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Arduino Combined with Fiber Optic Sensors for Security of Archaeological Sites

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ABSTRACT: Due to the importance of archaeological sites due to their high heritage, artistic value, and assets, they have become targets for theft and tampering by many fraudsters and thieves. This necessitated providing effective protection against various attacks, such as excavations next to archaeological sites for the purpose of uncovering some valuable materials or even for other purposes, to damage these places and the interior of antiquities when moving them or trying to drag them. The objective of this paper is to design monitoring and early warning system-based fiber optic sensors combined with an Arduino microcontroller. The designed system consists of two detection stages. The first is the internal stage, where the Arduino is connected with passive infrared sensors (PIR) and a Global System Mobile (GSM) module, and the second is an external protection system built around the archeological site by burying a fiber optic cable at a depth of about one meter around the building connected to an optical time domain reflectometer (OTDR) and a processor for data processing. The system is capable of detecting any movements, any attempt to remove any parts, or any abnormal movements inside or outside archaeological sites, as well as warning officials to take the necessary precautions. However, this system is mainly designed to react as soon as the sensor captures the movements or vibrations that come across the cables or PIR and vibration sensors.

KEYWORDS: Arduino microcontroller, fiber optic sensors, Monitoring techniques, Security protection systems

I.INTRODUCTION

Heritage buildings and historical monuments have an important place in any society due to their historical and artistic status, such as old palaces, buildings, historical monuments, etc. It represents enormous cultural value. However, vandalism is caused by natural or human factors. These priceless treasures may be damaged or even lost. Therefore, providing the necessary protection is very important to protect it from damage and theft. The challenges that those responsible for these antiquities often face are how to protect these places, what are the appropriate protection methods, and what are the special conditions for protecting each historical monument. and how to protect it internally and externally. Many techniques are used with different methods for monitoring and protection. The researchers in [1] provided an outline of the real-time case framework for monitoring and evaluating risks, and this framework is based on the so-called Historical Heritage Management System, which is an online platform that collects data from visual inspection and online monitoring systems. The system exploits low-cost distributed sensing and Bayesian technology. The paper in [2] discusses a study on developing technological tools for real-time risk management of historic buildings, the research includes the development of a prototype of a historic heritage management system, and demonstrating its effectiveness in a Trenton case study. It shows that the proposed risk updating method can handle all cases in time. The purpose of the work in [3] is to protect homes against threats, damages, and all criminal activities with passive infrared (PIR) and laser sensors. The method depends on the cutting beam of the laser source or PIR sensor. There are different warning cases: the first is without GSM (Global System Mobile) to alert aerobically by voice, and the second is with a GSM modem and Arduino. The system sends short message service directly to the user via GSM networks. This system is built using open-source hardware, and the Proteus program was used to simulate Arduino operation. In this paper [4], the authors propose a security system based on IoT innovation. The Raspberry Pi3, Arduino, PIR sensor, web camera, and buzzer make up the system. They developed a system that included the histogram of gradient HoG and support vector machine (SVM) human detection capabilities, as

well as a buzzer to alert the homeowner. The results demonstrate the way that framework can recognize the gatecrasher within a space of seconds with an exactness of 89%. The field of vibration and acoustic detection has been paying close attention to the application of fiber optic distributed acoustic sensing (DAS) in recent years. DAS technology is a very powerful technology that is now being deployed very effectively to defend assets from incursion, as well as perimeters, borders, and buildings. Additionally, it can make it easier to locate the threat position. In essence, it's mainly based on the measurement of Rayleigh scattered light, which occurs when light traveling through the cables scatters again along the route of the sensor cable due to flaws (called "scattering centers") recorded at the sender end [5]. Theoretically, mechanical vibrations occur when physical activity or threat motions occur near a buried fiber cable. These vibrations generate variations in backscattered light. Such variations have been studied and classified to extract the goal signal. Phase-sensitive "optical time-domain reflectometry" (Phase-OTDR) was created for this reason [6, 7]. Unlike traditional OTDRs, phased OTDR pulses have coherent lights that are transmitted over fiber optic cables. The detection therefore takes place via the relative phases of the reflected fields of the scattering centers. To monitor vibrations resulting from multi-point threats across a fiber cable, it provides an effective way to monitor and detect all threats at once and determine their locations, which is considered a major challenge in this field. The effectiveness of the DAS system can also be assessed by its different applications; for example, it is used in train location and speed tracking in real time [8], the suggested technique for detecting traffic flow [9], intrusion detection of pipelines [10]. The Φ -OTDR system's time-evolving sensing signal is used for detection in complex, noisy situations. It is broken down using a multi-scale wavelet decomposition technique, efficiently extracting human incursion signals and separating environmental interferences and system changes. This approach provides the highest SNRs [11]. Underwater acoustic channels are doubly spread, with the inverse DCT-DCT structure providing orthogonality, smaller implementation area, faster computation, larger peak-to-average power ratio reduction, better noise immunity, and better bit error rate performance. [12], DAS for fence monitoring [13], drone detection and localization [14], monitoring multiple dynamic events in real time [15], convolutional neural networks are utilized to analyze down hole distributed acoustic sensor data for micro seismic occurrences [16], border monitoring [17], security monitoring of smart campuses [18], and distributed optical fiber sensing for perimeter security [19]

A. Background (Literature Survey)

The paper in [20] offers a low-cost, adaptable home control and monitoring system that can be accessed and controlled remotely using an Android-based smartphone app. Unlike prior systems, the suggested system offers a unique communication protocol for monitoring and controlling the home environment with features beyond simple switching and does not require a dedicated server PC. The presented paper in [21] they use an Arduino using a passive infrared ray sensor and GSM modem to obtain the alarm signal as instructions from the Arduino and then send a message to the specified mobile phone number indicating that there is a threat detected. They created and implemented a highly effective, portable security alarm system.

The paper "Sensing and controlling the threats using Arduino and internet of things (IOT) discusses embedded technologies and the internet of things (IOT) with an emphasis on Arduino. Embedded blocks and script programming are used, along with sensors such as accelerometers, flex sensors, magnetic sensors, flame sensors, and WI-FI modules [22]. The designed technique detects the movements, by Arduino Security System equipped with a PIR sensor. An alert is triggered by the Arduino after the PIR detector senses movement. In addition, Arduino will employ Wi-Fi modules to transfer data to consumers using programs that are downloaded into a user's smartphone. Using a smartphone, the alarm system can only be turned off by homeowners. Through the use of a Wi-Fi module, the application and circuit are connected. the system's ability to identify threats. With the goal to achieve end-to-end feature extraction and recognition based on the similarity of intrusion signals [23]. The authors in [24], developed a robust intrusion event recognition scheme using convolutional prototype networks (CPL). They integrated prototype learning variables into MSCNN training, achieving an average recognition accuracy of 84.67% for known intrusion events and 83.75% rejection rate for unknown disturbance events. The study in [25] analyzed 63 research publications on smart home safety and security systems using the Arduino platform, aiming to extract relevant data from prominent literature sources. The research aimed to improve the safety and security of smart homes.

II. ARDUINO MICROCONTROLLER

Among the most widely used microcontrollers is the Arduino platform. Many project options, including home security, tracking packages, remote car monitoring, control systems, and even solar energy projects. The Arduino microcontroller is an open-source devices that is simple to program and can updated at any time [26]. The original purpose of the Arduino microcontroller was to enable experts and students to create devices that could use sensors to interact with their surroundings. Arduino microcontrollers can be used to obtain information through their inputs and outputs such as light, temperature, vibration and etc. They may be realized by combining it with a GSM module users may send and receive data via text messages by connecting an Arduino to a GSM module [27,28], enabling remote project management over cellular networks almost anywhere in the globe. In addition, We can use it by sending a series of required instructions to the microcontroller on the board via programming language (based on Wiring) and the integrated development environment (IDE) of the Arduino software to deal with variety of parts and sensors used for many applications. The Arduino Connected to the computer via the USB cable, Arduino platform consists of two parts: software and hardware. They are easily programmable using the high-level programming language like Python , C and C++, writing programs and uploading them to your board is possible with the Arduino Software (Integrated Development Environment) (IDE). Arduino can be used with different security methods to add an extra layer of protection .The Arduino can be used with a wide variety of sensors like light, infrared, fire, ultraviolet, motion, biometric sensors such as fingerprint or facial recognition to enhance security[29].

III. ARDUINO SENSORS

Arduino sensors are devices that allow an Arduino board to interact with its environment. The sensors detecting changes in the chemical or physical properties of their surroundings and then converting them into electrical signals, these signals is used depending on the applications various sensors used, like light, temperature and vibration sensors [30].

A. GLOBAL SYSTEM FOR MOBILE MODULE

The Arduino GSM shield enables an Arduino board to send and receive SMS messages as well as make phone calls. SIM card (Subscriber Identity Module) is required to contact the network. They also have an International Mobile Equipment Identity (IMEI) number, similar to phones. With the GSM to Arduino Uno receive and transmit pin, the GSM module connects to the Arduino board and sends and receives data to communicate with the system[27,31,33].GSM module.

B. PASSIVE INFRARED SENSOR

Passive infrared sensor PIR is an electronic sensor consists of pyro electronic sensor which generate energy when exposed to heat that means when human or animal body will get in the range of the sensor it will detect the movement because the human body emits heat energy in form of infrared radiation that wear the name of the sensor comes from, and the term passive means that the sensor is not using any energy for detecting purposes, it just works by detecting the energy given off by the other objects. The module also consists of designed cover named frenzel lens which focus the infrared signals onto the pyro electronic sensor that detects infrared (IR) light emitted by objects within its field of vision. The most common use for them is in PIR-based motion detectors [25].

IV. FIBER OPTIC SENSORS

Fiber optic cables used as sensors from many years ago. The main idea is to use optical fibers as sensors to measure forces, pressures, temperatures, and vibrations. This technology relies on the use of optical fibers to transmit light and measure changes in the optical signal produced by the monitored conditions. The system is to process and locate the backscattered light in an optical fiber to detect and extract changes, which happened at a specific point along the sensing

path in Distributed acoustic sensing system DAS. The backscattered lights that occurred in the optical fiber is called Rayleigh scattering [6,32], which is a form of elastic scattering, in which the scattered light frequency is similar to the incident light. Distributed acoustic sensing (DAS) is a technology that uses Rayleigh backscattering from a buried fiber-optic cable to detect vibration signals happened around the sensing path (DAS) system. When laser beam is sent through the fiber cable light backscattering occurs when tiny imperfections in the fiber are present. Vibration is produced around the sensing route by a variety of actions, including striking, driving, and movements besides many other vibrations with distinct acoustic characteristics. Threat vibration along the fiber path causes this backscattering light then, Rayleigh backscattering measured and processed to localize and detect the threats around the buried sensing fiber optic sensors[6, 7,32,34-37].

V. PROPOSED METHOD

The designed method as illustrated in the block diagram as shown in Figure. 1.

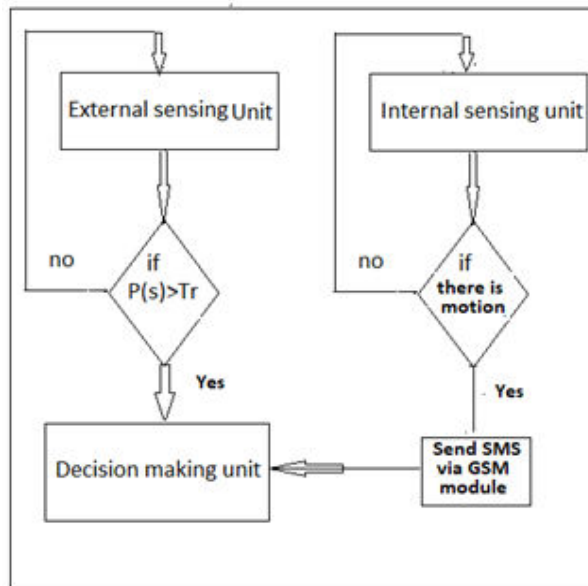


Figure. 1: The proposed method.

A. FIRST STAGE (EXTERNAL SENSING UNIT)

The main idea of this stage is to sense any activity or vibration near the archaeological sites using fiber sensors that buried at a depth of about one meter around the archaeological by locating the backscattered light using phase OTDR. Phase OTDR measures the Rayleigh backscatter for each transmitted pulse. The characteristics change due to any mechanical vibrations that interact with the buried fiber optic cable and any changes that happened at a specific point along the sensing path. The sensed data sent for processing. The goal in this phase is to identify and obtain the threat signal $H(t)$ that sensed around the archaeological sites from the entire signal $S(t)$ by erasing the noise $N(t)$ as in “Equation (1)”.

$$S(t) = H(t) + N(t) \quad (1)$$

where $S(t)$ is the backscattered signal, $H(t)$ is the intrusion signal (Threat signal), and $N(t)$ is the noise. The method aims to locate the threat signal $H(t)$ from the backscattered signal $S(t)$ in a fiber optic cable by removing noise $N(t)$ and using

wavelets as a de-noising method [7]. Wavelets can localize signal features and effectively remove noise and environmental interference, preserving important signal characteristics. Then the difference method is used for high-pass filtering and locating the changes that happened by finding the difference between signals, the autocorrelation is used between signals to improve the interferometric visibility of the vibration near the sensing path. The power of each signal is calculated and sorted and the max value is taken as the threat which exceed the pre-defined threshold. If signals greater than the threshold then threat is detected and information sent to the decision making unit. The algorithm as shown in Figure 3.

B. INTERNAL SENSING UNIT

In this unit, Arduino uno controller connected with a GSM Module and PIR sensor. The passive infrared sensor (PIR) measures infrared (IR) light emitted by moving objects that emits heat, if any human or animal presence in the sensor detection range, then the output bin of PIR sensor gives high logic. The GSM module is activated and will send the message "there is threat detected" to decision making unit using phone number. The protection system architecture is depicted as in Figure. 2.

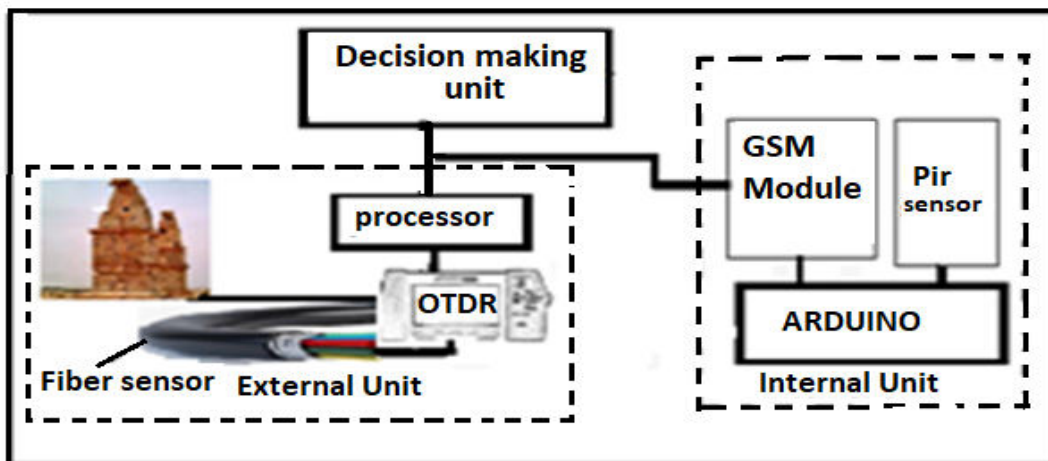


Figure. 2: protection system architecture

VI. RESULTS AND DISCUSSION

In this section, we discuss the implementation of the security monitoring system evaluation results. We integrate and implement the designed system. All of the electronic components in the first stage are integrated into a one environment using the Arduino as shown in Fig 3.

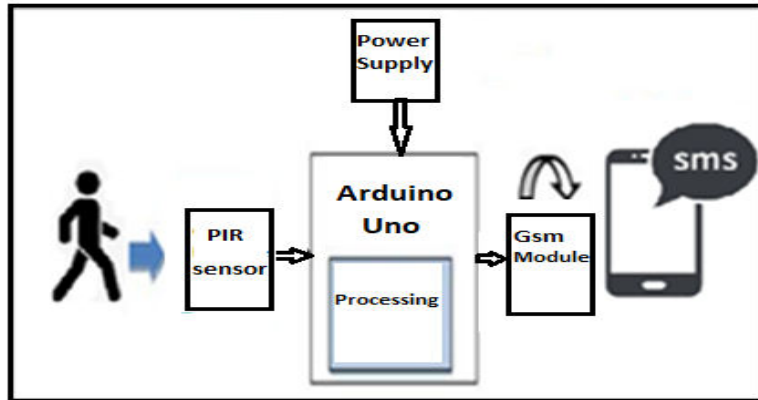


Figure. 3:Block diagram of stage I.

In this stage when PIR sensor detects any movements that occurs within its detection range, Arduino process and instructs a GSM module to send short message to the control unit. This phase is tested in faculty of science Bani waleed university and gives good results. In the second stage, we test the designed protection system by applying a series of tests recorded and created data sets that were generated at the Atilim University laboratory [7]. The data are collected from different tools: hammer, pickaxe, shovel, and walking. They were tested using the algorithm, and all the threats were successfully detected with a percentage of 98%. Data sets are shown in Table 1.

No.	Record name	Tool type	Number of hits	Threat detected
1	D-177_MH5	Walking	3 laps	Yes
2	D-095_MH5	Pickaxe hits	5 hits	Yes
3	D-096_MH5	Pickaxe hits	5 hits	Yes
4	D-061_MH5	Hammer hits	10 hits	Yes
5	D-76_2MH6	Hammer hits	10 hits	Yes
6	D-051_MH5	Walking	5 laps	Yes
7	D-177_MH5	Walking	3 laps	Yes
8	D-095_MH5	Pickaxe hits	5 hits	Yes
9	D-096_MH5	Pickaxe hits	7 hits	Yes
10	D-061_MH5	Hammer hits	10 hits	Yes
11	D-076_2_MH6	Hammer hits	10 hits	Yes
12	D-002_MH6	Hammer hits	11 hits	Yes
13	D-100_M03	shovel hits	5 hits	Yes
14	D-097_MH5	Pickaxe hits	7 hits	Yes
15	D-102_M11	shovel hits	5 hits	Yes
16	D-209_M06	Pickaxe hits	3 hits	Yes
17	D-090_M08	shovel hits	6 hits	Yes
18	D-100_M08	shovel hits	5 hits	Yes
19	D-097_MH4	Pickaxe hits	7 hits	Yes
20	D-102_M14	shovel hits	5 hits	Yes

Table 1. Recorded datasets[34].

Finally, the data is sorted, and we found the maximum-valued bins, which correspond to the Threat events as illustrated in Fig. 4.

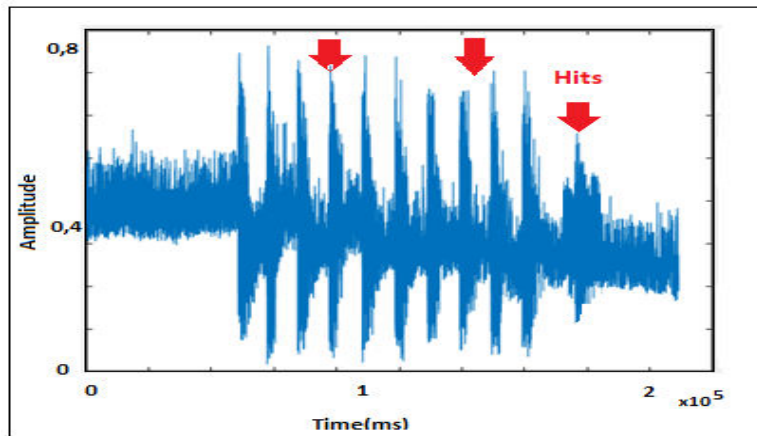


Figure. 4. Detected threat with 11 hits

VII. CONCLUSION

The paper has presented a combined technique Arduino microcontroller for internal protection and fiber optic sensors for external protection and monitoring. The system uses motion sensors and fiber-optic sensors to detect threats to antiquities, both inside and outside the building, providing robust protection for large, sprawling, and sometimes open areas, such as open spaces and deserts. The internal stage uses the PIR sensor which is connected to the Arduino and external stage uses the fiber optic sensors that are buried about one meter under the ground and near the buildings, this stage will sense any movements or steps near the protected places depends on back scattered signal that generated by threat movements or digging near the wall, these movements generate vibration sensed by fiber optic cable and sent to the OTDR as backscatter signal, these signals are processed and the power of each correlated signal is calculated at each channel and sorted in a vector form in descending order, which shows that the maximum-valued channels were threat signals. These signals are sent to the main system, and the system sends alert signals to all control systems, providing them with all information about the threat and its location to take the necessary action. The results show that the approach is quite successful in identifying potential risks as well as unapproved exploration and drilling activities close to archeological sites. The combination of Arduino microcontroller and fiber optic sensors to detect all threats achieves high accuracy and efficiency. The method is easily adaptable to identify various risks of relevance for a wide range of security applications.

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