Automated IoT-based Monitoring and Control System for RadioBroadcasting Network in Tanzania: A Case of Tanzania Broadcasting Corporation (TBC)

Hamisi Msimbe[1†], Prof. Michael Kisangiri[2††] and Dr. Judith Leo[2††],
msimbeh@nm-aist.ac.tz michael.kisangiri@nm-aist.ac.tz Judith.leo@nm-aist.ac.tz
The Nelson Mandela African Institution of Science and Technology,
Arusha, Tanzania

Abstract
A conventional system of monitoring and controlling radio towers requires ceaseless and physical attendance of human operators who oversee the operating conditions. Strenuous and daily effort is needed to access the broadcasting towers located on remote and elevated land surfaces. In general, the process is manual-based causing high operating costs and time consumed is high in information management of the equipment. This paper presents an automated IoT-based monitoring and control system to reduce the operation and time costs in radio broadcasting network. The proposed system employs an ultrasonic sensor, MQ2 sensor, DHT22 sensor, and raspberry pi camera attached to raspberry pi 4 board for continuous use of ESP32 to monitor and control forwarding power, reflected power, electrical units, fuel level, temperature, humidity, and smoke and then, send updated information to a blinky mobile application installed in the smart device. Based on the validation process, participants have agreed that at an average rate of 86% the developed proved to work effectively in ten radio broadcasting towers of TBC and can enhance the high- speed retrieval of information and minimizes operating expenses. Therefore, the study recommends implementation of the developed system to all TBC's towers.
Keywords:
radio broadcasting network; telecommunication system; monitoring and control system; ESP32; blinky mobile application; operating status

1. Introduction

A radio broadcasting network is a telecommunication system composed of towers deployed on mounted land surfaces for transmitting audio and video programs from a single transmitter to numerous receivers. According to the literature, the transmission systems of radio broadcast depend on the power of the transmitter, gain of the antenna, and height of propagating antenna [1]. Additionally, the usable range of radio frequency spectrum which was addressed by the International Telecommunication Union (ITU) is 3 kHz up to 300 GHz. To be noted that, the ITU is the organ responsible for assigning various frequencies of communication for different fields worldwide [2]. Furthermore, the current radio broadcasting technology is propagated within the RF range in frequency of 87.5Mhz up to 108Mhz employing FM propagation and reception techniques [3] which does not depend on clear skies and fine weather [4].

Moreover, the broadcasting tower consists of equipment such as a transmitter, generator, uninterrupted power supply (UPS), feeder cable, and pair of antennas [5]. Whereas, in a long-distance broadcasting which are required to cover country-wise, the radio stations have to transmit their programs from studio to the satellite via uplink amplifier which propagates the wave at its uplink frequency in gigahertz (GHz). Subsequently, [6] a radio network consisting of broadcasting towers and land surface satellites dishes installed in various regions of a country which are integrated with digital receivers or decoders to pick up the signal from the satellite via downlink frequencies assigned by the communication regulatory authority. The digital receivers decode high-frequency signals in megahertz (MHz) to lower frequency signals [7, 8]. Whereas, the lower signals are sent to the frequency modulation (FM) transmitters for processing and broadcasting in a frequency assigned by the regulatory authority within regions of the country with uphill areas.

Therefore, the scenario shows that the traditional operation of the broadcasting network needs teamwork of technicians and engineers who attend physically to the radio towers in order to take readings of the basic parameters of the transmitters. Hence, strenuous and daily efforts are needed to access the broadcasting towers located on elevated land surfaces or uphill mountains even during the bad weather conditions such as heavy rainfall, cold or warm temperatures. According to the survey which as done among

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the technicians and engineers who are taking readings and operating conditions of broadcasting equipment, as well as acquiring and writing daily reports of the equipment every day; it has been observed that these technicians spend a lot of time climbing up the mountain and descending to the flat earth surface which is tiresome, sometimes dangerous, and also, waste a lot of time [9].

Hence, there is a need of automating the existing processes which required technicians and engineers to climb up just to check the status of the equipment and take readings. Therefore, this study presents the developmental stages of an automated IoT-based monitoring and control system for radio broadcasting network in Tanzania which aims at reducing the tedious work done by the technical personnel working at these broadcasting towers.

2. Literature Review

According to the literature, it has been noted that technology such as Internet of things (IoT) can improve remote data accessibility and schedule it for numerous businesses and people. Additionally, the IoTs have been demonstrated to be fundamental in remote reception, managing and accessing information. Furthermore, IoT technology can facilitate remote accessibility of information via internet-enabled devices to connect each other remotely all over the world [10]. Moreover, there is the latest services and opportunities which have emerged due to technological changes by enabling these devices to work more effective using internet [11]. Hence, the capability of automation, easy accessibility, as well as real-time monitoring of intended information, make IoT useful to many operations [12].

Consequently, it is believed that the technological advancement resulted in the new features in industrial revolution 4.0, security systems, and surveillance systems which are the output of the IoTs [13]. However, it is also noted that IoT features doe not only impact the technological advancement but also, support well enough on the social welfare of society due to production of real-time services such as internet banking, telemedicine, e-payment, e-government, and distant learning facilities [14]. Based on these findings, IoT can be used to automate monitoring and control of activities in different fields as well as enhance the reliability, performance, and efficiency of the system [15].

In this study, different studies have been explored on the monitoring and control systems in various fields of engineering such as power substation, industrial production, steel casting industry, health system, and home system. However, most of these studies have only concentrated on others parameters and excluded forwarding and reflected powers of broadcasting towers. The following are some of the review's studies, for example the authors in [16] explained that devices from any part of the world can be viewed remotely once connected to the internet using a heterogeneous or homogeneous sensor network technicians spend a lot of time climbing up the mountain and descending to the flat earth surface which is tiresome, sometimes dangerous, and also, waste a lot of time [9].

The latest network architecture allows heterogeneous equipment to lengthen the operating spectrum for WSN and deployed sensor nodes to keep a check over the regions [17]. The impulse of detected phenomenon (heat, pressure, humidity, etc.) is reported to the base stations for further processing.

In [18] heterogeneous Wireless Sensor Network (WSN), deployment of relay nodes that ensure fault tolerance with a higher network connection is conveyed. IoT provides simplified ways to view and manage computerized devices with faster execution at a specific time [19]. Computation processes enhance the easy acquisition of information of contemporaneous events occurring either preceding or simultaneously [20].

Authors in [21], showed voltage fluctuation in batteries of telecommunication towers which was monitored using mobile applications to retrieve real-time data, as well as temperature, fire, and gas leakage were monitored. With the IoT platform, storage and transferring of the data through the local area network (LAN) is possible. System operators can remotely retrieve the data in real-time and access the data from the network attached storage (NAS) on the network [22]. Monitoring of operation parameters including temperature, voltage, and current sensors with the assistance of microcontroller and Global System for Mobile (GSM) module is performed in which there is relay acting like a switch to monitor the production line [23]. The identified fault which occurs to the induction motor is monitored and solved in time after performing extra operation and evaluation of machinery condition [24]. Another study [25], employed only a gas sensor (MQ-5) to detect gas leakage using Arduino Uno to send information to the cloud. An alarm from the buzzer is used to alert the observer and reduce the occurrence of fire. In another study in which the Proposed system monitors and processes data such as temperature, humidity, smoke, fire sensors for security purposes by a raspberry microprocessor. All the sensors' data will be posted into the server for wireless security monitoring with the assistance of ESP8266 which incorporates a raspberry pi processor. Buzzer module notifies the employee at the industry for security. The study improved worker security using necked eye checking concerning any industrial emergency [26]. Authors in, [22] proposed an IoT-based online monitoring system for continuous steel casting that is capable of processing huge amounts of data, and the proposed framework design offers sufficient flexibility to coordinate advanced hardware equipment and computer program functionalities. Authors in the field of health [27], introduced a Low-power wearable electrocardiogram (ECG) monitoring system for multiple-patient remote monitoring in which non- experts use them to observe the health of the patients at the household.

Previous works have not been deployed the use IoTs in the broadcasting sectors, therefore to eliminate the challenges, IoT based monitoring and control system has been designed and implemented in radio broadcasting towers. As a result, expenses incurred during traditional operations have been escaped because the systems are integrated with the internet and reported directly to the cloud in which all the data can be captured from the server, as a result there is no need to employmany technicians or engineers who have to physically visit thetowers. Retrieval of information in the radio network by inserting queries and collecting results in large area coverage rather than physical attendance to every point in the field [28]. In addition, every internet-enabled device undergoes self- operation without man intervention and at any time command can be inserted to change the mode of operation remotely over the blinky mobile app. Lastly, physical attendance to the system is unnecessary with increased security and privacy of the information within a network.

3. Material and Methods

3.1 Study Area

The study areas for this study is at the Tanzania Broadcasting Corporation (TBC) which is in Tanzania. Tanzania is one of the countries situated along the East Africa region with a total dimension of 945,087 square kilometers. It is approximated that the whole territory of Tanzania is constructed with radio broadcasting towers situated in uphill land surfaces, mountains, high buildings, or elevations. Therefore, the data collection for the proposed solution is collected among ten regions in Tanzania, including; Tanga, Tabora, Arusha, Lindi, Dodoma, Dar es Salaam, Mwanza, Shinyanga, Singida, and Katavi [29]. Additionally, the followed rapid application development (RAD) approach which allows various stages and functionalities to be developed concurrently. Moreover, RAD in Fig. 1 ensures incrementally achievements of the analysis, design, implementation, and testing processes and hence, it is less expensive approach, flexible, and high productive due to the fact that it also allows code reuse in the process [30].

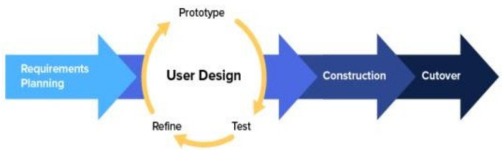

Fig. 1 Five-phases of Rapid Application Development [30]

3.2 Hardware Tools

The process of identifying requirements through data collection was followed by designing the circuit diagram of the proposed system as shown in Fig.2. Then, simulation of the hardware components was conducted through the use Proteus software to check the viability of the circuit diagram as shown in Fig.2. Fig.2 consists of ESP 32, interfaces for digital humidity and temperature sensor (DHT22), Mq2 gas sensor, ultrasonic sensor, and an optional interface for the GSM module. Simulations were conducted and validated before integrated the components as proposed in the circuit diagram in order to ensure that they work as intended. Therefore, after these processes, all sensors were integrated into the ESP 32 module in the Proteus software. The Espressif Systems (ESP) 32 as a totally independent system or as a slave gadget incorporating microcontroller unit (MCU), is selected in the proposed system due to its capability of minimizing communication stack overhead on the major applications and processing. It is interfaced with other electronic sensors to enable Wi-Fi or Bluetooth connectivity for sending data to the Blinky mobile app. The DHT22 module is connected to pin 33 and senses the temperature and humidity of surrounding air inside the broadcasting room. The board is powered with either 3.3 voltages (V) or 5V in which interconnection between the sensor and only a single port of the microcontroller takes place. The MQ2 Gas/Smoke Sensor is connected to pin 32 and detects gases leakage like liquefied petroleum gas (LPG), propane, carbon monoxide, hydrogen, alcohol, methane, propane, methane, and smoke. Hence, the device is made up of sensing elements that vary their resistance after making contact with the gas. Therefore, in the process a small deviation of resistance is used to sense the amount of gas released. Additionally, the device is connected to 5V direct current (DC) mains and it can detect the gas concentration of 200ppm up to 10,000ppm. Furthermore, the gas is used to detect the presence of fire and releases a command signal to the microcontroller that admits the amount of liquid to extinguish the fire that emerged. Moreover, the ultrasonic sensor has two pins; the Trig pin and the Echo pin which are connected to pins 25 and 26 respectively which are used to detect the distance of an object by realizing ultrasonic sound waves

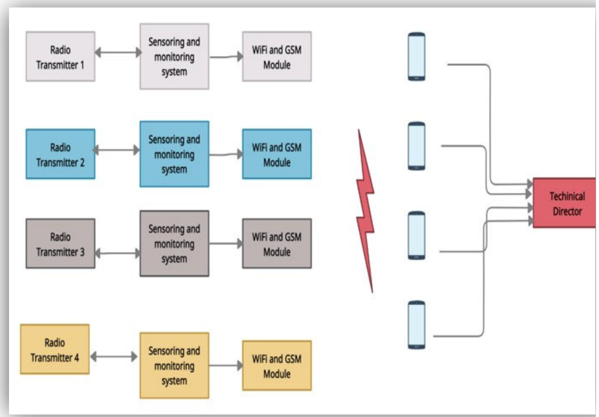

Fig. 2 The Circuit Diagram of the Proposed System

direct toward it. Then, the object reflects the sound waves to the devices which converts sound into an electrical signal. In return this object is used estimate the level of fuel in the generator by placing it at the top of the fuel level tank facing the fuel surface. Hence, as a result, the device calculates the remaining level of fuel within the tank and sends a signal to the microcontroller for processing.

Lastly, raspberry Pi 4 model as the single-board computer is connected with an external keyboard mouse and monitor or television (TV) for easy programming, configuration, and computation of the system. The board is chosen because of its high capability to enable high-speed processing speed, multimedia transmission, large memory, and faster internet connectivity of the captured images of forwarding power, reflected power, and electrical units. The Pi board receives footage from raspberry Pi 5Mp camera board module having the 5-megapixel camera with capability to capture 2592x1944 static images as well as 720p60 and 640x480p60/90 video camera. This camera captures still images of transmitter and energy meter displays, after that information is transmitted to the Blinky mobile App through the internet connection for reporting purposes. The whole connectivity describe is also shown in the architectural diagram in Fig. 3.

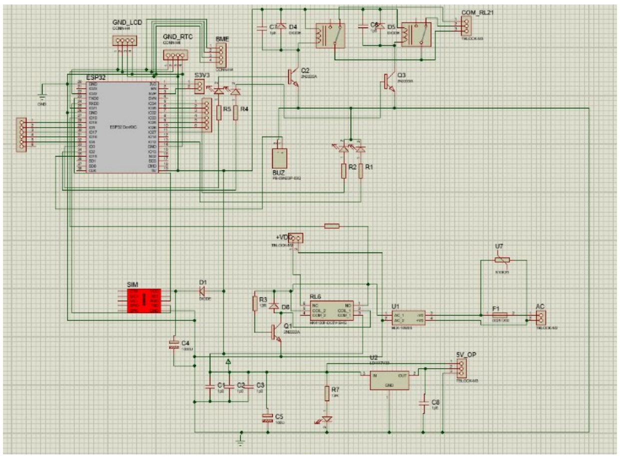

Fig. 3 The Architectural Diagram of the Proposed System.

3.3 Software Tools

In terms of the software, C++ which is a powerful and general-purpose language that supports different features of programming such as object-oriented, procedural, functionality, was used. Additionally, C++ supports fast and powerful executions as well as dynamic memory allocation. Hence, this language has been applied to program the microcontroller ATmega328P using Arduino Integrated Development Environment (IDE) within the proposed system. Moreover, the customization of the blinky mobile App enables control and managing of the embedded systems which is installed remotely in the radio broadcasting equipment. Additionally, the App can run in both the android version 4.2+ and iPhone operating system (iOS) version 9+. It can also, run on many hardware modules, approximately 400 devices including ESP 8266, ESP 32, NodeMCU, any model of Arduino board, and any model of Raspberry Pi in which all of these components are used in building the proposed system. Furthermore, the app can be supported by internet connection of all types including Wi-Fi, ethernet, cellular communication, and Bluetooth, to mention a few hence, making it useful in the proposed solution. Moreover, the app is available on all online stores such as google play store and apple store. Lastly, in the proposed system, the app is used to retrieve the information from various regional broadcasting stations to the mobile and smart devices of the technicians who are responsible for towers.

3.3 Validation Process

A field study on one month was conducted at TBC in some regions of Tanzania, whereby a total of 20 technicians who operates regional transmitters were involved. the questionnaires focused on getting information on the Speed, capacity, performance, reliability, and usability of the developed system.

4. Results and Discussion

4.1 Results of the Developed System

This section briefly presents the results of the developed system in which on results, it can monitor and control seven parameters that are forward power, reflected power, generator fuel level, temperature, humidity, fire, and electrical units balance as shown in Table 1.

Table 1. The Outcomes of the System

Device	Parameter measured	Circuit Readings	Mobile App Reading
DHT22	-Temperature -Humidity	- 30.1ºC - 47%	- 30.1ºC - 47%
MQ22	-Smoke	- No fire	- 0
Ultrasonic Sensor	-Fuel level	- 57 litres	- 57 litres
FM transmitter	-Forward power -Reflected Power	- 1500W - 40W	- 1500W - 40W
Energy meter	-Electrical Units	- 5444Kwh	- 5444Kwh

The following in Fig. 4 shown the front and side views of the developed prototype of a network broadcasting tower and Fig. 5 shows the processes of fixing the embedded systems at the tower. In brief, the following is explanation of the functionalities of the developed system as shown in Fig. 4, Fig. 5 and

Fig. *6*. The developed system has fire alarm to monitor and control the existence of fire. Whereas, the DHT22 sensor is responsible for detecting the temperature and humidity of the room. Then, the notification is sent to the cloud via the ESP 32 in which the information is seen to the blinky application by the technician or engineer. Since the air conditioning system is responsible to ensure the optimal condition of 250C for the operation of the equipment. Hence if the mentioned threshold is above the range, the technician will receive an alert and take immediate action by physically visiting the site in order to perform maintenance of the air conditioning (AC). Additionally, the Raspberry Pi-based system automatically measures the forwarding power, reflected power, and electrical units balance through the use of image processing techniques. The system is fixed with two cameras along with a liquid crystal display (LCD) circuit

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Company Limited (TANESCO) is unpredictable for that reason the amount of fuel can also be monitored via mobile App which enables the station operator to understand when to refuel generator tank in order to save operating cost and time. The screenshot of the Blinky application in

Fig. *6* shows the image of seven parameters that are monitored and controlled by the system. Moreover, the alarm of the fire is observed on LCD and the mobile App by displaying the amount of gas concentration in the room of the network broadcasting tower

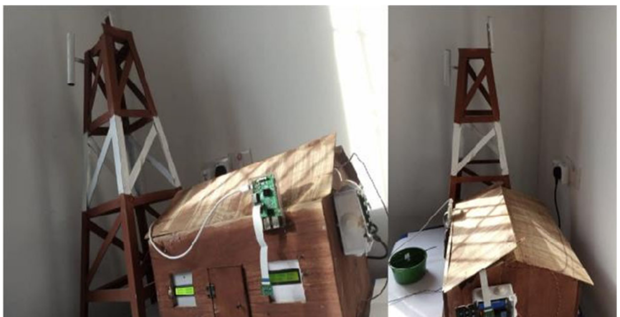

Fig. 4 Front and Side Views of the Developed Prototype ofa Network Broadcasting Tower

interfaced to a raspberry pi, hence it can continuously process the incoming camera footage in order to identify the current reading of the transmitter display and energy meter. Therefore, after sensing readings in front of the camera, it processes the camera input, and then, extracts the number part from the image for processing the optical character recognition (OCR). The system then displays the extracted readings on an LCD. For the case of forwarding power, any range can be considered as the desire for the radio transmission because it does not affect broadcasting, but for the case of the reflected power which prohibits the transmitter to broadcast on the acceptable range, notification is sent to the technicians through the blinky app in order to check up the fault which causes high reflected power on it. Therefore, technicians and engineers use smart and mobile devices to observe the amount of forwarding power and reflected power which are existing on the transmitter. Furthermore, the amount of fuel within the tank can be observed remotely via a fuel level detector sensor which shows the current reading of tank level. Since in Tanzania

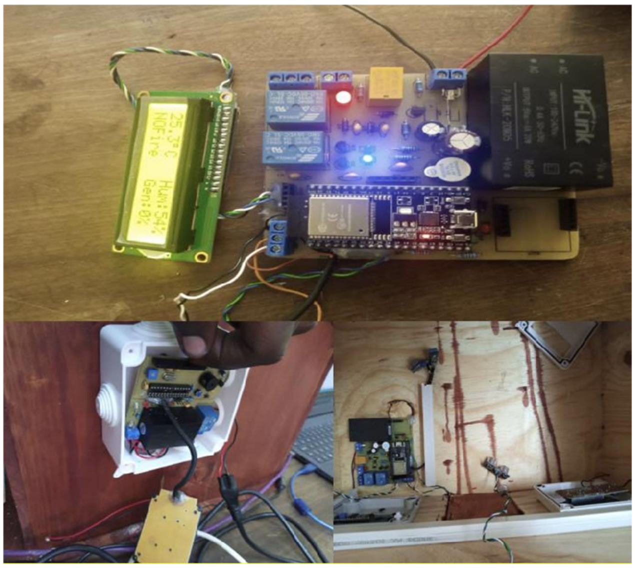

Fig. 5 Fixing of the Embedded Systems at the NetworkBroadcasting Tower

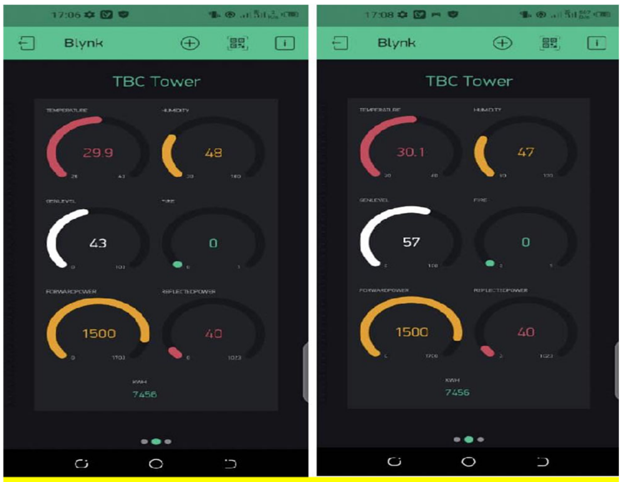

Fig. 6 Observation of Various Parameters in theMobile App

4.2 Validation of the Developed System

The overall results of system validation as shown in Fig. 7 indicate that each measured parameter performed well at more than 50%. Whereby the speed performed at the rate of 80% of all participants, capacity at the rate of 85%, performance at the rate of 90%, reliability at the rate of 85%, and usability at the rate of 90%. The remaining average rate of 14 % of the validated parameters represent participants with lack of enough knowledge on the developed and integrated features. Hence, the study briefly conducted training to share the benefits and case studies of the integrated features so as to make the participants become aware of the benefits and impact of technological advancements.

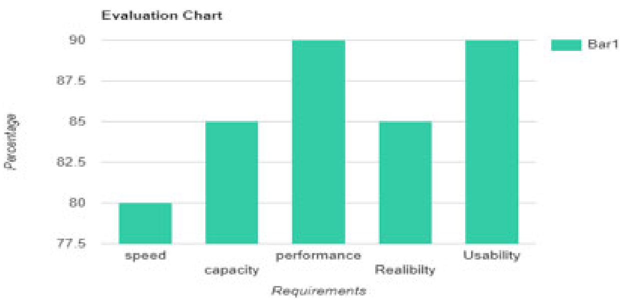

Fig. 7 Results of Validation Process

5. Conclusion and Recommendation

The current study is based on retrieving the information of seven parameters namely forward power, reflected power, temperature, humidity, fuel level, electrical units, and fire. The sensors are used to send information to the blinky App installed in the smart devices of towers operators via ESP32 and raspberry 4 modules. Based on the integrated features and validation study which was conducted, the study proved successfully to reduce cost and time of operating the towers installed in each district by remotely monitoring and controlling the radio towers network in Tanzania. Hence, through the use of the developed system, the broadcasting media can easily continue increasing their coverage and installation of new radio towers since the operation cost is minimal. Future research should design its mobile application and add more parameters to be monitored and controlled which have not been addressed by this study. Therefore, the study recommends implementation of the developed system to all TBC's towers in Tanzania in order to reduce the operational cost and time consumed in the daily processes at the broadcasting towers.

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