400 pieces of information has been generated as well as generated lab data presented in Table 3. In Table 3, randomly generated experimental data for different sampling points are presented. In real application, volumetric water content data are measured by gravimetric method. In Table 4, the 400 data generated for subscribers are presented. The information from Table 3 and Table 4 have been compiled. As an example, at point P1 where actual soil moisture is 2%, 16 subscribers have chosen “Dry” class. At point P2 where actual soil moisture is 7%, 15 subscribers have chosen “Dry” class. Other cells are filled in the same way.

Table 4 provides information (wetness frequency vs. water content) to plot the probability distribution function (PDF) for different wetness classes (Figure 3). Figure 3 shows frequency of subscribers’ choice versus experimental data in different soil wetness classes. In this figure, the centroid of each distribution is calculated and demonstrated by vertical lines. This part of methodology has been initially tested and once the actual data is collected, it can be extended to provide adequate information for ANN model to be used in order to find the quantified soil moisture data.

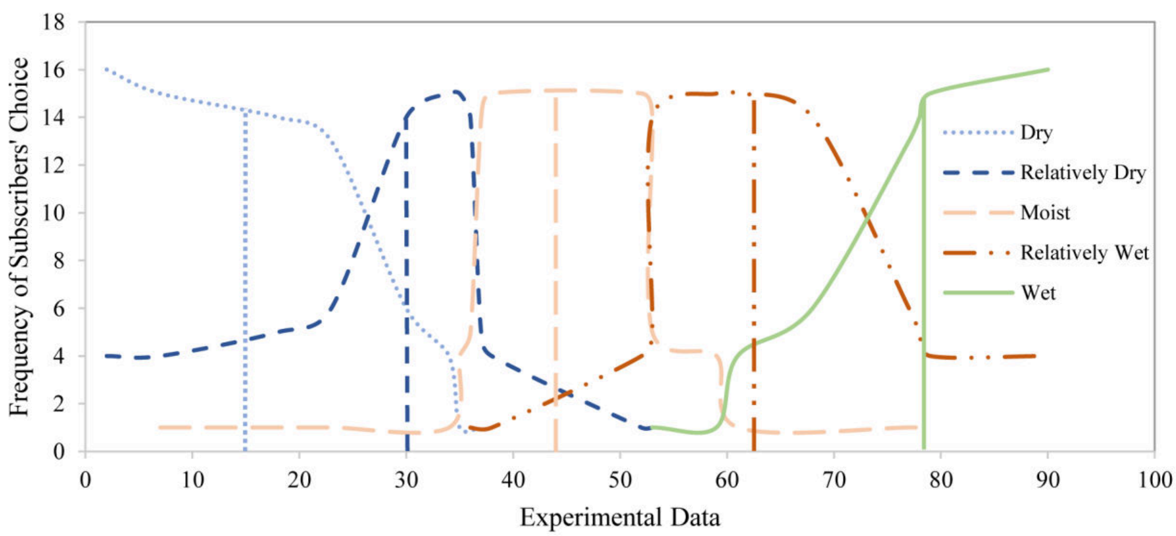

Figure 3. Frequency of Subscribers' Choice vs. Experimental Data for Different Soil Wetness Classes

5 SUMMARY AND CONCLUSION

Soil moisture is perhaps the most important hydrological/meteorological variable that connects many attributes of hydrologic cycle. Also, soil moisture as an indicator for the long-term effects of climate change is the center of many attentions. In spite of the great importance of soil moisture data, it is not widely available because its sampling is relatively expensive, and it does not have a custodian in many developing countries. In this study, a new framework is proposed and initially tested for utilizing soil moisture of different data sources such as direct field measurement, satellite and citizen science to derive better soil moisture information with higher accuracy/spatial resolution. For this purpose, Aharchay river basin located in East Azerbaijan, Iran is selected. The methodology consists of two parts. First, a regression analysis using explanatory variables is carried out to improve the accuracy of satellite-based data. Then a framework for preparing a platform to communicate with a social network of subscribers to collect soil moisture information is presented where there is no monitoring station available. Preliminary findings indicate the significant value of this framework for basic modeling for collecting precious soil moisture data. This paper is a starting point to explore different sources from citizen science to satellite technology to obtain high-resolution soil moisture maps.

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Low Cost Monitoring Systems for Environmental and Water Resources Applications

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ABSTRACT

This work describes utilizing low cost solutions for environmental and water resources monitoring. These solutions were made possible by the vast and recent development of printed circuit boards (PCBs) with microcontrollers, and the accompanying integrated development environment (IDE) programming platforms. Systems were developed for three applications: the first was a water evaporation monitoring system that was intended to measure the amount of reduction in evaporation when using floating solar panels to cover a water body. The second application was a power outcome monitoring system of the solar panels, those floating and comparable ground-mounted ones, while the third system was developed for stream stage monitoring and was intended to continuously monitor flood water. The three systems were successfully developed and implemented and essential data was recorded and analyzed. The cost of each of the systems was 5%–10% of the cost of comparable commercial systems. The efforts were successful only by collaboration of people in different disciplines: civil and environmental engineers, microelectronic specialists, and communication engineers.

INTRODUCTION AND PREVIOUS WORK

Understanding and modeling the behavior of natural systems is difficult due to lack of full comprehension of the dynamics of these systems and the complexity of the interaction between their various components. Thus, data is key for proper understanding and analysis of water resources and environmental systems.

While hydrological data is necessary, its presence can be rather limited, especially in Jordan, where historical data is scarce and often unreliable. Severe weather, attributed to climate change, has direct impact on people's livelihoods; it results in severe floods with extensive damage and unfortunately occasional loss of lives. Proper records of hydrological data help assess these hazards and prepare for them. The needed data can be used for generating floodplain maps, developing numerical models to estimate runoff quantities, or identify locations where early warning system units can be deployed. The data needed for these applications involve rainfall patterns; quantity, spatial and temporal distribution, and runoff trends and patterns. Quantifying evaporation is also necessary for proper capture of the hydrological cycle components. It is estimated that 92% of the total precipitation in Jordan is lost to evaporation.

Typical equipment for water resources and environmental system monitoring can be expensive. Many of these systems involve expensive sensors, data loggers, data transmission mechanisms and power sources. In addition, most equipment need to be field mounted which makes them subject to vandalism. Therefore, due to the equipment's high cost, this can be inhibiting to the monitoring and measurement efforts.

This research utilized low budget array of sensors, connected to Printed Circuit Boards (PCBs) with microcontrollers coupled with a data logging system in which the data from the sensors is saved to a micro SD card. The prices of the individual components are relatively low and these systems will record data similar to those recoded by more expensive equipment.

The first application involved two waterproof ultrasonic sensors along with six water temperature sensors, and an air temperature / humidity sensors. The system was used to monitor the rate of evaporation from two small scale ponds, one completely open to the sun, while the other is covered by floating solar panels. This system allowed the researchers to continually monitor the desired parameters and keep a record of the rate of change of the different parameters. The research investigated the potential advantage of using floating solar panels in reducing the overall evaporation. The second related application was for measuring the energy yield of different types solar panels placed at different locations, some floating over the water and the others ground mounted.

The third application involved developing a system for floodwater stage measurement. This system is integratable with a metrological data collection where the collected data is stored and transmitted via telemetry. This system had to be supplied with its own power supply via a solar panels module due to its installation in a remote location. This system was developed to support a flood management and control initiative in the ancient city of Petra and in the governorate of Madaba south of Amman.

The interest in these low cost systems is increasing; several researchers utilized these units for water quality monitoring. Lorena Parra, et al. (2018) utilized low cost sensors for monitoring water quality and fish behavior in aquaculture tanks during the feeding process. They created a network of wireless sensors to monitor physical processes inside fish farm tanks such as temperature, turbidity, conductivity, illumination in the tank, water level, and even the fish feeding behavior. In addition to monitoring, the system has the capability of sending alarm to the workers if a problem arises. The work by Lorena Parra utilized very low cost electronic components to measure the parameters listed above, the total cost of their system was less than 90 ₤. The researches created calibration charts that were used to translate the voltage signal from the individual components to meaningful values.

One specific application in a cave and marine environment was that of Beddows and Mallon (2018). Their applications involved monitoring the vadose zone by developing a drip counter inside an underground cave. The developers used a Mini Ultra Arduino along with an RTC and SD card modules to develop their data logging system. The other application was to track flow velocity in a submerged cave system. Here, the method was to test the inclination angle of a body suspended in a moving liquid. In both application, the researchers utilized readily available raw material to develop their casing and measurement devices. A major challenge in their work, similar to our challenge, was to optimize the power consumption as these systems will be remotely deployed and will be largely inaccessible. Their power optimization involved hardware and software modification which resulted in a very reasonable power consumption to the extent that a system running on 3 AA batteries could last for more than a year.

Other studies focused on the water quality analysis (eg. Hyder Khaleeq, et. al. (2016), Niina Kotamäki, et al. (2009), Peng Jiang, et al. (2009), Vijayakumar, and Ramya. (2015), and Niel Andre Cloete, et al. (2014)). Most of these studies involve analyzing physical water quality parameters such as temperature, pH, flow, and conductivity. Some even studied oxidation-reduction potential such as Niel Andre Cloete, et al. (2014). Some of the studies utilized small low cost computer board, the Raspberry pi (K.GOPAVANITHA and S.NAGARAJU, 2017).

This system allowed integration between the sensor array and the cloud in which the data is stored, analyzed and displayed. Niel Andre Cloete et al (2014) utilized basic electronic components and created a Veroboard for the sending and receiving modules. For the communication, they utilized Zigbee components for wireless communications. The sensor signals needed conditioning and a calibration between the resulting voltage and the sensor reading was established.

Hyder Khaleeq, et al. (2016) utilized a higher end microcontroller with a LabVIEW interface for viewing and analyzing the results. On the other hand Lorena Parra, et al. (2018) utilized the more economical Arduino Mega 2560 printed circuit board with microcontroller.

MATERIALS AND METHOD

These low budget tools developed and discussed here support research in three fields, evaporation rate quantification, field flood monitoring systems and photovoltaic panel power yield. These research activities are part of a comprehensive hydrological research conducted at the German Jordanian University. These systems are described in the following sections.

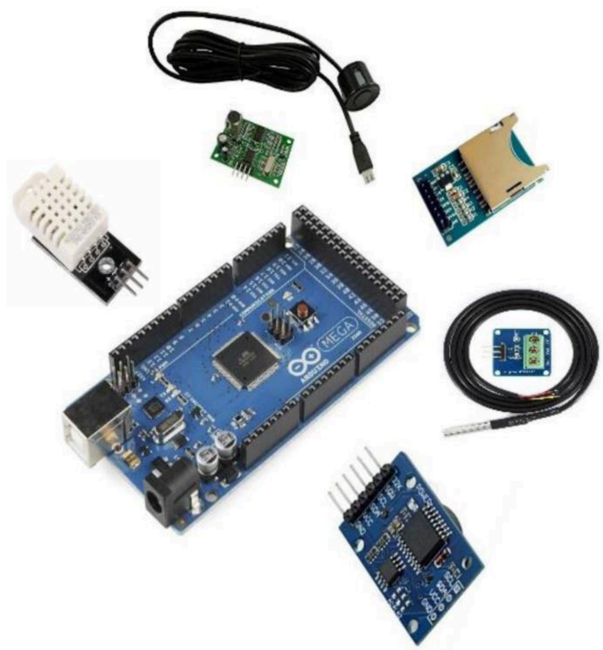

Figure 1. The different components used in the Evaporation rate quantification study

Evaporation rate quantification

This part of the research involved investigating the effect that floating solar panels have on the evaporation rate reduction from the water body. Floating solar panels provide shading to the water body thus reducing the direct solar radiation. The pilot scale setup involved constructing two 2x2 meter ponds filled with water, one covered by two solar panels mounted on a floating structure, while the other was used as a control and was subject to direct solar radiation. The level of water and temperature values were continuously monitored in both ponds. The measurement system involved an Arduino Mega 2560, two Water Proof Ultrasonic Modules for measuring the distance to the water surface, six DS1820 Stainless steel package waterproof temperature sensors placed at the water surface, the middle of the water column, and 10 cm above the bottom of the tanks. In addition, the system included an SD card module to locally store the data, it also included a DS22 temperature and humidity sensor. Each sensor reading was associated with a time, for that the Real Time Clock module (RTC DS3231) was used.

The system was operated for several months under various atmospheric temperatures and solar radiation values. The system was capable of capturing the reduction in the water surface elevation with time. The sensor readings were cross-validated with manual measurements of water level for an extended period of time, thus the accuracy of the sensor reading was verified. The system of sensors allowed the researchers to verify the evaporation reduction due to the floating panels, it also allowed investigating the effect of the panel inclination angle on the reduction potential.

Photovoltaic panel power yield

Coupled with the project discussed above is another component that investigates the power yield of the PV panels. The test involved two panel sets, one ground mounted and the other floating, each set had two panels, one is mono crystalline and the other is poly crystalline.

The aim was to study the impact of the floating nature of the PV panels on the energy yield. For that, a measurement system was developed, the system involved a data logging mechanism, a variable rheostat, and a set of temperature sensors to monitor the temperature of the PV panel surface.

This system is more involved than the previous one. Here, the measurement is set such that the current from each of the four panels is allowed through sequentially; the current from the first panel passes through a fixed predetermined resistance in a rheostat to simulate a load in the circuit, the voltage, current and power are recorded. A relay system is then used to vary the load in the rheostat, and the voltage, current and power are also recorded. The process is repeated for four different resistance values. Once done, the current from the second panel is let through, and the process is repeated again for the four available panels. The whole measurement process is controlled by the controller on the Ardunio Mega. Figure two illustrates a schematic of the system.

Stream stage measurement system

This system was designed to support research involving monitoring rainfall and runoff processes and therefore collecting essential data for developing numerical models. This system was more challenging than the previous ones since it needed to be a stand-alone system with no external power source. Therefore, it had to supply its own power via solar panels, additionally, it needed to be connected to the internet at the remote locations to be installed at. The system is composed of an ultrasonic sensor to measure the distance, an Arduino Pro mini, an SD card module to store the data, an RTC module to keep track of time, a GSM module to send the data to specifically prepared web server, where it can be displayed on any device connected to the internet. In addition, the system involves a battery, a solar panel and a charge controller for its power supply.

This system is designed to measure the stage of the flow when it happens. The wadies on which these devices are installed are ephemeral streams that are usually dry and flow happens only during flood events. The stage measurements will be used in calculating flow using Manning's equation.

Power consumption of the different components was high for a stand-alone system, which posed a challenge in the system's development. Several variations in the hardware design and software structure were tried to reach an acceptable power usage. The developed system can be an essential part of a much-needed early warning system for the wadies in various locations in Jordan.

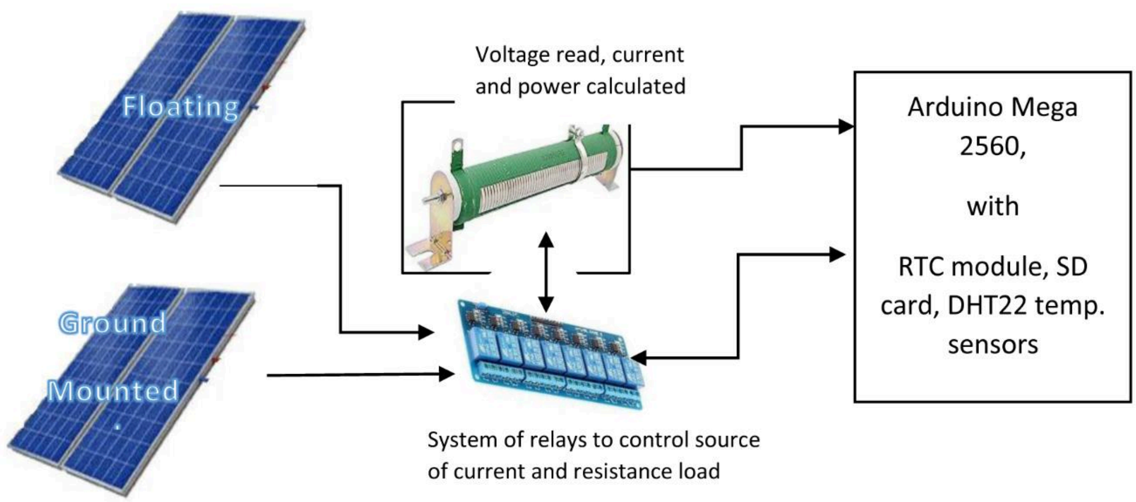

Figure 2. A schematic of PV panel measurement system

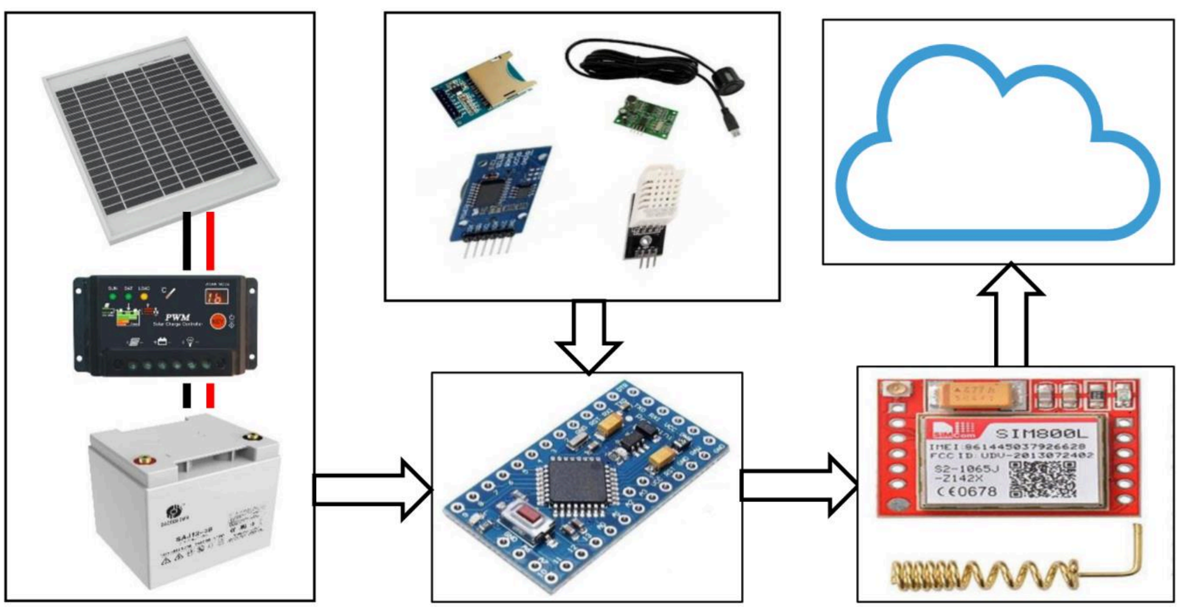

Figure 3. A schematic of the stream Flow rate measurement system

RESULTS AND DISCUSSION

For the water evaporation study, the pilot setup was done in the premises of the German Jordanian University. Monitoring started in August and continued throughout the summer and the subsequent winter. The ultrasonic sensors were mounted a fixed distance above the edges of the pools. As water evaporated, the distance to the water surface increased, these measurements are recorded on an hourly basis. Along with distance, temperature is also recorded. Coupled with these measurements, a weather station installed next to this setup continuously measures and records wind speed and direction, solar radiation, precipitation, temperature and humidity. These parameters along with the pilot system's parameters are collected and analyzed and the rate of evaporation is evaluated. The low budget monitoring system was successfully implemented; it was continuously monitoring and recording data up to the time this paper was written. The preliminary results of this research indicate an advantage to using the floating solar panels in reducing the overall evaporation from the covered water pool as compared to the other open water pool. The evaporation reduction percentage ranged between approximately 50 to 73 % depending on the inclination angle of the solar panel.

Figure 4. The pilot setup for evaporation reduction by floating solar panels study (Left), and the measurement system (data logger, ultrasonic, and temperature sensors) (right)

The second system was used for measuring the power outcome of the solar panels. The comparison here was done between the floating and the ground mounted systems shown in Figure 4. In addition, each system is composed of two panels, a mono crystalline and a polycrystalline. Each of the two panel is rated at a different power output. As described earlier, this system is more complex than the previous one in that it is designed to get the power from the panel, run it through a series of four resistances at different values, placed to simulate real load on the PV panel. The voltage and current are measured, and the power is calculated. This study is a long term study that would require doing the test at different temperatures and seasons, the system was prepared in December and is currently taking measurements at 15 minute interval when online. While the preliminary results show an enhanced power generation for the floating panels, the data currently available is still not sufficient to statistically verify that. Some preliminary results show an improvement ranging between 2% and 50% in some cases, yet, in other tests the results were not decisive in one direction or the other. This research still requires substantial investigation and data logging for significant trend detection.

The third system was not commissioned by the time this paper was written. It was designed, built and tested at the German Jordanian University campus, but not installed in the field. The biggest hurdle in this system is its large power consumption. The original version of the system included a Wi-Fi module and a portable Wi-Fi router (TP-LINK M7300), figure 5 shows the original setup of the main board of the system. This setup was later modified to get better power performance, some of the additional non-essential components were taken out, the Arduino Mega was replaced with a mini-pro and the Wi-Fi assembly was replaced with a GSM module. The power consumption was reduced significantly. By the time this paper was written, the system was in its final stages of campus testing, no field data was generated yet.

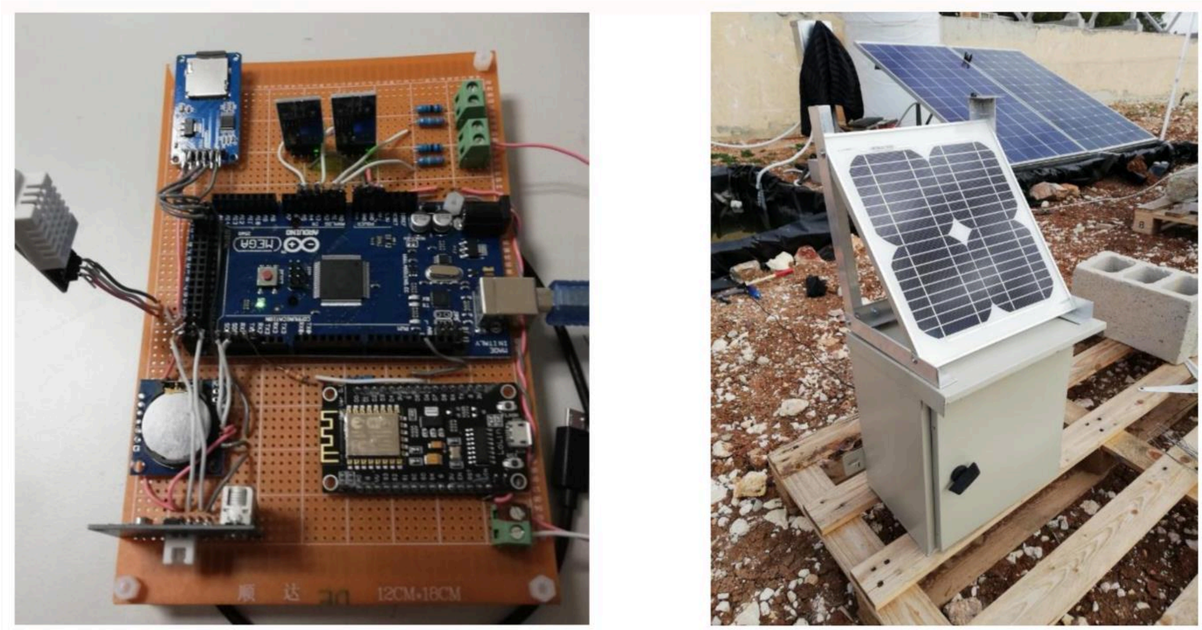

Figure 5. The original setup of the stream stage measurement system

CONCLUSIONS AND CHALLENGES

The developed systems used for environmental and power monitoring were very handy and efficient. They involved sensors to take the needed measurements, a microcontroller with a printed circuit board, a data logging systems to store the data, and a transmission module to store the data on the internet for easy retrieval and decision-making.

With any new "product" development, there is a fair amount of design optimization needed. Similarly, in this work, there were challenges that required continuous optimization. Some electronic components failed, and required replacement, especially in the PV power tests. In some cases, the failure was due to misconnections or malpractice in the board development, in others it was the electronic components themselves. Sensor readings will also need to be verified, sensor distance measurements were verified by comparing them to manual measurements, temperature readings were verified from two independent sources, and voltage outcome was also verified using a handheld multimeter. As mentioned earlier power consumption need to be optimized, especially in stand-alone units, this optimization is both hardware and software related. Data transmission and its reliability can be of concern if the system is to be used for applications such as early warning systems. Therefore, duplication of these systems may be necessary.

Despite the previously mentioned challenges, these home-developed systems were excellent in achieving the purpose for which they were designed. With the Internet of Things gaining a lot of momentum, the availability of the electronic components and the know-how is expanding and is at everybody's disposal. These systems and highly customizable to the researcher's needs and are low cost to allow for more flexibility in their usage.

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