Design of Wearable Medical Device for Triaging Disaster Casualties in Developing Countries

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***Abstract*—Disasters create mass casualties and the number of casualties usually surpasses the capability of medical resources, hence, medical teams must attach paper triage to casualties for determining the priority of treatments based on the severity of their condition. However, since the casualties' condition could change at anytime, the paper triage cannot provide the latest information of their health condition. Therefore, we have developed a wearable medical device that can continuously monitor the health condition of casualties. It is a lightweight and low-cost wearable electronic triage with sensing system that can monitor the vital sign of casualties and classify them into three levels of severe conditions, i.e., major, delayed, and minor status. The electronic triage is mainly built from a low-power 8-bit microcontroller unit, RF units, and sensors including pulse oximetry and thermocouple breath sensor. This electronic triage has been developed using affordable electronic components that are available in developing countries such as Indonesia, so that, our electronic triage can be easily manufactured and maintained locally. Furthermore, we have also developed a simple android-based mobile application for data acquisition, priority classification, data storage and data transfer to medical record server in hospitals.**

I. INTRODUCTION

A disaster can be caused by either a natural disaster or a man-made disaster and it usually creates mass casualties. When catastrophes occur, casualties need to get medical treatment immediately and the health condition of casualties needs to be recorded for further assessment. In the disaster scene, the number of casualties usually surpasses the capability of medical resources. In order to efficiently allocate medical resources, medical teams usually conduct paper triage for determining the priority of casualties treatments based on the severity of their condition. There are three phases of triage in modern health care system [1], i.e., pre-hospital triage for dispatching ambulance and pre-hospital care resources, triage on scene by first clinician attending the patient, and triage on arrival at hospital. In this research, we are interested in the pre-hospital triage and triage on scene by first responder in disaster scenes.

In an emergency situation, the medical team usually applies a simple triage and rapid treatment (START) [2] protocol to assess the casualty's medical condition and the urgency of medical attention. The START protocol sorts casualties based on 3 (three) vital signs, i.e., breath rate, pulse rate and mental status. According to the condition of these vital signs, casualties are classified into 4 (four) groups of colors indicating the priorities of casualties‘ treatment as follow:

- GREEN: a casualty with minor injuries who will not need the treatment urgently.
- YELLOW: a casualty with significant injuries but treatment can be delayed for short period of time.
- RED: a casualty with major injuries and need an immediate medical treatment.
- BLACK: a casualty is deceased

The START has a standard of procedures to treat casualties in the disaster scenes. Firstly, the medical team moves all casualties who can walk to a treatment area and tags these casualties with GREEN color. Secondly, the medical team assesses the respiration of the casualty. If the casualty‘s breath is less than 30 breaths per minute then assess the capillary refill/radial pulse, otherwise, tagged as RED. The casualty, who is not breathing, is tagged as BLACK. After assessing the respiration, the medical team assesses capillary refill/radial pulse. If the casualty refill is less than 2 seconds or the radial pulse is present, then assess the mental status. Otherwise, tagged as RED. Finally, the medical team assesses the casualty‘s mental status by giving a simple command. If the casualty can follow the command then tagged as GREEN, otherwise, tagged as RED.

Upon completion of the initial triage, casualties need to be re-triaged since the health condition of casualties can change at any time, hence, the use of a paper triage tag is inefficient because it cannot provide an updated status of casualties' health condition. In this paper, we have designed an electronic triage attached to casualties to continuous monitor their vital signs. The electronic triage is built from low-cost electronic components that are available in developing countries such as Indonesia.

II. RELATED WORK

Many researchers have proposed a health monitoring system for emergency medical care. Reference [3] has developed an embedded medical system for triage. The system uses biomedical sensors (pulse oximeter, electrocardiogram, and blood pressure cuff) to monitor the vital signs of a patient. Ref [4] discusses the implementation issues and describes the overall system architecture for Bluetooth sensor network for patient monitoring and corresponding heart activity sensors.

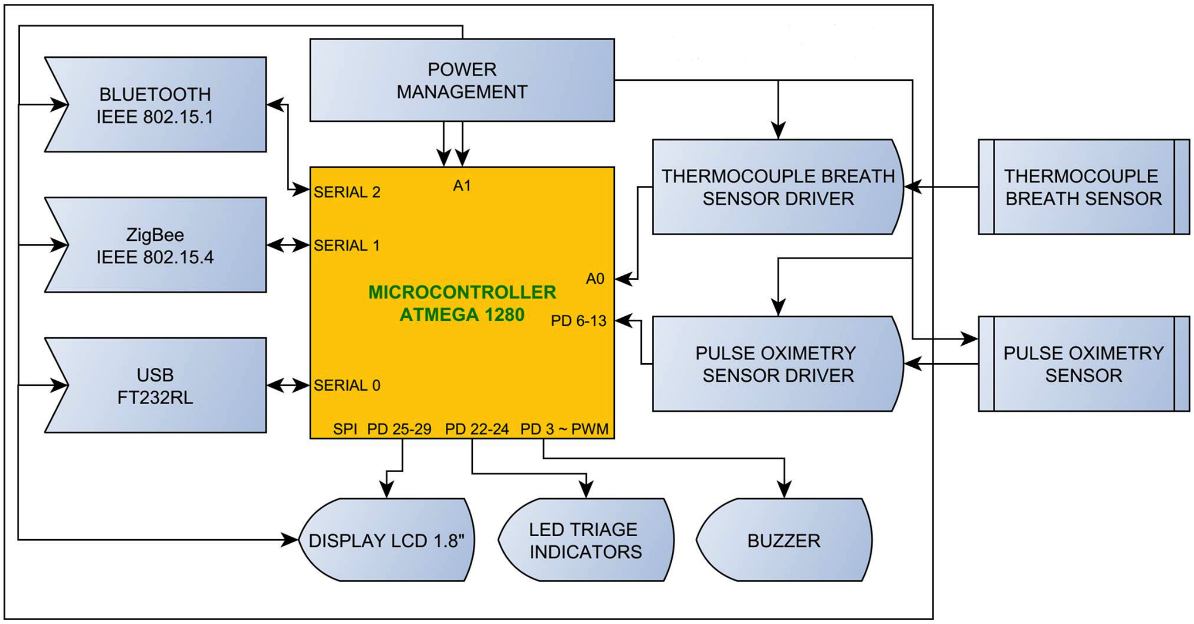

Fig. 1: **System Block Diagram**

Ref [5] proposes a new low-cost, low-power wireless sensor platform implemented using the IEEE 802.15.4 wireless standard, and describes the design of compact wearable sensors for long-term measurement of electrodermal activity, temperature, motor activity and blood volume pulse. However, all systems in [3] [4] [5] do not provide respiration sensor to measure the breath rate of the casualty, which is one of the important vital sign needed for classifying casualties' priority in START method. Reference [6] develops an electronic triage system for disaster scenes. The system provides two types of electronic triage, i.e., eTriage-full and eTriage light type. e-Triage-full type provides measurement of pulse rate, SpO2 and breath rate using nasal cannula. Meanwhile, e-Triage light provides the measurement of pulse and SpO2 only. The system uses IEEE802.15.4 wireless standard to transmit the vital signs from e-Triage tag to triage server.

Our electronic triage operates in a similar way to electronic triage such as [3] [4] [5] [6] but we have designed an electronic triage using appropriate technology for developing countries. Since most developed country medical devices are expensive and too difficult to be repaired in developing countries, we designed the electronic triage from electronic components that are available and affordable in developing countries, hence, our electronic triage can be easily manufactured and maintained locally. Details of components considered to be an appropriate technology for developing country such as Indonesia are described in section III. Furthermore, we have combined the use of electronic triage with a smartphone to offer a large functionality such as the casualty's localization, data storage, classification, visualization, and data transfer. We use an android-based smartphone that is widely used and affordable in developing countries.

III. System Design

We have designed an electronic triage that can monitor causalities vital sign, i.e., breath rate, pulse rate, and blood oxygen saturation (SpO2), as parameters for conducting START triage. Figure 1 and 2 show that our electronic triage mainly consists of biomedical sensor units (thermocouple breath sensor and finger probe pulse oximetry), ATmega1280 microcontroller, output unit (an LCD display and three LED indicators), RF unit (Bluetooth and ZigBee) and power supply. Table I shows the technical specification of the electronic triage. The electronic triage is attached to the casualty's wrist (see Figure 3), the thermocouple breath sensor is attached to the casualty's nose to monitor the breath rate, and the finger probe pulse oximetry is attached to the casualty to monitor the casualty's pulse rate and the level of SpO2. The microcontroller reads the casualty's breath rate from the thermocouple breath sensor and pulse rate/SpO2 from the finger probe pulse oximetry. The casualty's breath rate is measured in unit of respiration per minute (RPM) and the normal range of breath rate is between 15 and 30 RPM. Furthermore, the casualty's pulse rate is measured in beat per minute (BPM) and SpO2 is measured in percentage. The normal range of pulse rate and SpO2 are between 60 and 100 BPM and greater than 94%, respectively.

We have embedded an algorithm of priority classification based on vital signs from sensors in the microcontroller as shown in Algorithm 1. In this algorithm, the vital signs of casualties are classified into 3 (three) categories of severity levels, i.e., major, delayed, and minor status. Major means casualties have major injuries and need an immediate medical treatment. Delayed means casualties have significant injuries but treatment can be delayed for short period of time. Minor

Fig. 2: **Electronic Triage**

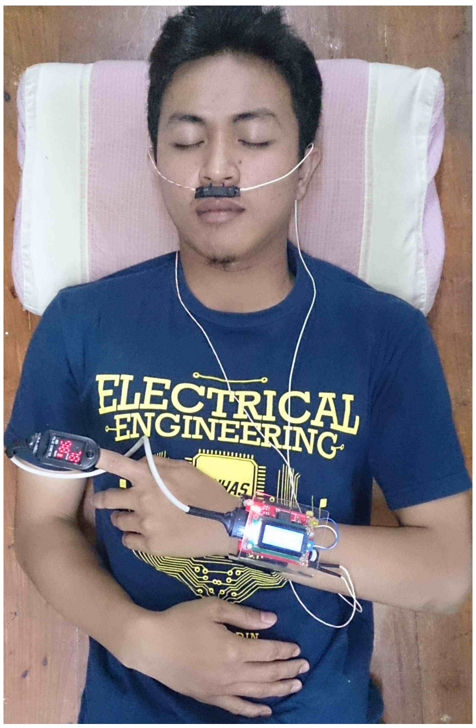

Fig. 3: **a casualty wears electronic triage**

means casualties have minor injuries who will not need the treatment urgently. These three severity levels are represented in three LED colors in the device. Red LED indicates the major status, yellow LED indicates the delayed status, and green LED indicates the minor status.

The algorithm works as follow. First, the microcontroller reads thermocouple breath sensor and evaluates the breath rate of casualties. If the breath rate is between 15 and 30 RPM, then the microcontroller reads the pulse oximetry and evaluates the pulse rate and the percentage of SpO2. If the breath rate is between 10 and 14 RPM or 31 and 35 RPM, then the microcontroller turns on the Yellow LED indicating the delayed status. Otherwise, the microcontroller turns on the Red LED indicating the major status. If the pulse status is between 60 and 100 BPM, then the microcontroller evaluates

TABLE I: Electronic Triage Specification

Microcontroller	ATMega1280
Clock Speed	16MHz
Register Width	8-bit
RAM	4KB
Flash	128KB
I/O Current Max	40mA
Power	2,146 mW
Sensors	Pulse Oximetry, Termocouple Breath Sensor
Wireless Interface	Bluetooth and ZigBee
Output Interface	3 x LEDs and 1 x LCD
Battery	1,350 mAh Li-ion
Operation time	2.3 hours
Size	8(W)x5(H)x5(D) cm
Weight	120 gram

Algorithm 1 Priority Classification based on Vital Signs from Biomedical Sensors

$p \leftarrow$ casualty's priority
if $breathrate \geq 15$rpm & $breathrate \leq 30rpm$ **then**
  $p \leftarrow Minor(Green)$
else if $breathrate \geq 10$rpm & $breathrate \leq 14rpm$ **then**
  $p \leftarrow Delayed(Yellow)$
else if $breathrate \geq 31$rpm & $breathrate \leq 35rpm$ **then**
  $p \leftarrow Delayed(Yellow)$
else if $pulserate \geq 60$bpm & $pulserate \leq 100bpm$ **then**
  $p \leftarrow Minor(Green)$
else if $pulserate \geq 50$bpm & $pulserate \leq 59bpm$ **then**
  $p \leftarrow Delayed(Yellow)$
else if $pulserate \geq 101$bpm & $pulserate \leq 110bpm$ **then**
  $p \leftarrow Delayed(Yellow)$
else if $SpO2 \geq 95\%$ **then**
  $p \leftarrow Minor(Green)$
else if $SpO2 \geq 90\%$ & $SpO2 \leq 94\%$ **then**
  $p \leftarrow Delayed(Yellow)$
else
  $p \leftarrow Major(Red)$

the percentage of SpO2. If the pulse rate is between 50 and 59 BPM or 101 and 110 BPM, then the microcontroller turns on the Yellow LED indicating the delayed status. If the percentage of SpO2 is greater than 94%, Green LED is turned on indicating that the causality is in minor status. If the SpO2 is between 90% and 94%, then the microcontroller turns on the Yellow LED indicating the delayed status. Otherwise, Red LED is turned on indicating the major status. For mental status of casualties, we input manually through a smartphone using android-based mobile application described in section VI. Therefore, our electronic triage can function as a complete START triage when it is operated with a smartphone application, otherwise, it functions as breath rate, pulse rate and SpO2 level monitoring.

IV. Biomedical Sensors

The following subsections describe the technical specification of biomedical sensors used in our electronic triage and the reason behind why we consider it as an appropriate technology for developing countries such as Indonesia.

A. *Thermocouple Breath Sensor*

We use thermocouple to measure the breath rate of casualties. The thermocouple has two conductors that can detect the change in temperature. One conductor is placed close to the nose and the other one is placed close to the mouth

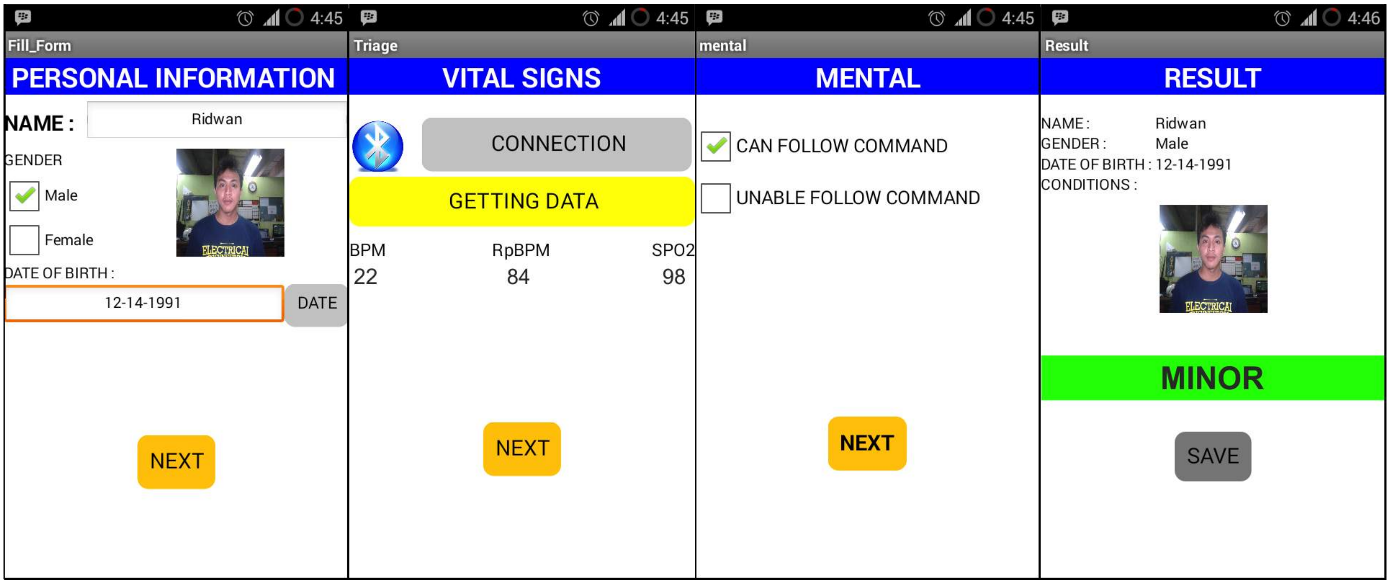

Fig. 5: **Triage Mobile Application Screenshot**

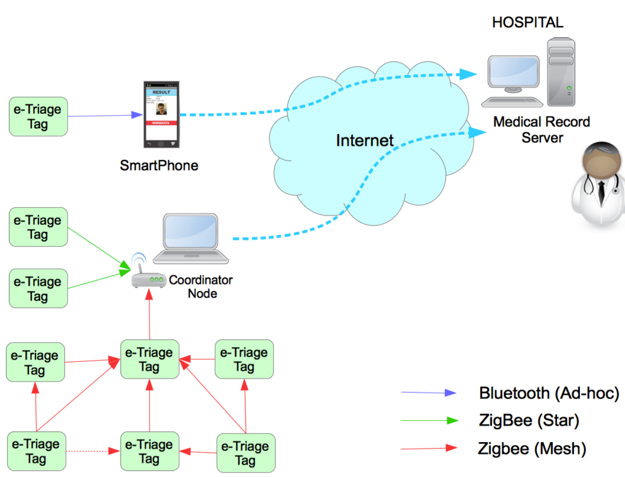

Fig. 4: **Network Architecture**

as a temperature reference. Airflow that comes out from nose contains CO2 that has a higher temperature than the reference temperature. From the temperature difference of two conductors, breathing is measured. Thermocouple breath sensor is inexpensive way to measure breath rate and it may be a fairly reliable method to detect complete airflow cessation (i.e., apneas) [9] due to lack of temperature variation between two conductors.

B. Finger Probe Pulse Oximetry

Pulse oximetry is a non-invasive device to measure the percentage of haemoglobin with oxygen (HbO), i.e., blood-oxygen saturation (SpO2), and pulse rate. It consists of two LEDs with different wavelengths, i.e., red (650 nm) and infrared (950 nm) LEDs, and a light detector to measure the difference in the light absorption of HbO and haemoglobin without oxygen (Hb) . HbO absorbs more infrared lights than red light while Hb absorbs more red lights. The pulse oximetry uses the ratio of absorbed red light and infrared light to calculate the blood-oxygen saturation. The normal percentage of oxygen saturation is greater than 94%. We use the finger probe pulse oximetry because it is inexpensive (priced as low as $10) [10] and is available in developing countries.

V. Wireless Network Architecture

We propose a wireless network architecture for triage as shown in Figure 4. The electronic triage acts as sensor node for collecting vital signs of casualties and processing vital signs data to classify the level of severity. Our electronic triage provides two communication protocols, i.e., Bluetooth and Zigbee, to meet the need of ad-hoc communication with a smartphone and mesh network for large-scale disaster scenes, respectively. The Bluetooth links the electronic triage with the smartphone for data acquisition, classification and data transfer to the medical record server in hospital. We use HC-05 Bluetooth module [7] that operates in 2.4 GHz frequency band and it can handle a data transmission rate of up to 1 Mbps with RF range up to 10 meters. On the other hand, the Zigbee provides a mesh communication mode allowing electronic triage acts as a router and re-transmit packets on behalf of any other electronic triage. This mesh communication provides multi-hop capability that is suited for large-scale disaster scenes within large buildings. We use XBee Series 2 wireless interface (ZigBee-based protocol) operating in 2.4 GHz frequency band. The XBee series 2 supports point-to-point, point-to-multipoint, and mesh communication. It is specified to handle a data transmission rate of up to 250 Kbps using 2 mW transmit

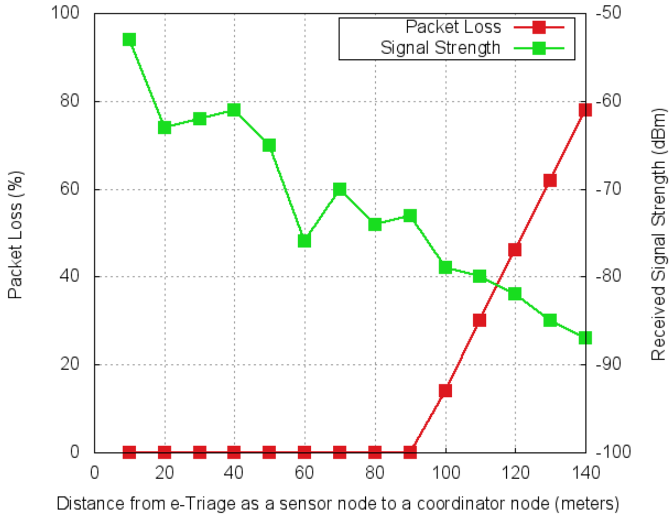

Fig. 6: **Packet Loss vs. Distance from a coordinator node to e-Triage**

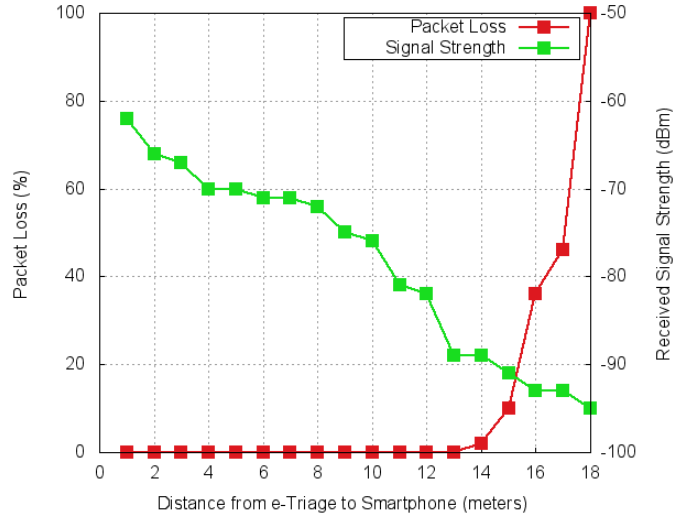

Fig. 7: **Packet Loss vs. Distance from an e-Triage to Smartphone**

power that can achieve a distance range of up to 120 meters.

VI. Android-based Mobile Application for Data Acquisition, Classification, Storage and Transfer

We have developed a simple android-based mobile application for data acquisition from electronic triage through Bluetooth interface and to classify casualties into four triage categories. This mobile application can transfer the casualty's priority data to medical record server in hospital through available wireless connection such as Wi-Fi and 3G connections.

Figure 5 shows four application user interfaces describing the steps of triaging the casualty based on START method. First, the application allows a user to input the casualty's identities including name, sex, age and a photograph of the casualty. Then, the user peers the Smartphone with electronic triage in order to grasp the vital sign of the casualty through Bluetooth interface. After obtaining the vital signs, the user assesses the mental status of the casualty by giving a simple command to the casualty, then the user inputs the mental status of the casualty by checking the checkbox manually in application user interface. Finally, the application classifies the casualty into four groups of severity levels based on START method and this information is stored in the smartphone and will be sent to the medical record server in the hospital. According to this information, the medical team conducts further assessment and treatment to casualties once they have arrived in the hospital.

VII. Performance Evaluation

A. *Wireless Communication*

We conducted experiments to evaluate the performance of our ZigBee and Bluetooth communication. The experiments aimed to determine the effective distance between the electronic triage as a sensor node and the coordinator node for Zigbee communication mode as well as between electronic triage and a smartphone for Bluetooth communication mode to deliver vital signs data with no or less packet loss.

First, we evaluated the performance of ZigBee communication. We placed an electronic triage starting from 10 to 120 meters (increased by ten meters) away from a coordinator node in the indoor environment to find the effective distance between the coordinator node and the electronic triage to deliver vital signs data. In this experiment, the electronic triage sends 32 bytes of data (SpO2 and breath rate data) every 0.5 seconds to the coordinator node in point-to-point communication mode. We use an X-CTU software [11] to measure the received signal strength and packet loss that occur in the coordinator node. The experiment results in figure 6 show that the packet loss increases as the distance between the coordinator node and the electronic triage increases. From figure 6, we can see that packet loss occurs at a distance of 100 meters. Therefore, we can conclude that the maximum effective distance between the coordinator node and the electronic triage to deliver the vital signs data is less than 90 meters.

For bluetooh communication, we placed a smartphone starting from 1 to 20 meters (increased by one meter) away from the electronic triage in the indoor environment. We use a mobile application named Bluetooth SPP Pro [12] to measure the received signal strength and packet loss. From Figure 7, we can see that packet loss occurs at a distance of 14 meters and we found that the smartphone experienced a lost connection with electronic triage at a distance of 18 meters. Therefore, we recommend to use the smartphone at a distance of less than 12 meters for pairing with the electronic triage.

B. *Operation Time*

We evaluated the operation time of the electronic triage by measuring the output currents of electronic triage and then simulate the battery discharging based on the output currents. We measured the output currents of the electronic triage on standby and operation mode. The standby mode means that

TABLE II: Measured current, voltage and power of electronic triage

CONDITION	CURRENT	VOLTAGE	POWER
Standby Mode	390mA	3.7V	1,443mW
Operation	580mA	3.7V	2,146mW

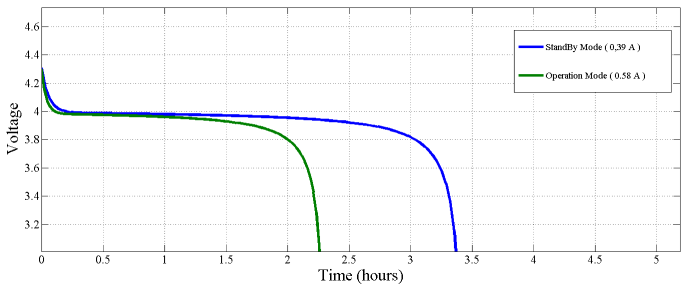

Fig. 8: **Operation time of e-Triage**

the electronic triage is switched on but it does not operate their primary function. On the other hand, the operation mode means that the electronic triage operates and performs their primary function, i.e., reading vital signs through sensors, classifying severe level of casualties, and sending vital signs to smartphone through Bluetooth interface. Our measurement results show that the output currents of the electronic triage are 390 mA and 580 mA, in the standby and the operation mode, respectively, as shown in Table II. We use a Matlab Simulink to simulate the battery discharging of the electronic triage to determine the operation time according to the output currents of the electronic triage. Our electronic triage uses a rechargeable li-on battery with 3.7 volt and 1350 mAh. The simulation results show that operation time of electronic triage are 3.4 hours and 2.3 hours for standby and operation mode, respectively, as shown in Figure 8. In order to save more power to achieve longer operation time, we can turn off the LCD Display of the electronic triage when we do not need it.

VIII. Conclusion and Future Work

In this paper, we have designed an electronic triage for disaster casualties. Our electronic triage aims to assist medical teams in triaging and closely monitoring the vital signs of casualties while waiting for hospital transport in disaster scenes. The electronic triage is lightweight and built from low cost electronic components that are available and affordable in developing countries, hence, our electronic triage can be manufactured and maintained locally. It measures the breath rate and pulse/SpO2 level of casualties using thermocouple breath sensor and pulse oximetry, respectively. We have also developed an android-based mobile application for data acquisition, classification, storage and transfer from electronic triage through Bluetooth interface. We evaluated the effective distance of communication between electronic triage and a coordinator node through Zigbee interface as well as between electronic triage and a smartphone through Bluetooth interface. The experiment results show that the effective distance for communication between electronic triage and the coordinator node through ZigBee interface is less than 90 meters. On the other hand, the effective distance for communication between electronic triage and the smartphone is less than 14 meters. Furthermore, our electronic triage could operate about 2.3 hours according to battery discharging simulation results using Simulink.

In the near future, we will evaluate the performance of our electronic triage compared to conventional paper triage tag in terms of amount of time spent to triage the casualty and develop a web portal for medical record servers in hospitals.

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