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Solar isotropic generator of acoustic waves

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ABSTRACT

The Philippines, located along the Pacific Ring of Fire and within the typhoon belt, is one of the most disaster-prone countries in the world. Its geographical vulnerability exposes the nation to recurring environmental challenges, posing significant threats to human lives, livelihoods, and critical infrastructure. Recognizing the urgent need for effective disaster preparedness, researchers developed an early warning system called solar isotropic generator of acoustic waves (SIGAW). The study introduced a solar-powered early warning system that can be remotely triggered using global system for mobile (GSM) communication. Additionally, a customizable sensor input board was designed to adapt to the specific requirements of various communities. A complementary website for system monitoring was also developed as part of the project. The researchers employed a developmental research methodology to achieve the study's objectives. This approach involved designing and constructing the early warning device, developing the customizable sensor board, integrating GSM communication for remote operation, and creating the monitoring website. The study's key findings include the successful development and installation of SIGAW systems across several municipalities in Quezon Province, including Atimonan, Lopez, Gumaca, and Calauag. These systems were engineered to provide alarm functionality for multiple types of disasters. The customizable board was equipped with input pins compatible with both digital and analog output sensors, while the wireless triggering mechanism, powered by GSM, was tested for reliability.

Keywords: early warning system, wireless sensor network, GSM

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1. Introduction

Batangas State University, in collaboration with the Department of Science and Technology (DOST) Region 4A, successfully deployed solar isotropic generator of acoustic waves (SIGAW) units in various municipalities across Quezon Province. This initiative was particularly significant due to Quezon's location along the eastern coast of Luzon, making it highly vulnerable to tsunamis generated in the Philippine Sea or the Pacific Ocean [1].

Quezon Province is classified as having a high tsunami hazard, with data indicating a greater than 40% probability of a potentially damaging tsunami occurring within the next 50 years. The critical need for proactive disaster preparedness was emphasized by historical events such as the 8.9-magnitude earthquake that struck northeastern Japan on March 11, 2011. This event prompted the Philippine Institute of Volcanology and Seismology to raise the tsunami alert level for the eastern coastline, including Quezon, from Level 1 to Level 2, necessitating mandatory evacuations in coastal towns. Such incidents underscored the urgency of developing effective early warning systems for coastal communities [2,3].

The SIGAW project addressed this need through a different approach. The researchers began by gathering essential preliminary data specific to the implementation areas and benchmarking existing tsunami early warning systems to evaluate their strengths and limitations. Following this, the team focused on the design and development of SIGAW's hardware components, which were characterized by modularity, multifunctionality, reconfigurability, ruggedness, reliability, and efficiency. Additionally, critical software components, including firmware, libraries, and a development interface, were developed to ensure the system's effectiveness.

2. Materials and methods

This study used the experimental development research methodology, a systematic approach aimed at developing customizable hardware for early warning systems. The process involved designing and testing the hardware to evaluate its effectiveness and adaptability for various applications. This method was applied to explore and enhance potential innovations for disaster preparedness systems.

2.1. Assessment of location

The researchers used a structured methodology to identify the most suitable sites for system installation. The process began with defining the project's objectives, which emphasized disaster preparedness, sustainable energy, and enhanced communication capabilities. Four key criteria were established: susceptibility to tsunami events, availability of reliable global system for mobile (GSM) network coverage [4], presence of open spaces suitable for photovoltaic (PV) system charging [5], and accessibility of the installation sites.

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Data collection played a central role in the assessment. Field surveys were conducted to evaluate potential sites against the established criteria. These surveys were supplemented by consultations with local stakeholders, including community leaders and residents, to gather qualitative insights into local needs, challenges, and vulnerabilities.

2.2. Design and development of the SIGAW hardware

The development of the alarm system followed a structured methodology that included the design of a printed circuit board (PCB) and the fabrication of a stainless steel tower. The researchers began by identifying the system's core functionalities, which were divided into key modules: the power supply, microcontroller unit (MCU), GSM module, and relay output.

Figure 1 shows the block diagram, which mapped the interconnections between the modules and served as a guide to ensure the effective integration of all components during the development process.

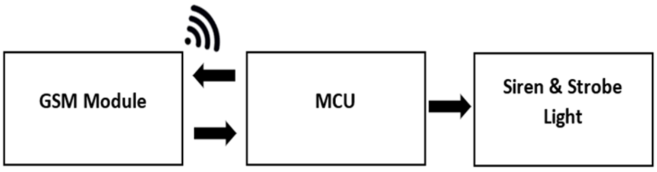

Figure 1. Block diagram of interconnections of the SIGAW unit.

2.2.1. Board development

The researchers began the PCB design by creating individual circuits for each module using electronic design software [6], as shown in Figure 2. The power supply circuit was designed to convert a 12V DC input into a stable 5V DC output, utilizing components such as a voltage regulator and smoothing capacitors to ensure reliable operation.

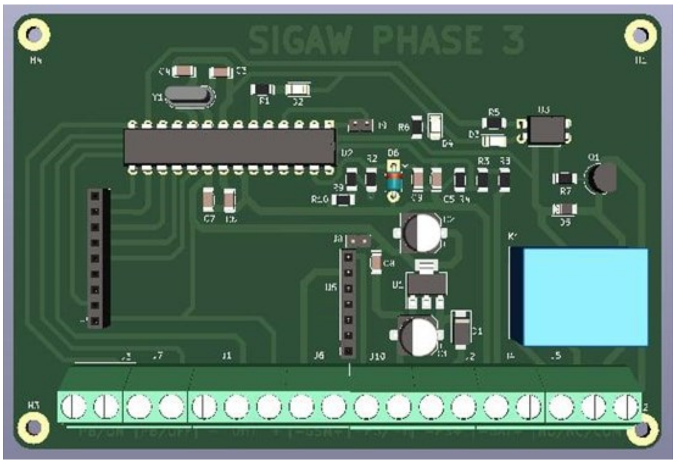

Figure 2. PCB design of the SIGAW board.

The microcontroller was configured to interface with the GSM module and the relay output. The relay circuit was specifically designed to activate the siren and strobe lights, serving as the system's alarm mechanism.

2.2.2. Tower mast development

To ensure the structural integrity, durability, and functionality of the tower mast in outdoor environments, the design process began with the creation of a 3D model using Computer-aided design (CAD) software, as shown in Figure 3. This allowed for precise visualization and dimensioning of the tower. The tower was designed to support three 50-watt solar panels, six 126 dBA sirens, and a waterproof enclosure to house the batteries and electronic components.

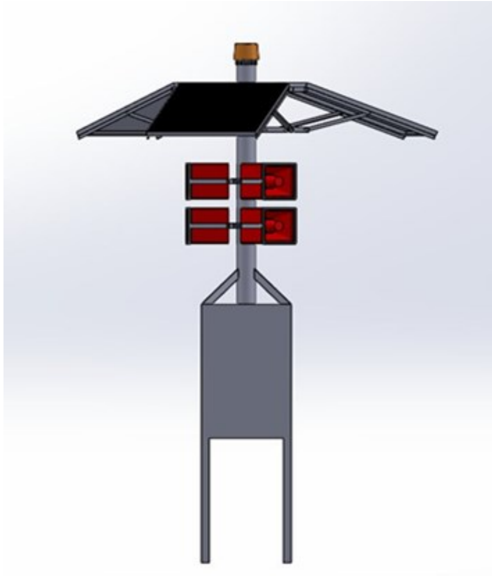

Figure 3. 3D design of SIGAW tower mast.

The design incorporated specific features to facilitate the integration of the system's components. Mounting brackets and frames were included to securely hold the three solar panels at an optimal angle for maximum solar energy capture. The six 126 dBA sirens were strategically arranged to ensure 360-degree sound coverage and can be heard at a distance of 500 m - 750 m. Cable conduits were added to protect the wiring and maintain a clean aesthetic.

A waterproof enclosure was fabricated to house the batteries and electronic components, providing protection from water ingress and other environmental factors. The enclosure was equipped with seals and gaskets to maintain a watertight seal, and ventilation openings with filters were included to regulate temperature while preventing dust and moisture intrusion.

2.3. Website development

The development of the website for the SIGAW Early Warning System followed the Agile methodology. This approach allowed the team to work in iterative cycles, providing flexibility and enabling continuous improvement throughout the development process. Key features were developed incrementally through sprints, ensuring timely feedback and adaptation based on user input. Regular testing, reviews, and updates were conducted to ensure the system remained reliable and responsive to evolving project requirements [7].

2.4. Performance validation

The alarm system was tested to validate its performance, with a focus on its GSM-based triggering functionality and periodic status reporting. The testing methodology ensured that the system operated reliably under simulated real-world conditions.

The GSM-based triggering capability was tested by sending activation commands from a mobile device to the system [8]. Upon receiving the command, the system's response was observed, with immediate activation of the relay controlling the sirens and strobe lights. Multiple tests were conducted to ensure consistent and reliable triggering, confirming that the system responded promptly to commands, regardless of network conditions.

To evaluate the periodic status reporting feature, the system was configured to send updates via GSM every three hours to a designated mobile device [9]. These updates provided critical information about the system's operational state, including power supply status and GSM connectivity. The messages were monitored to ensure they were received at the expected intervals and that their content accurately reflected the system's condition.

During the testing phase, the system was monitored under varying environmental conditions to assess its stability and reliability. Any deviations from expected behavior, such as delays in triggering or missed status updates, were documented for analysis and system refinement. This testing methodology ensured that the alarm system met its requirements for GSM-based triggering and reliable three-hour status reporting.

3. Results and discussion

This section presents the results of the SIGAW, an early warning system, focusing on its overall performance and effectiveness. The discussion interprets these findings, emphasizing their significance for disaster preparedness and the potential impact of the system.

3.1. Preliminary data gathering on implementation area and benchmarking of related products for early warning

The SIGAW project involved a series of activities to successfully implement the system. It began with a thorough examination of the proposed installation site to assess its viability. Following the site inspection, the SIGAW unit was installed as the central component. Several factors were considered in the process: (a) susceptibility to tsunami events, (b) selection of a suitable location near the local government unit (LGU) office to ensure access to an internet connection for server installation, and (c) the need for an open area to facilitate the charging of the solar power system.

Table 1 presents preliminary data collected before the implementation of the SIGAW Atimonan unit installation in four different areas: Poblacion Zone IV Barangay Hall (A1), Villa Ibaba Barangay Hall (A2), Villa Ilaya Barangay Hall (A3), and the MDRRMO Atimonan Operation Center (A4).

Table 1. Preliminary site assessment data for SIGAW Atimonan unit installation.

Considerations	A1	A2	A3	A4
Community Prone to Tsunami events	✓	✓	✓	✓
Access to good cellular network connection	✓	✓	✓	✓
Open area to facilitate the charging of PV system	✓	✓	✓	✓
Accessibility of the installation space	×	×	×	✓

Based on table 1, A4 stood out as the most feasible site for the SIGAW unit installation. This location satisfies all the necessary criteria: it is situated in an area at high risk of tsunami events, offers reliable cellular network reception, provides sufficient space for photovoltaic system charging, and is accessible for installation. These factors collectively suggest that A4 is the most appropriate and suitable site for the deployment of the SIGAW system within the municipality of Atimonan.

Table 2 presents preliminary data collected before the implementation of the SIGAW Gumaca unit installation in four different locations: Rosario Barangay Hall (G1), Tabing Dagat Barangay Hall (G2), Camp Gen. Arsenio P. Natividad (G3), and the South Quezon Convention Center (G4).

Based on the provided information, it is evident that the G4 (Table 2) emerges as the most feasible site for the SIGAW unit installation. This location satisfies all the necessary criteria: it is situated in a community at high risk of tsunami events, offers reliable cellular network reception, provides adequate space for photovoltaic system charging, and is easily accessible for installation. These factors collectively suggest that G4 is the most appropriate and suitable site for the deployment of the SIGAW system in the municipality of Gumaca.

Table 2. Preliminary site assessment data for SIGAW Gumaca unit installation.

Considerations	G1	G2	G3	G4
Community Prone to Tsunami events	✓	✓	✓	✓
Access to good cellular network con-nection	✓	×	✓	✓
Open area to facilitate the charging of PV system	✓	✓	✓	✓
Accessibility of the installation space	×	×	×	✓

Table 3 presents preliminary data collected before the implementation of the SIGAW Lopez unit installation in four different areas: Pansol Barangay Hall (L1), San Jose Barangay Hall (L2), Santa Teresa Barangay Hall (L3), and the Barangay Hondagua Health Center (L4).

Table 3. Preliminary site assessment data for the SIGAW Lopez Unit installation.

Considerations	L1	L2	L3	L4
Community Prone to Tsunami events	✓	✓	✓	✓
Access to good cellular network connection	✓	✓	✓	✓
Open area to facilitate the charging of PV system	✓	✓	✓	✓
Accessibility of the installation space	×	×	×	✓

Based on the provided information, it is evident that L4 (Table 3) stands out as the most feasible site for the SIGAW unit installation. This location satisfies all the necessary criteria: it is situated in a community at high risk of tsunami events, has reliable cellular network connection, provides adequate space for photovoltaic system charging, and is easily accessible for installation. These factors collectively suggest that the Barangay Hondagua Health Center is the most appropriate and suitable site for deploying the SIGAW system within the municipality of Lopez.

Table 4 presents preliminary data collected before the implementation of the SIGAW Calauag unit installation in four different locations: Lainglaingan Barangay Hall (C1), Tamis Barangay Hall (C2), Dapdap Barangay Hall (C3), and Sinag Barangay Hall (C4).

Table 4. Preliminary site assessment data for the SIGAW Calauag unit installation.

Considerations	C1	C2	C3	C4
Community Prone to Tsunami events	✓	✓	✓	✓
Access to good cellular network connection	×	×	×	✓
Open area to facilitate the charging of PV system	✓	✓	✓	✓
Accessibility of the installation space	×	×	×	✓

Based on the provided information, it is evident that the C4 (Table 4) is the most feasible site for the SIGAW unit installation. This location satisfies all the necessary criteria: it is situated in a community at high risk of tsunami events, has a reliable cellular network connection, provides an open area for photovoltaic system charging, and is accessible for installation. These factors collectively suggest that the Sinag Barangay Hall is the most appropriate and suitable site for deploying the SIGAW system within the municipality of Calauag.

3.2. Design and development of hardware for the SIGAW with modularity, multifunctionality, reconfigurability, rugged design, reliability, and efficiency

The process of designing and developing the SIGAW hardware, with a strong emphasis on modularity, multi-functionality, reconfigurability, ruggedness, reliability, and efficiency, was outlined in several key stages.

3.2.1. Board development

The development process began with the critical task of designing the microcontroller board, which involved creating a circuit design using specialized software. Preliminary designs were also developed through traditional manual methods, such as manual etching. Additionally, alternative methods, such as PCB etching using a PCB printer, were explored, although concerns about its suitability for robust industrial applications were raised.

To ensure high precision and quality, the PCB fabrication process was outsourced to a reputable company, which helped maintain rigorous standards and reliability. The design incorporated modular features, enhancing the board's functionality and versatility. This included the integration of various modules, such as temperature and humidity sensors, as well as GSM modules. The modularity enabled SIGAW to effectively adapt to diverse environmental conditions and communication requirements.

As part of incorporating SIGAW's new features, modifications were made to the circuit board. These changes included a transition from Through-Hole Technology (THT) to Surface-Mount Device (SMD) components, improving the overall performance and design efficiency.

The new microcontroller design, as shown in Figure 4, exhibits a remarkable level of adaptability in incorporating various sensors and communication modules. Specifically, it offers easy integration capabilities for sensors like the temperature and humidity sensor, which can be used to detect and monitor temperature and humidity inside the SIGAW unit. This flexibility enables the creation of innovative and customized solutions to meet specific requirements and leverage the full potential of SIGAW microcontroller-based systems.

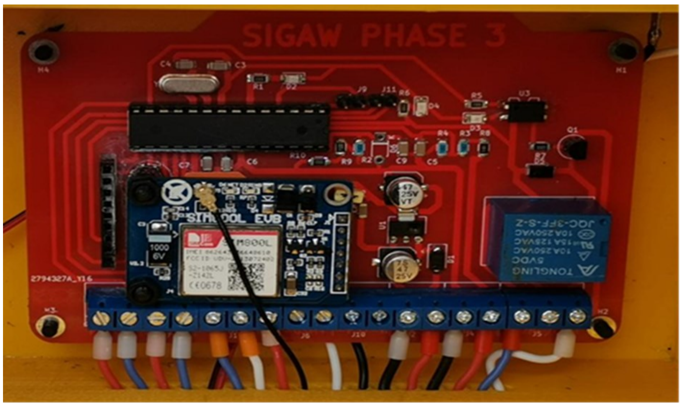

Figure 4. Modified SIGAW's circuit board.

3.2.2. Tower mast development and installation

The tower mast assembly played a key role in the hardware setup, facilitating the installation of the PV system, which was crucial for powering the SIGAW unit. In addition, an alarm system was integrated into the setup to alert users to potential tsunami events, thereby enhancing the system's reliability.

The installation of the SIGAW units was carried out, with support from the recipient Local Government Units, as shown in Figure 5. Following the installation, the operations of the SIGAW units were tested to ensure that they would perform as expected in the event of a tsunami. Representatives from the Department of Science and Technology Region 4A were always present during these events to oversee the installation and testing procedures.

Figure 5. Installed of SIGAW units at (a) A4, (b) G4, (c) L4, and (d) C4.

3.3. Development of software composed of firmware and online interface

Once the hardware components were designed and fabricated, the development of back-end programming became essential. This programming ensured that the hardware functioned correctly and was compatible with the various integrated modules. The primary focus was on optimizing hardware functionality and ensuring seamless compatibility across all components.

SIGAW aimed to provide a solution that integrated firmware development with a monitoring interface. This combination allowed for the effective management of SIGAW operations, including the ability to view real-time data such as temperature, humidity, and battery levels.

Figure 6 illustrates the SIGAW real-time online monitoring system. This system is designed to provide real-time data updates regarding the prevailing temperature, humidity levels, and other statuses of the SIGAW units.

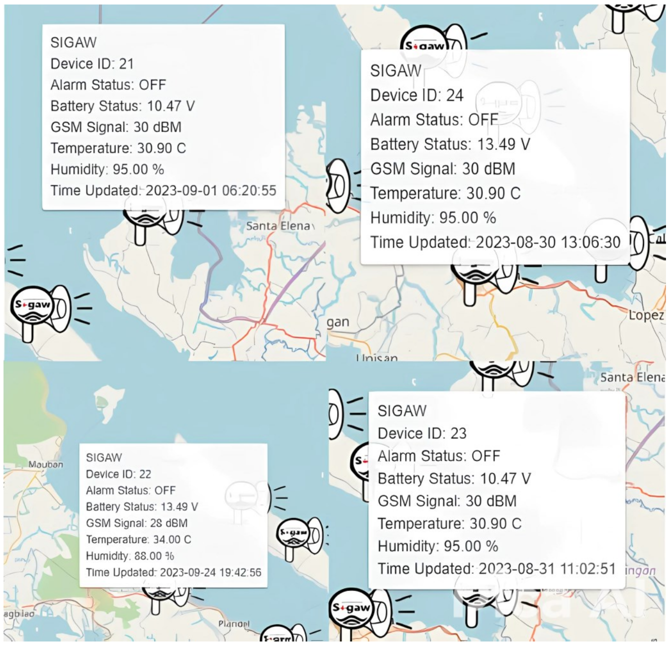

Figure 6. Installation of SIGAW units.

The front-end programming phase focuses on the development of the user interface, with the graphical user interface (GUI) being designed to offer users an intuitive platform for monitoring the SIGAW units. Users can access data from various sensors and communication modules, ensuring the system's efficiency and ease of use.

3.4. System testing and calibration

To ensure effective functionality, testing, and calibration were conducted. Table 5 presents a data set related to data transmission, with each row corresponding to a specific trial. Various parameters and measurements from these trials are recorded, including the trial number, data transmission speed in minutes, alarm state, humidity percentage, temperature in degrees Celsius, date, and time of measurement.

The trial number, located in the first column, serves to distinguish and organize the individual sets of measurements, facilitating data tracking and analysis. In the "Speed (min)" column, the data transmission speed is consistently recorded at 180 and 181 min for all trials, demonstrating remarkable accuracy with the data transmission speed set via GSM transmission. This parameter indicates the rate at which data is transmitted during these tests.

Table 5. Data transmission testing.

Trial #	Speed (min)	Alarm State	Humidity (%)	Temperature (°C)	Date	Time
1	181	0	95	30.8	July 1, 2023	1:08:00
	181	0	71	37.9	July 1, 2023	4:09:00
	180	0	45	42.6	July 1, 2023	7:09:00
	181	0	48	41.6	July 1, 2023	10:10:00
2	180	0	44.5	44	July 2, 2023	10:14:00
	181	0	57	38.9	July 2, 2023	13:15:00
	181	0	78	34	July 2, 2023	16:16:00
	180	0	91	32.4	July 2, 2023	19:16:00
3	180	0	62	37.6	July 3, 2023	13:20:00
	181	0	74	35.1	July 3, 2023	19:21:00
	180	0	88	33.2	July 3, 2023	22:21:00
	181	0	95	32	July 3, 2023	1:22:00
4	180	0	64	40.6	July 4, 2023	4:22:00
	181	0	33	48.8	July 4, 2023	7:23:00
	181	0	31	44.6	July 4, 2023	10:24:00
	180	0	40	44.1	July 4, 2023	13:24:00

The "Humidity (%)" column records varying humidity percentages, primarily ranging from 95.00% to 40.00%. Notably, Trial 4 exhibits a significantly higher humidity level, reaching 33.00%.

Temperature measurements, recorded in the "Temperature (°C)" column, show some fluctuations but generally remain within the range of 30.80 °C to 44.60 °C. Trial 4 records the highest temperature, reaching 48.80 °C.

The last two columns, "Date" and "Time," provide information on the date and time of each data collection. These records span from July 1, 2023, to July 4, 2023, and are documented down to the second.

Table 5 presents a series of data transmission trials conducted over several days, primarily focused on assessing how variations in humidity and temperature may impact data transmission performance. Other parameters, such as data transmission speed, remain relatively consistent across the majority of the trials.

4. Conclusions

The SIGAW Phase III for Quezon Province is a significant effort to strengthen disaster preparedness and enhance community resilience through the creation of the Wireless Integrated Solution for Emergency Response/ SIGAW early warning system. This initiative successfully achieved its main goal of developing a reliable tsunami early-warning system. By addressing its specific objectives, the study has made notable progress and produced innovative results.

The project began with groundwork, including the collection of preliminary data from the designated implementation area. A benchmarking process was conducted to ensure that the SIGAW system would integrate effectively with existing tsunami early-warning technologies. This foundational phase provided a solid basis for informed decision-making and efficient project execution.

The SIGAW system was designed and developed with a focus on modularity, multifunctionality, reconfigurability, rugged design, reliability, and efficiency. Strategic modifications, such as the transition to Surface Mount Device (SMD) components and adjustments to the circuit board, have improved the system's capabilities and adaptability, ensuring it meets future needs.

In addition to hardware improvements, the development of SIGAW's software components, including its firmware and online system interface, has enhanced real-time monitoring and system management. The software's ability to display key data such as temperature, humidity, and battery levels enables operators to make timely and informed decisions, further ensuring the system's overall reliability.

Testing and calibration processes were conducted to confirm the optimal performance of the SIGAW system. These procedures ensured that the system is fully functional and ready to support critical operations during tsunami events.

The project also demonstrated a strong commitment to community engagement through training sessions and tsunami drills. Local participants were equipped with the necessary knowledge and skills to operate and maintain the SIGAW system. Through hands-on demonstrations and interactive discussions, participants gained a comprehensive understanding of the system's functions and its response to various tsunami scenarios.

The completion of the development and installation of SIGAW Phase III for Quezon Province has contributed significantly to building infrastructure designed to safeguard communities and ensure their safety.

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