Flood Sensing Framework by Arduino and Wireless Sensor Network in Rural-Rwanda

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***Abstract*—Our society is increasingly reliant on embedded systems for many critical day-to-day activities. Nowadays, Wireless Sensor Networks (WSN) are widely used almost everywhere, including both residential areas, and undeveloped areas near the river. Therefore, embedded systems can reduce risks due to an increase of climate change in Rwanda with potentially devastating impacts of floods on local communities and their properties. Advances in embedded system, particularly in WSN, offer us critical opportunities to develop complex real-time early warning and monitoring systems. The WSN technology has been applied in monitoring natural disasters for the last couple of decades. This paper further proposes an innovative and inexpensive framework designed to provide early warning for natural disaster via a siren. It works by continuously recording and transmitting sensor data to the main server. The server processes the data and then provides the warning, so that vulnerable residents can be notified before the floods come around their houses, especially in high risk zones. The major components of our framework include Arduino, solar panel, flood detector (sensor) with other wireless sensor components, a chargeable battery, Xbee and access point.**

Keywords: Embedded system, Arduino, Wireless Sensor Network, Early Warning System, Climate change.

I. Introduction

Embedded systems in today's real-time response are increasingly playing an important role. An embedded system is one that is made for a particular task instead of general multiple tasks. Such systems can be applied to solve various issues in developing countries. In particular, in many of the developing countries like Rwanda, some of the citizens are still living in high risk zones without having a real time warning mechanism. The availability of technologies for developing villages near and a little bit far away from the river, with no access to electricity, is spreading only slowly. Therefore, citizens are mostly affected by frequent river flooding, flash flooding due to heavy rainfall and lack of real-time early warning system. The identified issue is shown in Fig. 1.

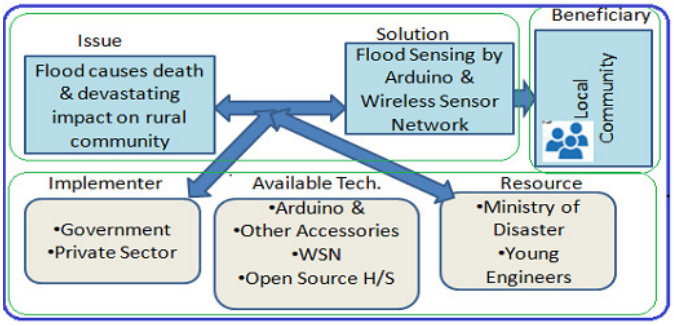

Fig. 1. Analysis of the problem

The main goal of the framework that we are proposing here is to minimize the loss to the community of people who have been living there in the last couple of years. Embedded systems and wireless sensors can improve social-welfare of citizens, since their main source of income is the land, food crops plantation and taking care of their cattle [1]. In Rwanda, more than two third of the population are relying on the agrarian based economy [2]. Thus, it is a big challenge for them and for the Government to move everyone from high risk zones to safe places, since it is too expensive; and it may take a long time for the Government to implement such kind of projects. In that regard, we propose an innovative framework that is comprised of affordable Arduino embedded computers and other inexpensive wireless sensor network devices (James, et al., 2013), to continuously detect floods and send an alarm warning voice through the siren. Citizens will get out of their vulnerable houses, and then move to a safe place. The main purpose of this framework is to save human life and reduce the loss of properties. The government will be able to expand the installation of those wireless sensor networks, since it is cost effective and easy to maintain. The government will save money by using those cheap devices like an Arduino

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that costs around thirty US Dollar [3] instead of spending hundreds of thousands US Dollar in expropriation and building new houses for the victims. In this paper, we introduce an advanced, innovative framework designed to keep detecting the level of water in case of floods near the river, then send the data through Arduino which that has the control program. An Arduino is used as a main component that facilitates the main functionality of the system. The communication is facilitated by both ZigBee Protocol and wireless networks.

II. Literature Review

Many research papers about flood early warning have been published over the last years, but we are not aware of any specifically showing a framework that can help a developing country like Rwanda to design and implement a flood early warning mechanism, using inexpensive tools with locally available materials, instead of expropriating residents in high risk zones. Authors in [4] have described a system that sends an early warning short message (SMS) to people before flood occurs. Our system will send early warning messages through sirens, since there is usually only partial, limited mobile network coverage in these areas. In [5], authors review research based on water level sensors for flood roads, that send messages through the web and mobile apps that requires all residents to be connected to the internet. Our system has a different model, in the sense that it focuses on rural areas of the developing country that have no internet coverage, a limited mobile network coverage, with limited access to electricity. Our early warning system will send alert sound through sirens deployed in the villages. The framework in this paper also includes the possibility of connecting one village to another in order to reduce the information sharing gap (lack of early warning through siren) among the citizens. In contrast to our proposal, expropriation usually affects farmers due to lack of access to their lands which are their main source of income. Also, it is too expensive for the government to accomplish that kind of project.

III. Lack of Flood Early Warning Systems in Developing Villages

Climate change seems to be a major challenge in today's global changes, whereby Rwandans are affected by floods after heavy rainfall in the rainy season. The increasing number of population, climate changes and deforestation are all posing potential barriers on land conservation and other natural resources management [6]. Furthermore, there are many factors, including the lack of ICT technologies appliance in some of the particular situations [7] in developing rural area. Usually, disasters occur in a very short time and it is not easy to stop them, but we can reduce the risks and the time delay by applying cheap available technologies [8]. Landslides and floods continue to affect economic development and social welfare of citizens, since there is no easy way to send an alert message before disaster occurs. Every year in the heavy rain season, floods affect our people and their properties in the local community; and tens of thousands of food plantation,

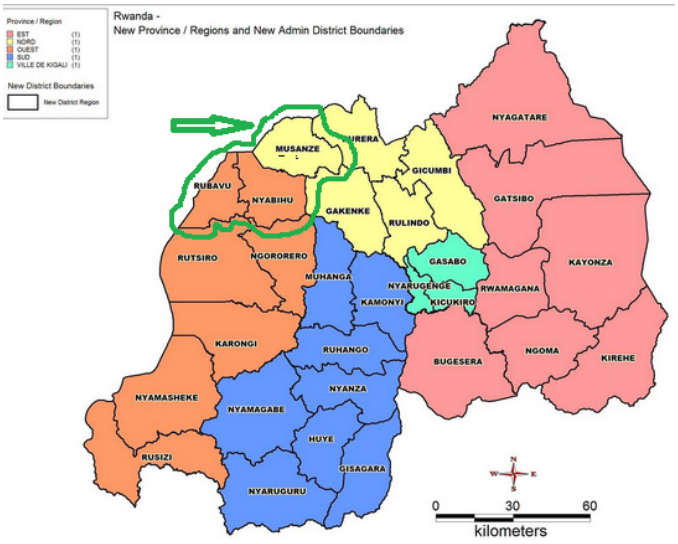

Fig. 2. Districts Map in Rwanda

trees in the mountainous areas and in the valley as well. The destruction of vulnerable houses is a major challenge, since a high number of victims are poor people in developing countries [9]. In addition to that, we cannot eliminate completely the frequent occurrence of natural disasters since they are influenced by climate changes. But the number of losses of properties and lives can be reduced by applying today's new technology like Arduino and other cheap wireless sensor network devices (James, et al., 2013). Protective methods must be taken before the flash flood occurs. When it comes to the torrential rain to people who are living in vulnerable houses, the most probable outcome is that floods surround the houses until they are demolished while people are inside, without having any noticeable alert. The problem of malnutrition, lack of clean water, unexpected death due to natural disasters, especially floods will continue disappointingly unsuccessful, since there is a lack of any kind of infrastructure to detect floods before vulnerable houses are destroyed [10].

In this case, some of the ICT Tools are needed to be in place, so that citizens can be informed through siren. All that will help and improve the possibility of using available cheap ICT tools in an isolated place by humans, especially for citizens who are living around and far away from the river. Rwandans still mostly rely on natural resources and agrarian based economy, whereby floods are affecting agriculture production [11]. The famous commonly affected districts by floods are Rubavu, Nyabihu and Musanze in the northern part of the country. The map in Fig. 2 shows (in green circle) the most affected districts [12].

IV. Arduino and Wireless Sensor Networks in High Risk Zones

A. Overview

In this innovative framework, we propose an embedded physical system that will include open hardware components

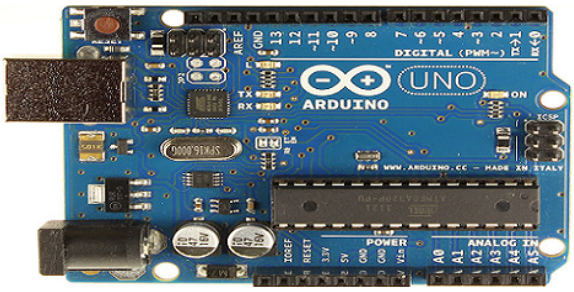

Fig. 3. Arduino Uno R3 Front

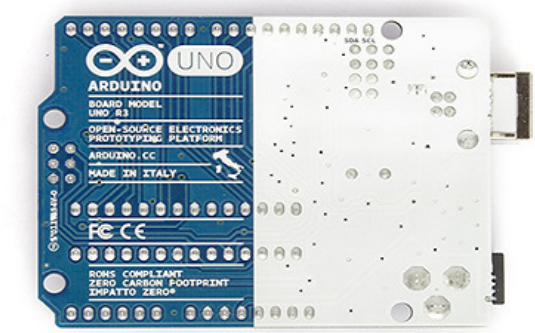

Fig. 4. Arduino Uno R3 Back

and software (see Fig. 6); the framework will continuously detect the presence of floods and send an early warning voice through siren. There is no need for people to periodically operate the system, since it interacts directly with the real world as an automatic and autonomous functioning system, reliability and dependability in its safe environment. "Arduino is an incredibly simple computer. It's very cheap as well, like $30, and you can learn how to program it. If you hook it up with the right electronic parts, you can actually use it to build objects that are essentially able to interact with people and interact with what's happening around them" (Massimo Banzi, 2012) [13]. Fig. 3 and Fig. 4 are the front and back sides of an Arduino Uno.

The framework in this paper, is basically built upon the Arduino Uno (Fig. 3, Fig. 4) in which its board is a micro-controller based on the ATmea328P [14] and its flexibility of open hardware and software for developers and other stakeholders who are not engineers. The above Arduino board has digital and analog ports that will allow us to plug various devices including sensors within the framework. Therefore, it will be a good opportunity to make a small network near the river, which will facilitate water level detection by sensing floods as soon as water comes out of the normal river, flows (see Fig. 5). All components will interact with a zero delay communication and be aware of where they are, thus they can detect whether or not water surpasses the expected limit boarders. Wireless sensor network in today's world seems to be everywhere as an enabling technology [15], especially in disaster risk reduction, management and agriculture related activities. Meteorologists and local community planners in

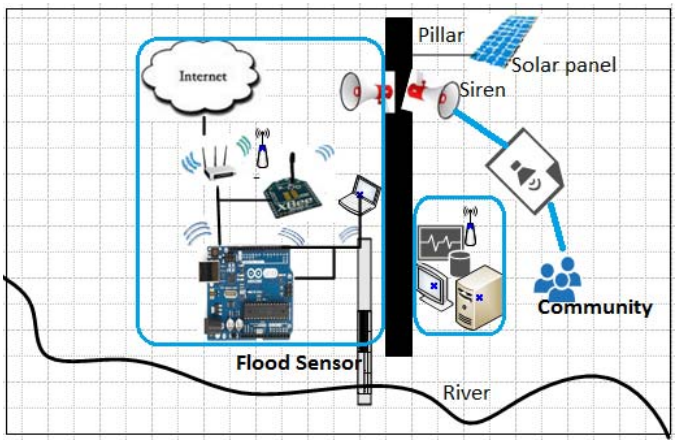

Fig. 5. Overall System diagram on the site

a particular region can rely and benefit from the data from having a bright future, while creating the smart village. The system structure simply shows a deployed system on the field: sensors are connected to Arduino that communicates via the ZigBee protocol [3], [16] and wireless communication with the wireless router. The ZigBee protocol within the embedded system will help data capturing without delay and improve transmission of receiving data by sensors [17]. The system can also be connected optionally to the internet to facilitate communication between villages, or to a central monitoring station; however, this is not a requirement, as our system is designed for stand-alone operation. Fig. 5 shows the overall system framework that should be deployed on the site, just near the river.

This innovative framework attempts to solve a real social-challenging situation in rural areas, by providing a real-time monitoring method of floods near the river. The framework has one or more Arduino, Arduino shields to connect the water level detector (sensor), USB power plug (optional), solar panel, a chargeable battery, server computer, MicroSD card for storing data, socket for Xbee modules, breadboard with wires and LED for signal testing [18], siren, data and graph screen display, strong pillar to hold (solar panel, Arduino and other small components of wireless sensors network), box to keep and protect Arduino for security purpose [19]. The solar panel in this proposed framework is among the most important parts. In addition, it is the main source of power supply for all devices. Solar panel thus benefits villagers, because of a limited access to electricity. The sensor network has a large set of small nodes, which communicate through wireless transmission. In this framework, the Arduino board is programmed to capture data, and then send signals whenever the water detector senses the presence of an increase of water compared to normal river flow level. Sensor nodes here will gather and assist in the communication process until the final analyzed results are generated, depending on received data. There will be a computer screen to display an analyzed (numerical and graph) result [17]. Real-time data transmission in this framework will be also be assisted by a WI-Fi protocol

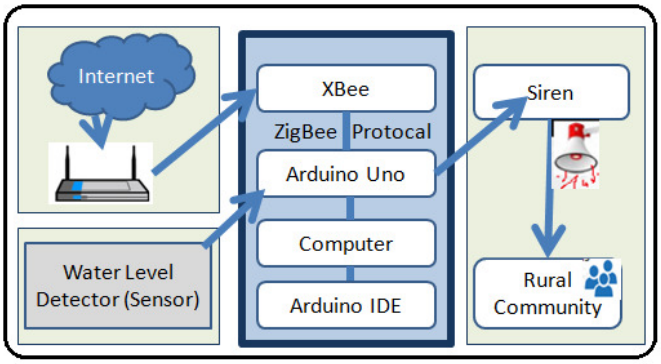

Fig. 6. Process model on the side of young engineers

and other different internet protocols. All devices mentioned in the framework are powered by a solar panel. Finally, as it is designed in the framework, an automatic alert warning sound will be sent through siren only when the detected water level surpasses normal expectation to dangerous level of water flow on the river. The overall flow diagram (see Fig. 6) of the framework is comprised of three main parts as it is explained in the next paragraph.

Fig. 6 is clearly designed for young engineers (Developers). It simply clarifies the embedded model of the physical system in the framework. On the other hand, water level detector (sensor) working together with other micro-controllers which are considered as sensors to Arduino and they are talking through ZigBee protocol and wireless in the framework. There is a router that is mainly connected to the internet for allowing other communication between devices. They sense the presence of an increase of water as inputs near the river (the left side was named: interactive part of the process model). In the middle (central part of the process model) that in which all external devices are connected. The software system that includes all instructions telling an Arduino what and how to sense, receive inputs and then processes them until the real output. Finally, processed data regarding the level of water near the river will assist in the execution of an early warning to the real physical environment. The system will only send an alert warning voice to the local community when the water level surpasses the normal level to the danger level.

B. System Security and Operation on the Site

The system will be deployed and maintained by the Ministry of Disaster Management and Refugee Affairs (MIDIMAR) in partnership with Knowledge Lab (KLab) and local community. Rwanda has a good leadership with a decentralized system that which gives a guarantee for the physical system protection on the site.

1) **Safety**
The system maintenance does not require many staff, and it is cost effective to replace devices like Arduino that can cost only around thirty US Dollar (James, et al., 2013, p xxiii). In case of maintenance, MIDIMAR will intervene financially. A notification will be sent to the person in charge, just in case the system stops working accidentally.
2) **Reliability** This proposed innovative framework is reliable due to its accurate information delivery mechanism on time. There is an expectation of less system failure due to its simple connected hardware and software. There in the village will be an advocacy campaign about why, how and what to do in case siren sends warning voice to the community.
3) **Flexibility** An Arduino board is available on the market, with an affordable cost for our young engineers to buy and implement things as mentioned in this framework. With its high flexibility, it will be easy to change the circuit and develop system software that which depends on local unique needs.
4) **Security** All devices on the site will be fixed on the top of a strong pillar/ pylon. This guarantees a protection from harm. Thus the installation of the Arduino and other wireless sensor network components will be outside near the river, it will not be possible to destroy the entire infrastructure.

Another issue is protecting the monitoring equipment from theft, vandalism, and damage from natural causes. In addition to developing a robust enclosure and installation layout, we want to try some of the following methods:

- The warning siren can be sounded if tampering is detected.
- The resale value of the equipment can be reduced by markings, e.g. the Arduino boards painted bright orange etc., or we can disable such features that are not used here, but would be required by prospective buyers (the USB port etc.).
- Legislation can be enacted to punish severely anyone who damages the system and thus endangers the lives of a population.
- People should be educated about the importance of protecting the system and helping with its maintenance, since it is in their own interest to do so.

C. Open Source Hardware

Arduino is the main component in this framework, which has open source hardware and source codes with the Arduino Integrated Development Environment (IDE) (Harold T. p1). This is very helpful for us to implement an amazing interactive flood early warning system.

D. Wireless Sensor Network

This framework has small wireless sensor network components (see Fig. 5), that has the capability of communicating through wireless. The flood level detector can sense the presence of an increased level of floods when it comes to the danger level. Both wireless and USB connectors allow the interconnection of the devices in the framework.

E. Embedded System

Embedded systems are central to this proposed framework, especially since the Arduino board having many parts that allow interconnection. As such, embedded system on Arduino board controls all devices as they are connected together. An Arduino board in the framework will be connected to sensors communicating through ZigBee and wireless mode; there is a router that is linked to the internet (See Fig. 5) to enhance communication between devices.

V. Conclusion

In this paper, we described a proposed innovative framework that covers both Arduino-based technology and other inexpensive wireless sensor network components to detect flood and send an alert to the local community. The main long-term purpose is to reduce the cost of flooding damage and save the life of the population in rural area, those whom live in a high risk zone. The particularity of this framework aims to propose and encourage the government to implement such kind of advanced technology (i.e.: flood sensing by using inexpensive devices, open source hardware and software) to reduce the cost of damage due to disasters. The future work along the implementation will be to find a way of training (assembling an Arduino board with its accessories, kits, shields and software with other wireless network devices) for young graduate engineers, those who use to come to KLab center located in capital city Kigali-Rwanda. There is also an important capacity building required, to develop the appropriate related policies for disasters mitigation and preparedness, involvement of citizens and ICT experts in planning and decision-making. This will not only improve safety in the rural areas, but also will enhance skills and knowledge between young engineers while improving the social welfare of citizens that later contribute to the development of the entire country.

VI. Future Work

The proposed framework could be adapted to many other monitoring tasks in a developing country, when a local response to immediate warning is needed. For instance, it can be applied in landslides, volcanic activity, forest fire, intrusions by poachers into protected areas and underwater gas emission from lakes. On the technical side, the proposed framework might not be suitable for covering very wide areas threatened by floods or other disasters. For such cases it might be necessary to increase the range of the wireless communication devices, by employing long-range transmitters [20], repeaters, or using TV White Spaces (TVWS) communications [21]. A further option is to enhance the efficiency of warnings by employing "disaster prevention radio" broadcasts. We intend to continue research in these directions too.

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References

[1] Republic of Rwanda, Ministry of Agriculture and Animal Resources (2009, p.1), *Strategic Plan for the Transformation of Agriculture in Rwanda - Phase II* .

[2] John F. May, Alex Kamurase,(2009), *Demographic growth and development prospects in Rwanda: Implications for the World Bank*. June 4-16, 2009. Kigali-Rwanda.

[3] James Floyd Kelly and Harold Tmmis (2013), *Arduino Adventures: Escape from Gemini Station* .

[4] Shivaray Shenoy.A, Shrinath P.S, Sharath. S, Balapradeep K.N (June 2014) *Water Level Monitoring and Flood Alert System* : K.V.G College of Engineering, Sullia Affiliated to VTU Belgaum, India.

[5] Remedios G.A, Johnver B. Bautista, Kim Carla B. Lleno, Katrina Hazel R. Malagday, Mark Anthony D. Muya (May 2014), *Road Flood Sensor with Web and Mobile Application Support* : Polytechnic University of the Philippines, Sta. Mesa, Manila.

[6] Daniel C. Clay, Valerie Kelly, Edson Mpyisi and Thomas Reardon, *Input Use Conservation Investments among Farm Households in Rwanda* : Patterns and Determinants.

[7] Professor Sir David King, Megan Cole, Ministry of Natural Resources under the Government of Rwanda, *Green Growth and Climate resilience-National Strategy for Climate Change and Low Carbon Development* , October 2011: Kigali-Rwanda.

[8] Maneesha V. Ramesh (2009), *Real-time Wireless Sensor Network for Landslide Detection* , 2009 Third International Conference on Sensor Technologies and Applications, AMRITA University, India.

[9] Harminder Kaur, Ravinder Singh Sawhney, Navita Komal, *Wireless Sensor Networks for Disaster Management* , in the International Journal of Advanced Research in Computer Engineering & Technology, Volume 1, Issue 5, July 2012: Guru Nanark Dev Univesity, India.

[10] Dr. Antoine Nsabimana, Dr. Chipo Mubaya, Dr. Jon Padgham, *Report on the Rwanda Science-Policy Dialogue on Climate Change* , 14-15 October 2010: Kigali-Rwanda.

[11] Olof Drakenberg, Emilie Cesar, *Environment and climate change policy brief-Rwanda* , May 22, 2013: Rwanda.

[12] Republic of Rwanda. National Institute of Statistics (2012), *Population and House Census* .

[13] Massimo Banzi (2012), *Q&A with Massimo Banzi: Cofounder of Arduino*. Techspecs,. Available from: http://blog.radioshack.com/2012/02/qa-with-massimo-banzi-cofounder-of-arduino/

[14] Stelios Zachariadis and Theodore H. Kaskalis (March 2012), *An Embedded System for Smart Vineyard Agriculture* : University of Macedonia, Greece.

[15] Jacques Panchard, P.R. Seshagiri Rao, M.S. Seshshayee, et al. (2009), *Wireless sensor networking for rain-fed farming decision support* : EPFL, Switzerland.

[16] Cholatip Yawut and Aathapath Kilaso (2011) *A Wireless Sensor Network for Weather and Disaster Alarm Systems* : Bangkok, Thailand.

[17] Kuang, Y. L, Sung, J.H and Wen, T.S (2013) *Mobile Monitoring and Embedded Control System for Factory Environment* .

[18] Harold Timmis, *Technology in action, Practical Arduino Engineering* .

[19] Zahoor Ahmad, Ehsan U. Asad, Abubakr Muhammad, Waqas Ahmad, Arif Anwar, *Development of a Low-Power Smart Water Meter for Discharges in Indus Basin Irrigation Networks* : Lahore, Pakistan.

[20] M. Zennaro, A. Bagula, D. Gascon, and A. Noveleta, *Planning and deploying long distance wireless sensor networks: The integration of simulation and experimentation*, in Ad-Hoc, Mobile and Wireless Networks, ser. Lecture Notes in Computer Science, I. Nikolaidis and K. Wu, Eds. Springer Berlin / Heidelberg, 2010, vol. 6288, pp. 191204. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-14785-2 15

[21] C. Mikeka,*, M. Thodi, J. S. P. Mlatho, J. Pinifolo, D. Kondwani, L. Momba, M. Zennaro, A. Moret, *Malawi Television White Spaces (TVWS) Pilot Network Performance Analysis*, Journal of Wireless Networking and Communications 2014, 4(1): 26-32