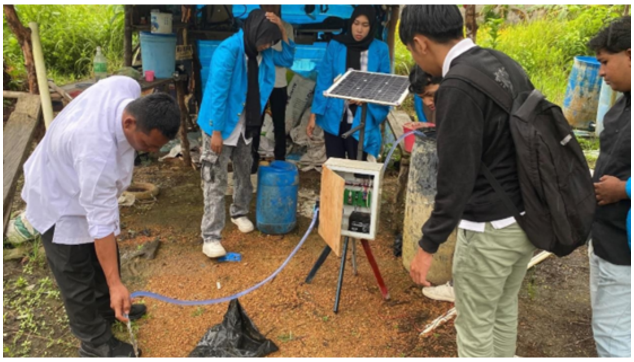

Figure 4 . Implementation of the solar-powered automatic irrigation system at Kampung Gisi

3.2 Condition analysis before and after implementation

Before deployment, farmers relied on manual irrigation, which required substantial labor and daily time commitments. On average, farmers spent several hours per day watering crops, and uneven distribution often led to overwatering in some areas and underwatering in others. This inefficiency increased water loss and reduced celery quality and yield (Choudhary et al., 2024; Turman et al., 2024).

After implementation, irrigation time decreased substantially, which allowed farmers to focus on other essential cultivation activities. Water use also became more efficient because soil moisture sensing enabled more precise irrigation decisions. Trial data showed that water consumption decreased by approximately 30% compared with manual practices. Farmers further reported that the system maintained more consistent soil moisture, which supported healthier crop growth and improved yields.

3.3 Community participation and impact

The project engaged local farmers throughout the process, including problem identification, design input, installation, and field testing. Farmers contributed practical insights during the design phase, which helped ensure that system features aligned with local needs and constraints. Participation during installation and testing also supported knowledge transfer, improving farmers' understanding of the technology and its potential benefits.

Adoption of the system produced meaningful local impacts. Farmers reported that the system was easy to use and that it improved productivity and operational efficiency. The system's reliance on solar energy also encouraged broader discussion about sustainable practices, and the hands on experience gained during the project enabled farmers to operate and maintain the system more independently, which supports long term sustainability.

3.4 Discussion on adoption of innovation

The introduction of a solar powered irrigation system demonstrates how appropriate technology can address critical agricultural constraints in rural settings. By automating irrigation, the system reduced labor demands and improved water use efficiency, which in turn supported farmer productivity and livelihoods (Ahmed et al., 2023; Alharbi et al., 2024). The use of solar energy further underscores the value of renewable power in advancing environmentally sustainable agriculture.

The results are consistent with broader efforts to apply smart irrigation technologies to improve water management, particularly in water constrained environments. The observed 30% reduction in water use in Kampung Gisi is notable, and it aligns with evidence from studies reporting efficiency gains from technology supported irrigation strategies in arid and semi arid regions (Júnior et al., 2024). Future work should prioritize cost reduction, including approaches such as scaling production, and it should also consider financial assistance, such as subsidies or low interest financing, to improve adoption. In addition, training programs and accessible technical support can strengthen farmers' confidence, and they can help ensure effective long term operation and maintenance of the system.

4. CONCLUSION

The implementation of the solar powered automatic irrigation system in Kampung Gisi addressed key limitations of manual irrigation by improving efficiency, reducing water waste, and easing farmers' workloads. The system met community needs by integrating sustainable technology with a practical approach, and it ensured more precise water delivery through automated soil moisture monitoring. Farmers participated actively in installation and operation, which demonstrated strong alignment between local priorities and the empowerment-based approach used in this project. Beyond improving agricultural productivity, the system also supported the adoption of renewable energy solutions while strengthening farmers' technical knowledge. Moving forward, community empowerment initiatives should emphasize wider accessibility, expanded training programs for broader adoption, and scalable system designs that can support diverse agricultural needs in similar rural settings.

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CONFLICT OF INTERESTS

The authors declare there no conflicts of interest.

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