BRAILLE BLOOD PRESSURE INTERPRETER FOR HOME BLOOD PRESSURE MEASUREMENT FOR VISUALLY CHALLENGED INDIVIDUALS

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Abstract -Hypertension has slowly secured its place as the severest disease burden in the world among Global Burden of Diseases (GBD). Hypertension management programs which are employed to control the disease have identified Home Blood Pressure Measurement (HBPM) to be the most efficient blood pressure monitoring tool to effectively control hypertension. This paper presents an innovative, low cost and user friendly universal technological solution for the visually challenged community who are seeking hypertension management programs without compromising the independency and privacy with regard to sensitive medical data. In place of an exclusive and high cost blood pressure meter with Braille output, an external USB compatible tactile interpreter has been proposed and implemented. Systolic and diastolic readings isolated using a commercially available Device Monitoring Software, verifies that such a device is indeed realizable with a micro-controller based tactile feedback system especially designed for this purpose.

Keywords - Blood Pressure, Braille, Hypertension management, Visually impaired

I. INTRODUCTION

The remarkable advent of technology and drastic changes in the human life style has led to an epidemic uprise of several chronic diseases in the recent past. The most severe cause of mortality and disease burden in the world today is hypertension according to the Global Burden for Diseases (GBD). Home blood pressure measurement (HBPM) is the internationally accepted procedure for a better hypertension management which involves frequent monitoring of blood pressure from home. However, for blind and visually impaired individuals, there exist no reliable and accessible mechanism/approach self-measure, interpret and record blood pressure measurements without the sighted assistance.

According to the World Health Organization as at 2014, estimated 39 million of world population is totally blind while 285 million are visually impaired. Moreover, the Centre for Disability research stated that in the year 2010, estimated 358 000 individuals were suffering from deaf-blindness in United Kingdom alone(WHO, 2014). WHO further revealed that over 82% of the individuals who are living with visual disabilities are aged 50 or above.

Unfortunately, these statistics are estimated to be gradually increasing every year and expected to be doubled by the end of year 2020. With the dawn of the present decade, lifestyle of both sighted and blind individuals have changed dramatically. Hypertension has slowly risen to the top in the Global Burden of Diseases (GBD) as the biggest contributor for mortality and the disease burden in the world. Hypertension, which is often assumed to be a problem in the developed countries is indeed the biggest disease burden in South Asian region too (Gupta, 2016).

The major developments in the field of biomedical engineering towards the visually challenged community during the past were often in rehabilitation (Hersh & Johnson, 2008). That is, development of Electronic Travel Aids (ETAs) and external prosthesis to stimulate visual cortex artificially (Dakopoulos & Bourbakis, 2010; Velázquez, 2010). However, the development of the first exclusive medical device for the visually challenged, the Braille Thermometer (Islam & Mondol, 2014), scientific community has taken several strides in developing dedicated medical equipment for vital signal measurement for the visually challeneged community. Two proposals have been put forward; the Starp-on blood pressure monitor (Shenzhen, 2013) and the Tensio blood pressure bracelet (Marcel, et al., 2016). Due to design constraints, regulatory limitations, and lower return for cost incurred, these devices have not been commercially realized.

Navigation, distance estimation and obstacle avoidance are the three major obstacles faced by the blind individuals throughout history which lead to limitation of the physical activity level among blind individuals (Maidenbaum, et al., 2014; Velázquez, 2010) while increasing the risk of cardiovascular diseases, like hypertension (Marcel, et al., 2016; Pickering, et al., 2005). Lack of physical activity and contraction of cardiovascular diseases has been established over 30 years ago (Weil, et al., 2002). Now that hypertension has become the deadliest disease burden in the world (Gupta, 2016) there exist a need for a proper and reliable approach for visually challenged to monitor their blood pressure values since Home blood pressure monitoring (HBPM) is considered to be the internationally recommended blood pressure measurement approach for management of hypertension (Weil, et al., 2002; Sattelmair, et al., 2011)

The internal market and consumer protection committee of the European Union has passed regulations stating that products and services available in consumer markets must be accessible to disabled individuals including the blind(Europa, 2017). However, the existing home blood pressure monitors lack accessibility for visually challenged individuals. This paper thus presents a simple, reliable and an accessible approach through technological innovation that will help improve the quality of life of visually challenged individuals through participating them in hypertension management program by empowering independent measurement of blood pressure while protecting their medical privacy.

II. METHODOLOGY

The objective of the research study was to develop an accessible approach that helps a visually challenged individual to self-measure blood pressure without sighted assistance. It was identified that without developing an exclusive blood pressure meter for the visually challenged, it is far more effective and meaningful in developing a standard blood pressure monitor compatible electronic reader that could convey blood pressure readings to the visually challenged using Braille, the universal language of the blind community. This electronic Braille display was named as "Braille Blood Pressure Reader" (Figure 1) by us since it is capable of more than just displaying blood pressure. The device when connected to a standard blood pressure meter via the USB port and blood pressure data with regard to systolic and diastolic blood pressure could be tactually displayed using electronic on a braille calibrated rotary display when correct protocol is adhered to. In other words, Braille blood pressure reader device can tactually convey blood pressure readings to the visually challenged, electronically store and create a data log of blood pressure readings, end of measurement signalling and measurement error signalling.

A. Architecture Overview

In the present study, three servo motors rotating on top of a braille calibrated display of raised dots would function as the actuator mechanism of conveying systolic and diastolic blood pressure values to the blind and visually impaired. When a blood pressure measurement is read by the Arduino board, the Servomotors will turn clockwise along the braille calibrated display. The shaft will point towards a braille number. By dragging the finger along the shaft and onto the braille number, blind person would be capable of reading blood pressure values independently.

Keeping a track of blood pressure variation during a given period of time plays an integral part in any hypertension management program. In order to facilitate that, each and every blood pressure reading taken during that time period needs to be recorded with data and time. Hence, a memory log of such records is proposed and implemented in this study using SD Card module. A memory log of the measured blood pressure readings play an important role in allowing the physician to evaluate and derive conclusions about the hypertension level of the patient, activity/effect of drugs prescribed and the progress/recovery of the patient in terms of hypertension management. Arduino SD card module will implement the function of memory logging.

A suitable mechanism that allows the visually challenged user to monitor and record their blood pressure without any errors of measurement or errors of calculations/processing is essential. In the case of such errors, the user must be notified to take the blood pressure back again. Moreover,

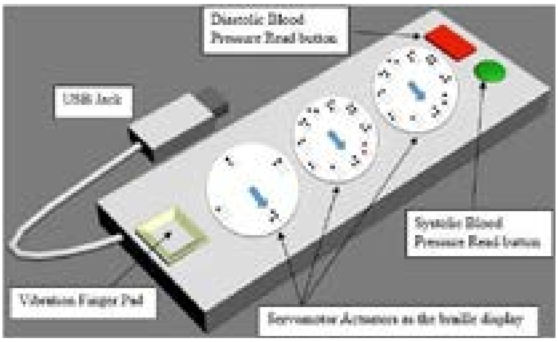


Figure. 1. The 3DsMax model of the proposed Braille blood pressure reader

user has to be notified of the end of measurement of blood pressure by the blood pressure monitor so that he can stop following measurement protocols and start reading blood pressure. These two functions of signalling is implemented using an Arduino vibration motor module.

Arduino will function as the brain of the braille blood pressure reader device. It is responsible for processing and manipulation of acquired data through USB port to derive systolic and diastolic pressure values in Braille. Hence, arithmetic and logic functions related to data acquisition are conducted by Arduino. Apart from that, Arduino is also responsible for actuation of the three servo motors, writing blood pressure data to SD card, controlling of vibration motor pad upon acquired USB data from the blood pressure meter.

Since, Arduino follows serial communication protocol it strictly follows the Master/Slave communication model where the master (host) controls the communication between the two devices whereas slave (also known as device) act upon the instructions, commands or requests of the master device. Slave cannot initiate communication with host nor can it end an existing communication. Hence, without the acknowledgement of the master, slave device cannot send to or receive data from the master. Since almost all Arduino devices are slave devices, a special

Arduino shield in the name of Arduino USB host had to be utilized in order to initiate and maintain communication with the blood pressure monitor to acquire data related to systolic and diastolic pressures.

As it was established that developing an exclusive blood pressure meter in braille exclusively for the blind/visually impaired community is an expensive and unrealizable solution. Hence, a standard blood pressure meter which has been inspected, tested and approved by a renowned global institution like Food and Drug Administration (FDA), Conformité Européene (CE) or British Hypertension Society (BHS) was selected upon the consultation of cardiologists from the Sri Jayawardenapura General Hospital, Sri Lanka. It was decided that Contec 08A blood pressure monitor which is approved by FDA and used for home blood pressure measurement by individuals with no visual complications as a standard tool for blood pressure measurement to be used for the Study.

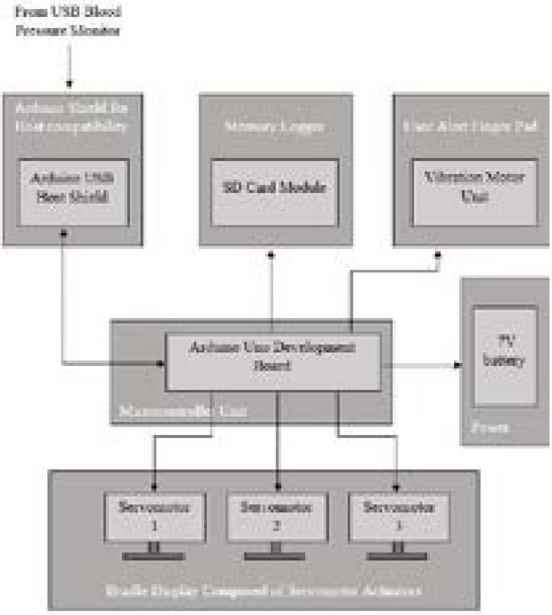


Figure2. The system architecture of the Braille Blood Pressure Reader

B. Development of prototype model

The entire study was designed in five phases. In phase 1 Literature survey and collection of data was conducted. Phase 2 was about developing the conceptual design and implementation. In phase 3 the Braille Blood Pressure Reader hardware components were developed. Phase 4 of the study primarily focused on data acquisition from the Contec 08A blood pressure meter and processing of data to derive meaningful information. The final phase of the study was developing the Braille blood pressure reader prototype by integrating all the independent components together

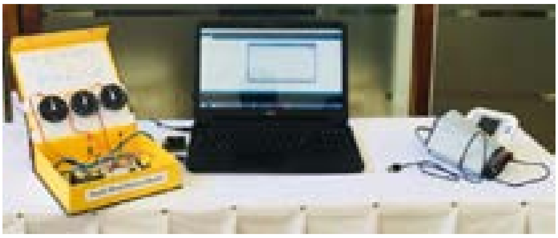


Figure3. Initial Testing Prototype Model of the Braille Blood Pressure Reader developed on a breadboard using three Servomotors

C. Data acquisition from the blood pressure monitor

First step of the data acquisition phase of prototype development was to confirm whether the blood pressure data with regard to systolic pressure and diastolic pressure could be obtained from the blood pressure monitor to the computer. Then, the obtained data was analyzed to identify the type and mechanism of data flow in and out of the device. The Contec 08A blood pressure monitor was connected to the computer via a USB port. Device Monitoring Studio 7.05 software was used to analyze the data acquired from the blood pressure meter. ELTIMA USB analyzer software was used to verify and validate the data obtained from the Device Monitoring Studio. Device Monitoring Studio was first programed to identify the USB device class of the blood pressure monitor. The USB device class determined the type and mode of communication protocol used by the blood pressure meter to exchange information between the device and the host.

Blood pressure measurements were taken from the blood pressure monitor and these readings in the blood pressure meter memory (EEPROM) were imported to the computer through Device monitoring studio software. The data transferred between the computer and the device during communication were also recorded using Device Monitoring Studio in two data visualization modes, namely; Structure View and Raw Data View. Structure view mode allowed visualizing acquired data identifying the target data packets and filter out required data packets based on their type and/or other distinct feature. Raw data mode allowed visualization of ingoing and outgoing data between the computer and the blood pressure monitor in two separate part-windows.

In order to develop a communication platform which allowed the Arduino to talk to the blood pressure meter and effectively transfer/acquire the systolic and diastolic blood pressure data, communication channels had to be established first between the blood pressure meter

EEPROM and the Arduino microcontroller. In order to facilitate this, the communication between the computer and the blood pressure meter had to be replicated between the blood pressure meter and the Arduino through the Arduino Host Shield. Hence, identification of other data packets like, handshake packets, control transfer packets and device descriptor request packets, device descriptor transfer packets had to be clearly identified. Device monitoring studio platform could be programed to filter out the required data packets in concern from other data packets when developing the communication platform.

D. Processing of acquired data to derive meaningful information

After obtaining blood pressure data via the Device Monitoring Studio 7.05 in Structural view and Raw Data view modes, observations were made on the type of data, length of data packets that was given out by the blood pressure monitor. Each blood pressure record obtained as a 16-bit hexadecimal data stream was conveniently filtered out using the structure view. The aim of this phase of the study was to distinguish the data packets containing the systolic and diastolic blood pressure values from the rest of the data packets. This was followed by extraction of those data packets from the obtained data stream to be displayed via the braille tactile display.

In order to isolate the required data string containing systolic and diastolic blood pressure values, first, incoming data packets were filtered out from the outgoing data packets using the Device Monitoring Studio 7.05. Thereafter, payload data packets were filtered out from the header packets, metadata packets, transfer request packets, descriptor request packets and other types of data packets using the Structure view mode. Using Packet View mode, only the data packets related to bulk/interrupt transfer were isolated from the rest of the data packets. This was done because payload packets are always a part of bulk/interrupt transfers. After filtering out the bulk/interrupt transfer packets, Structure view mode was used to identifying all the payload data packets from the remaining bulk/interrupt data packets. Payload data contained actual data communicated between the device and computer while the rest of the data packets were used to establish the connection between the device and the host computer.

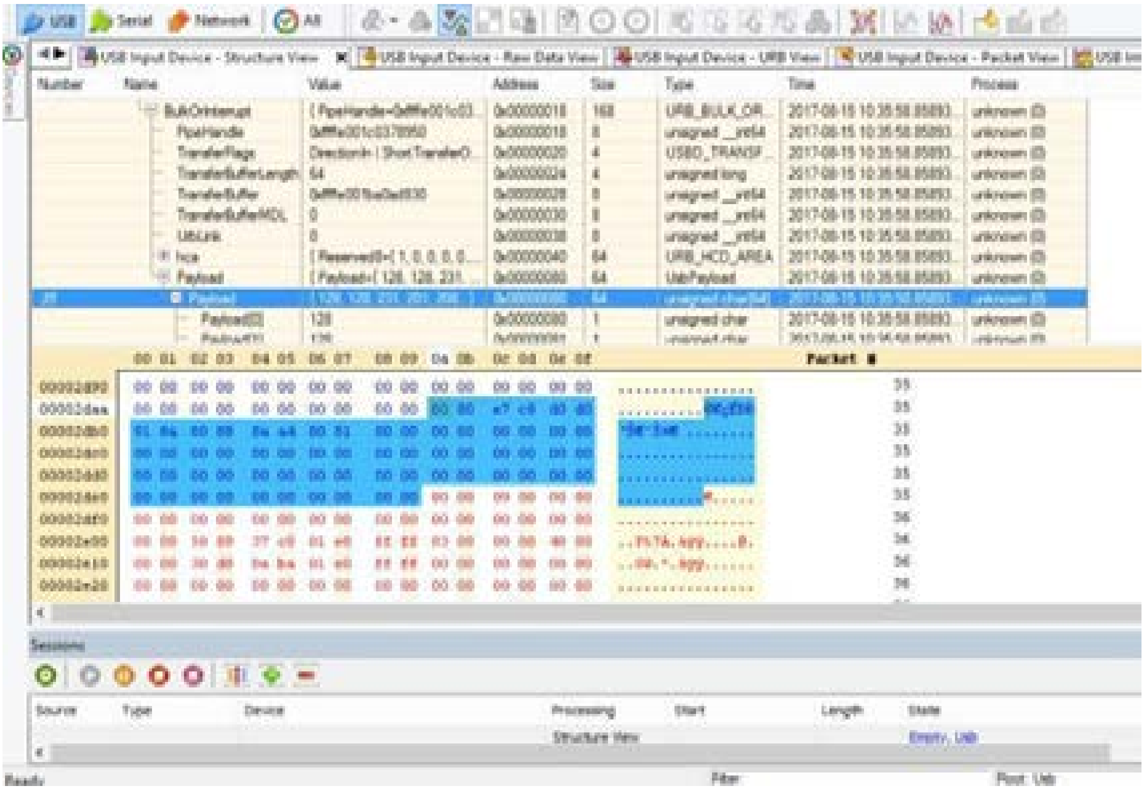


Figure 4. Part of Structural View mode in Device monitoring studio that was used to acquire raw data packets employed in communicating with the computer

F. Braille Actuator System

A rotary braille display was developed by using SG90 servo motors (Figure 5). Three servo motors was used to display units value, tens value and hundreds value respectively of diastolic and systolic blood pressure in mmHg. Servo motor displaying units values and tens values were programed to rotate from 0 to 9 during a full rotation. Hence, the angle between two integers was 36°. Remaining servo motor which was responsible of displaying hundred's value was modified to rotate only from 0 to 3 during a full rotation. The angle between two integers in hundred's scale was 90°. As a result, the maximum value which could be displayed using the three servo motor braille display assembly was 399 mmHg and the lowest value was 000 mmHg.

III. RESULTS AND DISCUSSION

A. USB Device Class

Device Monitoring Studio 7.05 device class was identified to be USB Human Interface Device (HID). USB HID class contains many predefined functions that allows them to be used across many platforms with no or very limited number of restrictions in communication protocol (Axelson, 2015). The cross-platform adaptability and minimum number of restrictions play a crucial role in data acquisition and developing communication protocol between the Arduino and the blood pressure meter.

B. *Type and amount of the data packets that were transferred during data acquisition*

When data acquisition was conducted with only one blood pressure reading was available in blood pressure meter memory, it was observed that 44 data packets were interchanged between the blood pressure meter and the computer. When the data transfer was conducted with two blood pressure readings in the blood pressure meter memory, total of 50 data packets were observed to be interchanged. During one cycle of data interchange, twenty data packets were observed to be transmitted per second between blood pressure meter and the computer within three milliseconds.

We observed that a total of 1618 bytes were transmitted from the device to the host (computer) during one transmission cycle of which 850 bytes were read from the device and a constant number of 768 bytes were written to the device It was also observed that a total of 3 milliseconds were required to prepare the host and the device to initiate communication between the two. As a result. It was clear that data are transferred at more than reasonable speed to convey the blood pressure effectively. As the waiting time to receive the Braille tactile response is below one second, the effectiveness of the device in delivering the feedback was considered to be acceptable.

C. Identification of Payload packets

Out of the data packets that were interchanged during data acquisition payload packets were identified by programing the acquired data in Structure view mode of the Device monitoring studio (Table). It was observed that payload packet data in packets 11, 19, 27, 31, 33, 42, 44 remained constant for each and every blood pressure reading taken during any time of the day. Variations were observed in the payload packet 35 in each of the blood pressure transfer suggesting that packet 35 could carry the data about systolic and diastolic blood pressure values for the particular measurement.

D. Blood Pressure data processing

When the blood pressure meter is concerned the data that is stored in the blood pressure meter memory for each and every measurement were clearly identified. They were; Systolic Blood Pressure (SBP) in mmHg, Diastolic Blood Pressure (DBP) in mmHg, Pulse rate, Mean Atrial Pressure (MAP) in mmHg, date of measurement and time of measurement. We concluded from the acquired data that the final data string of data were in the following order.

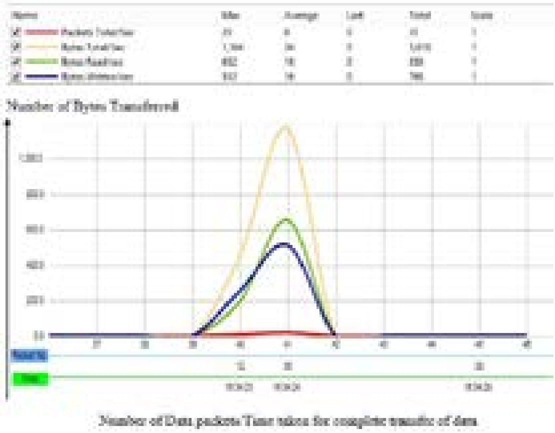
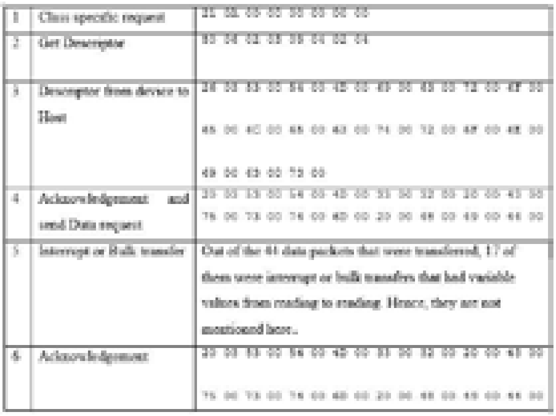


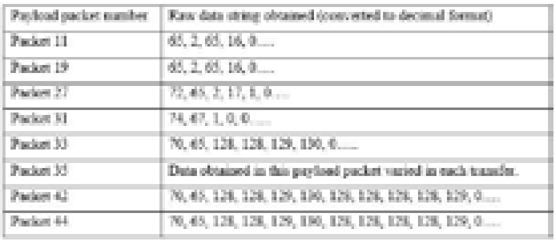
Figure 5. Number of Bytes transferred vs Packet number/Time graph obtained from the Device Monitoring Studio

Table1.Type of data in a typical data transfer between the computer and the blood pressure monitor



1	Class specific request	21 0A 00 00 00 00 00 00
2	Get Descriptor	[illegible]
3	Descriptor from device to Host	[illegible]
4	Acknowledgement and send Data request	[illegible]
5	Interrupt or Bulk transfer	Out of the 41 data packets that were transferred, 17 of them were interrupt or bulk transfers that had variable values from reading to reading. Hence, they are not mentioned here..
6	Acknowledgement	[illegible]

Table 2. All the payload packets transferred during data transmission between device monitoring studio and blood pressure monitor



Payload packet number	Raw data string obtained (converted to decimal format)
Packet 11	65, 2, 65, 16, 0....
Packet 19	65, 2, 65, 16, 0....
Packet 27	72, 45, 2, 17, 1, 0 ....
Packet 31	74, 47, 1, 0, 0.....
Packet 33	70, 45, 128, 128, 129, 130, 0.....
Packet 35	Data obtained in this payload packet varied in each transfer.
Packet 42	70, 45, 128, 128, 129, 130, 128, 128, 128, 128, 129, 0....
Packet 44	70, 45, 128, 128, 129, 180, 128, 128, 128, 128, 129, 0....

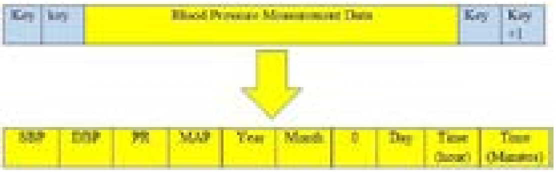


Figure 6. Order of blood pressure measurements in the packet 35 of the blood pressure data string

IV. CONCLUSION

The system has already been designed and implemented to a satisfactory level, yet few more tests, verifications and implementations are yet to be conducted. As of now, the Braille blood pressure reader is optimally functional using Arduino IDE, Serial monitor in a computer. All the peripheral devices including servomotor actuator system, SD card module, and vibration motor module have been tested and verified for their functionality separately. It should be noted that the results of the braille blood pressure reader system is encouraging. The results speaks for the efficiency and uniqueness of the implemented system in its ability to interpret the blood pressure readings to the visually challenged. Apart from showing systolic and diastolic blood pressure values, the system is also capable of storing the blood pressure readings and alert the user of end of measurement and error if encountered. This system does not require any special skills or training before use. It is portable and simple in design. Use of a microcontroller control and logic system has ensured that the device is inexpensive and affordable to any user. Using a raspberry pi microcomputer, as a control and logic device would have made implementation much easier yet the cost would be too high.

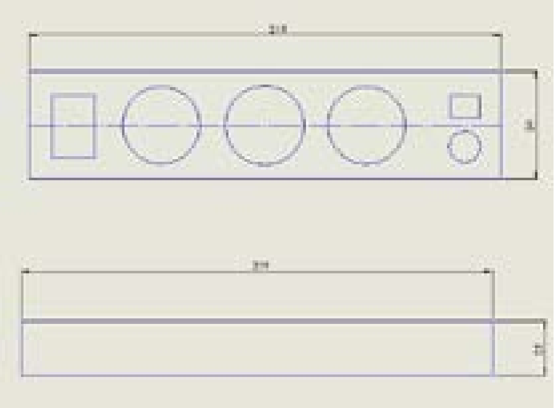


Figure 7. Physical dimensions of the blood pressure reader device in the initial prototype

V. FUTURE WORK

Currently, the blood pressure reader could be fully controlled using computer and Arduino IDE and serial monitor platform. However, development of an Arduino program to establish, completely control the blood pressure meter and finally display the reading is still under development stage and is yet to be realized. The problem was the unavailability of proper Arduino libraries for the Arduino USB Host shield. Furtherly, clinical trials were not carried out using blind test subjects to test whether they can easily interpret blood pressure values using the Braille blood pressure reader. Hence, by conducting clinical trials with blind test subjects could emphasize the actual effectiveness of the device in interpreting blood pressure data in everyday life.The Braille blood pressure reader has been developed only for the Contec 08A blood pressure meter. It has not been tested nor implemented with other types of USB compatible home blood pressure monitors. Hence, its applicability across different blood pressure meter platforms is yet to be identified.

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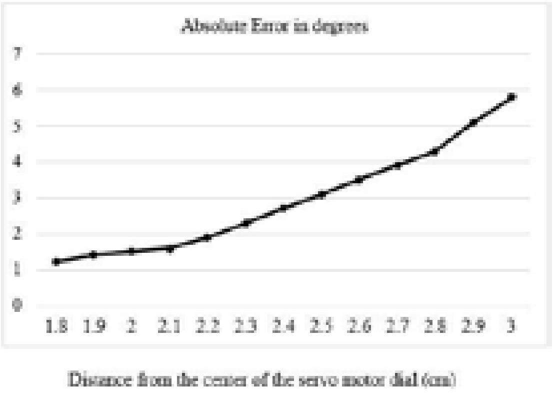

Figure 8. The graph of absolute error in degrees vs the Distance from centre of the servomotor dial

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