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AN INTELLIGENT WEARABLE SYSTEM FOR VITAL SIGNS MONITORING AND REPORTING

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Abstract: **Early detection and diagnosis of basic health conditions could lead to successful treatment and reduced fatality rate in developing countries, as it is possible to extract human bio-signals and use it to better understand the bodily health status and reaction to external factors. This proposed Vital Intelligent System (VIS) design have in-built sensors which a user wears as a wrist band without it interfering with his/her daily life activities to monitor his/her major vital signs (BT, BP, HR), which then connects to its android app for fuzzy logic which identifies the users vital signs and based on its fuzzy reasoning engine makes analyses to deduce proper health status and recommendation(s) to the user, a feature of which the existing systems have limitations to achieve. Using the Dynamic System Design Methodology (DSDM), a more technically robust, cost-effective and portable real time device was designed and its app suitable for any android device. This device will have an IoT interface (BLE) to connect to android phones; a GSM interface (SIM800L) relying on AT command framework to access defined medical personnel on the network in cases of emergencies; optical health LEDs to alert the user; thus, enabling consistent real time self-assessment of an individual's health condition. This work is a quest to provide a generalized smart three-in-one vital sign system to improve the real time monitoring and reporting of user's health status through optimizing the offline and online cross-interfaces of standalone sensors in line with the country network and health delivery system.**

Keywords: **Blood Pressure (BP), Body Temperature (BT), Heart Rate (HR), Wearable Health, Device (WHD), Vital Intelligent System (VIS).**

1. INTRODUCTION

Vital signs *are* the different crucial physiological/medical signs that can be measured; to indicate the status of the body's vital functions. it is possible to extract human bio-signals and use it to better understand the bodily health status and reaction to external factors (Dias, Cunha. 2019). Early detection and diagnosis of basic health conditions could lead to successful treatment and reduced fatality rate in developing countries, as many illnesses and diseases can be diagnosed early and hence treated before it becomes fatal. For example, heart attack, which is believed to be instantaneous gives signs, symptoms, to the sufferer but because the signs are not identified and responded to, the illness gets to the stage where it simply knocks down the sufferer. Hence observing the human vital signs are necessary. There are five traditional vital signs that have a major importance to be measured: heart rate, blood pressure, respiratory rate, blood oxygen saturation and body temperature. These five signals are generally considered essential to evaluate human health and a continuous monitoring should be made, especially in patients (Dias & Cunha, 2019).

Mainetti, Patrono & Vilei (2021) identified many wearable medical monitoring systems for vital sign, but a good number of the identified systems measured mostly one vital sign. Thus, this research dwells on developing a device to monitor three of the major five vital signs (of which others are relative to). The basic three vital sign which manifests in various health issues include Blood Pressure, Heart Rate and Body Temperature. Fuzzy Logic (FL) is an AI technique which finds application in diverse areas of endeavor. It is the use and development of computer systems that can learn just like humans without relying on explicit instructions in their programs. The use of intelligent systems (IS) techniques like FL, in patient monitoring and for helping in medical diagnosis has been established as an expanded area of research using its features and capabilities to turn data into useful information (Leite et al., 2021). In this research, input data from multiple sensors are analyzed with the intension of using them to predict the health status of the user. These sensor data have different ranges hence classification algorithms are best used. Each sensor data is classified, and the generated classes are then used together to predict the health condition of the patient giving the desired outcome, fuzzy logic method is most suitable to be used (Priya and Keerthy, 2021).

This study therefore tends to design a cost effective three-in-one third generation wrist wearable system that will accurately, comfortably and consistently measure users vital signs, passes it through an IoT interface (using Bluetooth Low Energy) to reach the intelligent app (using fuzzy logic algorithm) on the users smartphone to perform analyses and optimization in a bid to aid in the decision-making process of identifying and predicting the current health situation of the user, thus proffering recommendations which might occur based on the given parameters.

PROBLEM STATEMENT

Based on the review of literatures (Seneviratne et al., 2018; Chan et al., 2018; Perez et al., 2019) and the pilot analysis carried out in this work, the existing standalone single vital sign measurement apparatus, though 80% accurate, is 60% deficient, in the efficient and consistent real-time monitoring of users vital signs (example the irregular rhythm notification features in Apple watch, which won U.S. Food and Drug Administration (FDA) approval with along list of warnings and precautions in 2018 (FDA, 2018)), therefore showing a research gap to be bridged in this work, by hybridizing and optimizing the impact of these standalone apparatus to develop a hybrid (three-in-one) mobile intelligent vital sign monitoring device.

From review (Ozsahin et al., 2020) it can also be understood that the procedure for real-time monitoring of patients in medicine encompasses various uncertainties and imprecisions, thus this integrated wearable smart system for health vital sign monitoring has been proposed to address most of these challenges and deficiencies such as achieving a comfortable, cost effective, real-time, emergency alert section and an intelligent android app (deploying FL) for vital analyses and health tip recommendations depending on user's health status.

OBJECTIVES

The primary objective is to develop an Intelligent Wearable Device for Vital Signs Monitoring and Reporting. The specific objectives are to:

i. to determine the true position of wearable vital sign detectors in the open market.

ii. design and simulate the wearable device model.

iii. design the prototype wearable device.

iv. develop the fuzzy based android App.

v. integrate the App with the prototype device.

vi. test and evaluate the system.

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2. SUMMARY OF LITERATURE REVIEW

This work reviewed the conceptual, theoretical, and empirical frameworks for achieving the system development and analysis. Table 2.3 presents the summary of the reviewed existing work and their inherent difference from the proposed system.

Table 2.3: Summary of Related Existing Work Reviewed (source: Author)

S/N	Author/Year	Apparatus Developed	Technique Involved
1	Nair et al. (2019)	Developed a Vital Sign Monitor to measure ECG, HR, RR.	Big Apparatus, Sends Traffic to PCs, Uses BR/EDR
2	Ali et al. (2020)	Designed and implemented a smart e-Health system. (that is small and wearable-monitoring HR, BM)	Designed a wearable WHD, No Expert System, Uses http as IoT protocol.
3	Lousado et al. (2020)	Developed a device for near real-time monitoring and follow up of elderly and their health condition. (BP, BM)	Uses LoRa as IoT technique.
4	Mamdiwar et al. (2021)	Worked on essential to measure the usability and security of the elements of Biometrics	Proposed the Multiple Criteria decision (MCDM) Model for Decision Making, no application was developed
5	Shubham et al. (2018)	Developed an Automated System to measure Vital Signs (BP, HR, BT)	Implemented on Raspberry Pi, Big Device, Emergency Alert Sections
6	Goncalo et al. (2020); Koutras et al. (2020)	Described the application of Fuzzy Logic for monitoring diagnosis in the ICU	Uses Fuzzy Logic to make Medical Diagnosis, no data transmission using IoT as info are displayed using Multiparameter Screens
7	Arvind (2019)	Designed a Smart Watch for monitoring BM, HR, Humidity.	That cannot read BP and BT. No ML for data analyses
8	Lazazzera et al. (2019)	Developed a wrist band for BP estimation	Can read only BP, no data analyses
9	Wang et al. (2020)	Developed wearable piezo electric based system for measuring BP	Can read only BP. No IoT technique for transmission and no analyses of data.
10	Poor (2022)	Developed a thumb-like prototype Bio-disc for BP Monitor	Measures only BP, and no ML for data analyses. No alert/emergency section.
11	Dahad (2023)	Developed a standalone Minshi key-fob for BP, HR and BT. To be worn around the neck or attached to a keyring to be worn.	No real-time measurement and No ML app for data analyses. No alert/emergency section.

Abbreviations: BM-Body Movement, HR- Heart Rate, BT- Body Temperature, BP- Blood Pressure, WHD -Wearable Health Device, ECG – Electrocardiography

Samples of Feedback Record from different Smart Watch Vital Sign Monitors

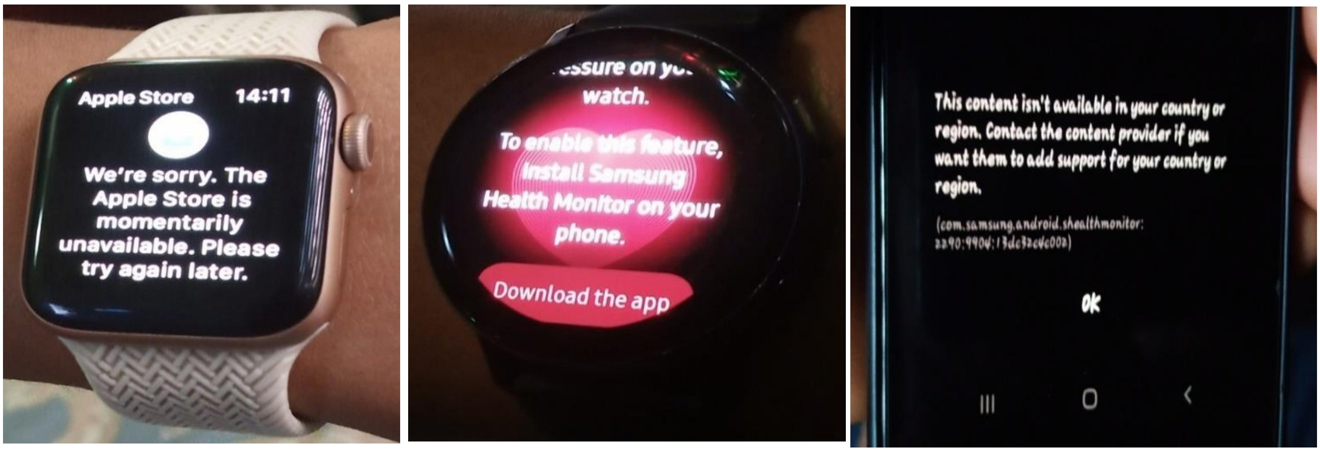

Figure 1.1: Samples of some feedback records from Apple S6 and Samsung Galaxy2 vital monitor.

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RESEARCH GAP

The empirical review of literature in this work showed the following research needs to explore and which the proposed intelligent system model seems to fix:

1. The absence of an integrated three-in-one vital sign monitoring wearable device that is:

i) capable of real-time measurement of BP, HR, and BT

ii) cost effective and comfortable.

iii) with an emergency alert section both to the user and his clinician

2. The absence of an intelligent App (using Fuzzy Logic) for the wearable health devices vital signs data analyses for medical recommendations.

CLASSIC MODULAR DESIGN METHOD

Here the individual hardware functionality to be designed is represented as a module. Electronic components are then used to satisfy the requirements of the module. The modules of this hardware are temperature sensing module – used to measure the body temperature; pressure sensing module – used to measure the blood pressure; ADC module – used to provide increased resolution for the voltage being measured; processing module – used to process the voltage gotten from the measurement and convert the voltage to the physical parameter value (data), package the data for display and interconnectivity; display module – used to display information; optical indicator module – used to give optical indication of the health status of the patient; GSM module – used to connect to the GSM network in other to send SMS etc; Bluetooth module – used to connect the wearable device to a smart phone; and buttons module – used to provide user input to the wearable device. All the components making up the embedded wearable device are put together to achieve different functionalities of the modules required for the system to become effective. These components are depicted in the system block diagram in the figure 1.2.

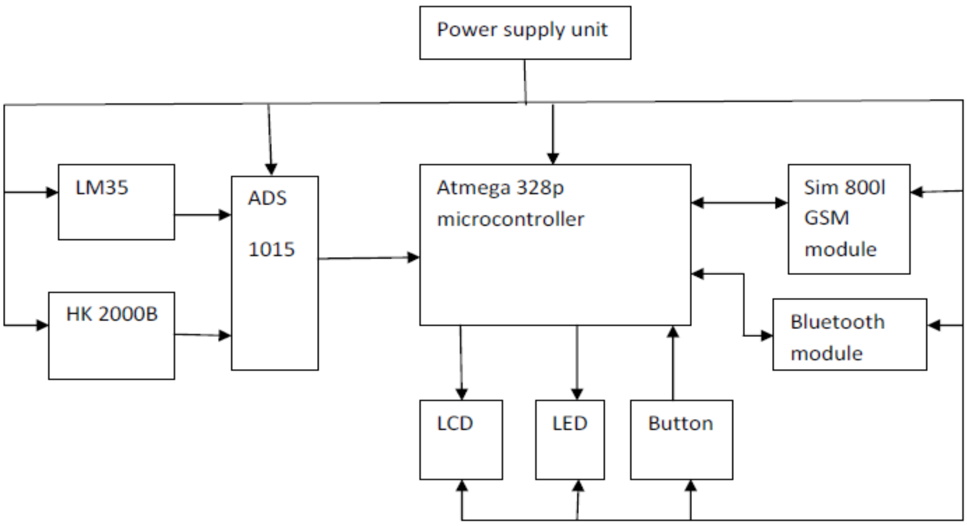

Figure 1.2: The High-Level System Block Diagram

The VIS Architecture

First a wearable device is developed which can measure the biometric parameters such as blood pressure, heart rate and body temperature. These sensors and measurements are managed by a microcontroller. The microcontroller ensures power management of the device and optimizations during measurement. It equally packages the measured data in a secure format and interfaces with a Bluetooth Low Energy, BLE, based IoT interface. (Mamdiwar et al. 2021) notes that for BLE based IoT interface data security can be enhanced and it consumes very little power. This wearable device will be worn on the wrist. Figure 3.31a below shows the Wearable Device that can measure Vital Signs with BLE IoT interface.

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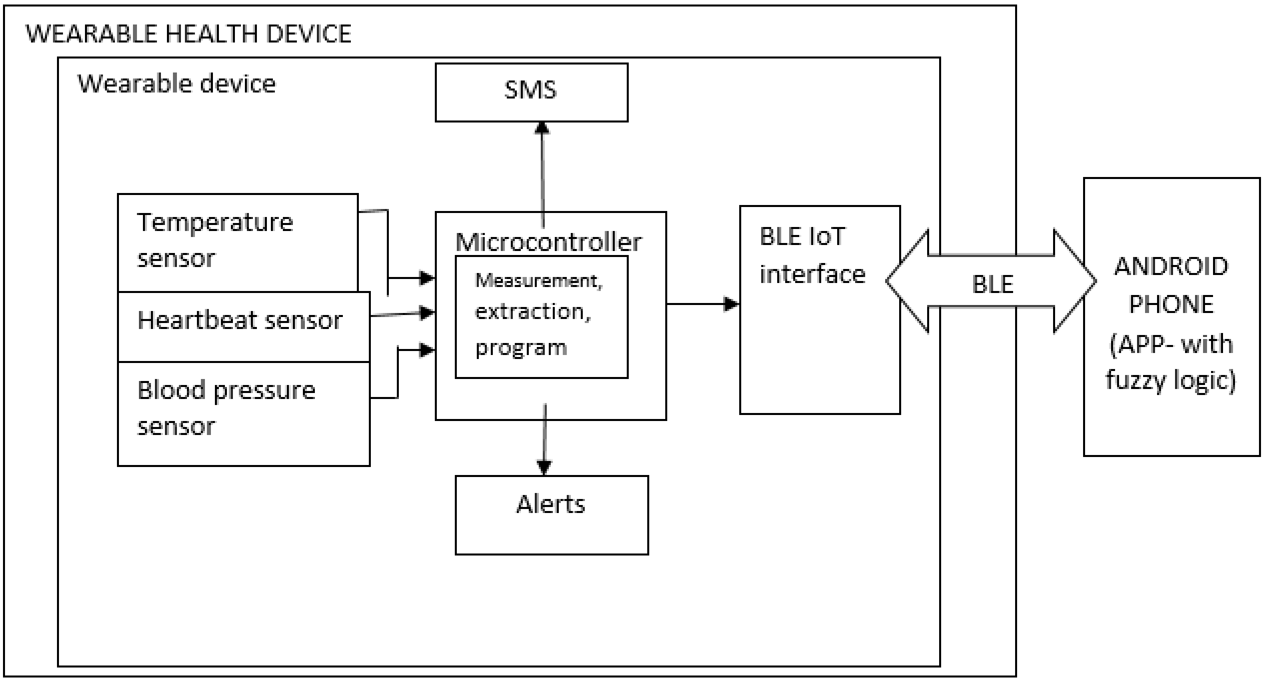

Figure 1.3: The Proposed system Architecture (source: Author)

DESIGN OF VIS ANDROID APP

The VIS Android app shall be written with the java programming language. The app shall use fuzzy logic concepts to implement vital sign analyses for health status information. The VIS android app receives data from the wearable device through a wireless network, the data passes through a fuzzy logic model, in order to predict the health condition of the patient from the data of the systolic and diastolic blood pressure, body temperature and heart rate. The fuzzy logic method was chosen in other to give explicit health condition based on the result of a combination of the input variables.

FUZZY LOGIC DESIGN PROCESS

The input parameters into the fuzzy logic controller are the temperature, the blood pressure (systolic and diastolic pressure) and the heart rate. These provide the crisp input values to be fuzzified consequent upon specifications of their membership functions. After being processed by the rule base and inference sub system, the output/defuzzification gives the health status of the patient which can be optimal health, good health, see doctor, and emergency. The structure of the fuzzy process is shown in figure 1.5.

DESIGN OF THE INPUT MEMBERSHIP FUNCTIONS

In this system, four (4) linguistic variables are used for the universe of discuss namely:

a) Systolic-pressure

b) Diastolic-pressure

c) Heart-rate

d) Temperature

Here, the Triangular Membership Function which is the most widely accepted and used membership function (MF) in fuzzy controller design, shall be used for the Fuzzification.

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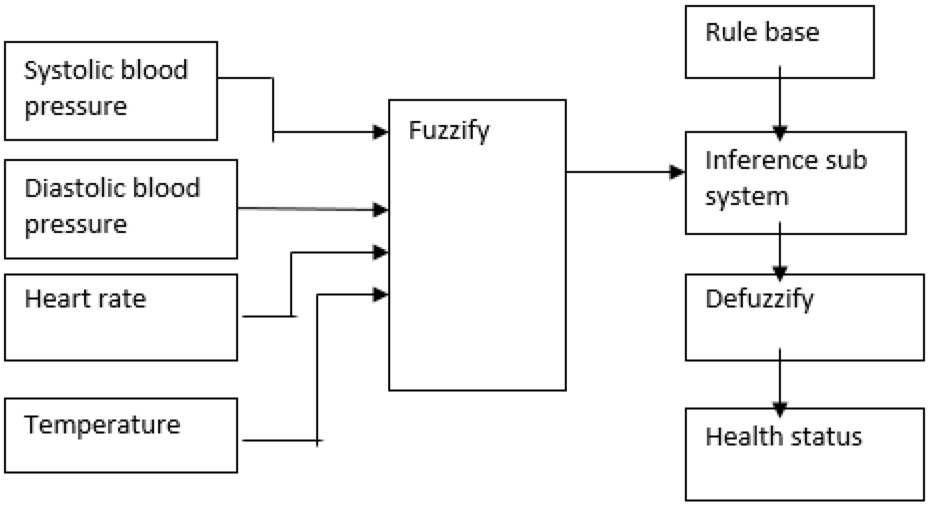

Figure 1.5: The Fuzzy Logic Process of the proposed system (source: Author)

A) **For the Systolic-Pressure Membership Functions**, the values considered range from 0mmHg to above 180mmHg. This range is divided into six (6) linguistic classifications as shown in the table 1.1 below.

Table 1.1: Systolic-Pressure Linguistic Classification (source: Author)

S/no	Systolic-pressure	Linguistic classification	Linguistic acronym
1	0 to 70	S-Low blood pressure	SLBP
2	69 to 120	S-Normal blood pressure	SNBP
3	119 to 130	S-Elevated blood pressure	SEBP
4	130 to 140	S-Hypertension stage1	SHyper1
5	140 to 180	S-Hypertension stage2	SHyper2
6	180 and above	S-crisis	SCrisis

The classification of the systolic pressure into the different Linguistic Classification and MF is provided by several expert opinions comprising the American College of Cardiology, Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure and the American Heart Association as shown in the figures 1.6.

Learn what is considered normal, as recommended by the American Heart Association.

BLOOD PRESSURE CATEGORY	SYSTOLIC mm Hg (upper number)	and/or	DIASTOLIC mm Hg (lower number)
NORMAL	LESS THAN 120	and	LESS THAN 80
ELEVATED	120 – 129	and	LESS THAN 80
HIGH BLOOD PRESSURE (HYPERTENSION) STAGE 1	130 – 139	or	80 – 89
HIGH BLOOD PRESSURE (HYPERTENSION) STAGE 2	140 OR HIGHER	or	90 OR HIGHER
HYPERTENSIVE CRISIS (consult your doctor immediately)	HIGHER THAN 180	and/or	HIGHER THAN 120

Figure 1.6: Medical Expert Classification by the American Heart Foundation for Systolic and Diastolic Blood Pressure Category (source: Harvard Health Publication, 2021)

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Using the triangular membership function, fuzzylite software was used to plot a chart of the systolic-pressure membership function as shown below.

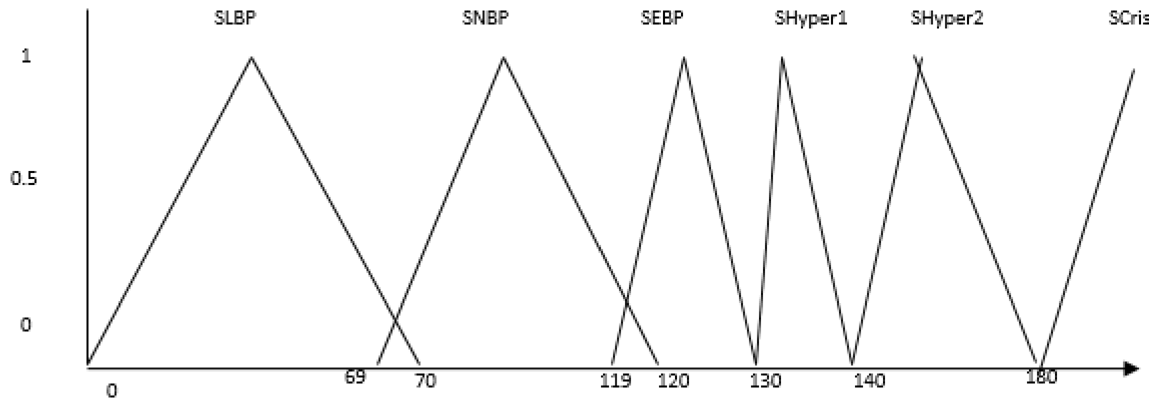

Figure 1.7: Systolic Pressure Membership Functions (source: Author)

Assuming a systolic pressure value of 120, the fuzzification of this crisp value into the fuzzy set using the triangular MF is shown below:

µSystolic-pressure (120) SNBP = $\{\frac{MFmax-Crisp}{MFmax-MFcenter}$

0

= (120 – 120) / (120 – 94)

= 0

µSystolic-pressure (120) SEBP = $\frac{Crisp-MFmin}{MFcenter-MFmin}$

0

= (120 – 119) / (125 -119)

= 1/6 = 0.1667

Hence, µSystolic-pressure (120) = {0,0.1667}

B) **For Diastolic Pressure Membership Functions**: the values considered range from 0mmHg to above 120mmHg. This range is divided into five (5) linguistic classification as shown in the table 1.2 below.

Table 1.2: Diastolic-pressure linguistic classification (source: Author)

S/no	Diastolic-Pressure	Linguistic classification	Linguistic acronym
1	0 to 60	D-Low blood pressure	DLBP
2	59 to 80	D-Normal blood pressure	DNBP
3	79 to 91	D-hypertension stage1	DHyper1
4	90 to 120	D-Hypertension stage2	DHyper2
5	120 and above	D-crisis	DCrisis

Figure 1.8 is equally applied for expert opinion for the diastolic pressure linguistic classifications and MF classification. Using the triangular membership function, fuzzylite software was used to plot a chart of the Diastolic-pressure membership function:

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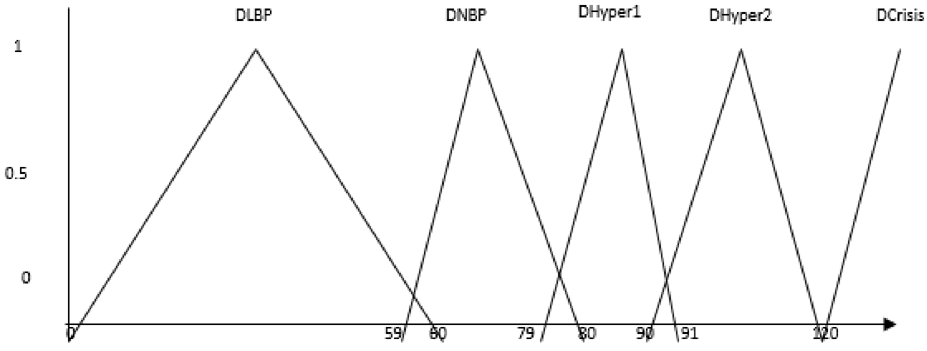

Figure 1.8: Diastolic-Blood Pressure Membership Functions (source: Author)

Assuming a diastolic pressure value of 79, the fuzzification of this crisp value into the fuzzy set using the triangular MF is shown below:

Using the triangle membership function as depicted above,

µDiastolic-pressure (79) DNBP = $\{\frac{MFmax-Crisp}{MFmax-MFcenter}$

0

= (80 – 79) / (80 – 69)

= 1/11 = 0.09

µDiastolic-pressure (79) DHyper1 = $\frac{Crisp-MFmin}{MFcenter-MFmin}$

0

= (79 – 79) / (85 - 79)

= 0

Hence, µDiastolic-pressure (79) = {0.09, 0}

C) **For the Heart-Rate Membership Functions**: the values considered range from 0bpm to above 100bpm. This range is divided into three (3) linguistic classifications as shown in the table 1.3 below.

Table 1.3: Heart-Rate Linguistic Classification (source: Author)

S/no	Heart-rate	Linguistic classification	Linguistic acronym
1	0 to 60	Low heart rate	LHR
2	60 to 100	Normal heart rate	NHR
3	100 and above	High heart rate	HHR

Using the triangular membership function, fuzzylite software was used to plot a chart of the Heart-rate membership function as shown below.

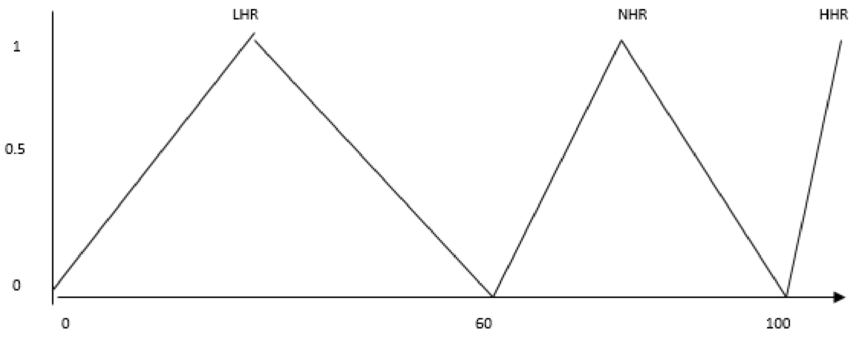

Figure 1.9: Heart-Rate Membership Functions (source: Author)

Assuming a Heart rate value of 63, the fuzzification of this crisp value into the fuzzy set using the triangular MF is shown below:

µHeart-rate (63) NHR = $\frac{Crisp - MFmin}{MFcenter - MFmin}$

0

= (63 – 60) / (78 - 60)

= 3/18 = 0.167

Hence, µHeart-rate (63) NHR = {0.167}

D) **For the Temperature Membership Functions**, the values considered range from 0^{o}C to above 41^{o}C. This range is divided into five (5) linguistic classifications as shown in the table 1.4 below:

Table 1.4: Temperature Linguistic Classification (source: Author)

S/no	Temperature	Linguistic classification	Linguistic acronym
1	0 to 32	Cold	TCD
2	30 to 36	Cool	TCL
3	36 to 38	Normal	TN
4	38 to 41	Light fever	TLF
5	40 and above	High fever	THF

Using the triangular membership function, fuzzylite software was used to plot a chart of the temperature membership function as shown below:

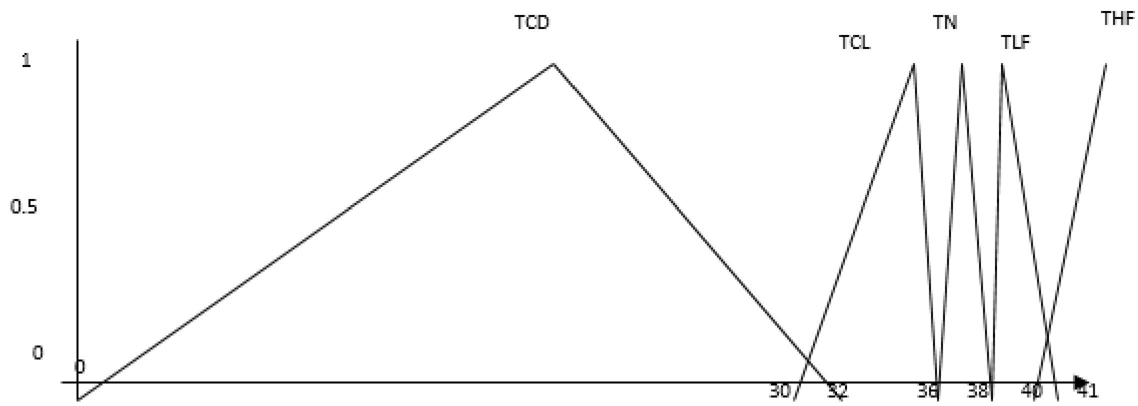

Figure 1.10: Temperature Membership Functions (source: Author)

Assuming a Temperature value of 37.9, the fuzzification of this crisp value into the fuzzy set using the triangular MF is shown below:

µTemperature (37.9) TN = $\{\frac{MFmax - Crisp}{MFmax - MFcenter}$

0

= (38 – 37.9) / (38 – 37)

= 0.1/1 = 0.1

Hence, µTemperature (37.9) = {0.1}

DESIGN OF THE OUTPUT MEMBERSHIP FUNCTION

This fuzzy system has one (1) linguistic variable used for the output namely Health-status. This Health-status has values ranging from 0 to 100 and it is divided into four (4) linguistic classifications as shown in table 1.5 below:

Table 1.5: Health-Status Linguistic Classification (source: Author)

S/no	Health-status	Linguistic classification	Linguistic acronym
1	0 to 40	Emergency	E
2	35 to 60	See doctor	SD
3	60 to 76	Good health	GH
4	75 to 100	Optimal health	OH

Using the triangular membership function, fuzzylite software was used to plot a chart of the health status membership functions as shown below:

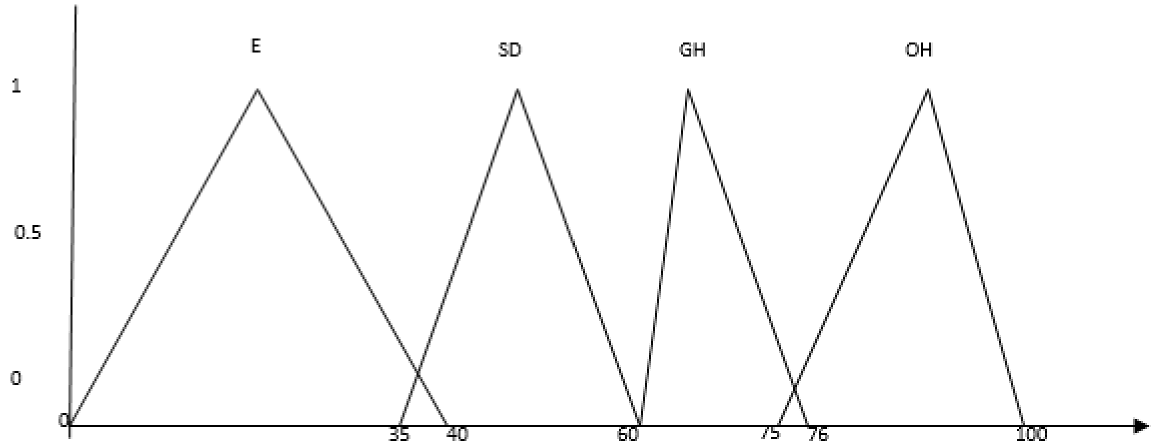

Figure 1.11: Health Status Membership Functions (source: Author)

FUZZY LOGIC INFERENCE AND RULE BASE

Using the Mamdami Inference Sub-system the degree of membership of any of the crisp input variable values was determined. It also checks to see which rules are fired/activated by the input combination, then it computes the fuzzy output set based on the fired/activated rules. A given variable value will belong to at least 2 membership functions at varying degrees. In order to determine the degree of membership, the Side-Side-Side (SSS) postulate for similar triangles is applied. The expressions used for the computation of degree of membership of each linguistic variable in the universe of discuss is shown below:

$$\mu Variable(crisp)MF = \begin{cases} \frac{MFmax - Crisp}{MFmax - MFcenter} & \text{for MFcenter} < \text{Crisp} \\ 0 & \end{cases} \quad (3.2)$$

$$\mu Variable(crisp)MF = \begin{cases} \frac{Crisp - MFmin}{MFcenter - MFmin} & \text{for MFcenter} > \text{Crisp} \\ 0 & \end{cases} \quad (3.3)$$

Where the membership function MF is defined by three values MFmin, MFcenter and MFmax. The Crisp is the precise value of the input variable. MFmin is crisp value that define the beginning of the particular membership function. MFcenter is the crisp value within the membership function whose membership value is 1. MFmax is the crisp value that define the end of the particular membership function. Crisp is the real numeric value being fuzzified.

For example: systolic pressure of 120mmHg belongs to the two-membership function SNBP and SEBP. To fuzzify this value see figure 1.13.

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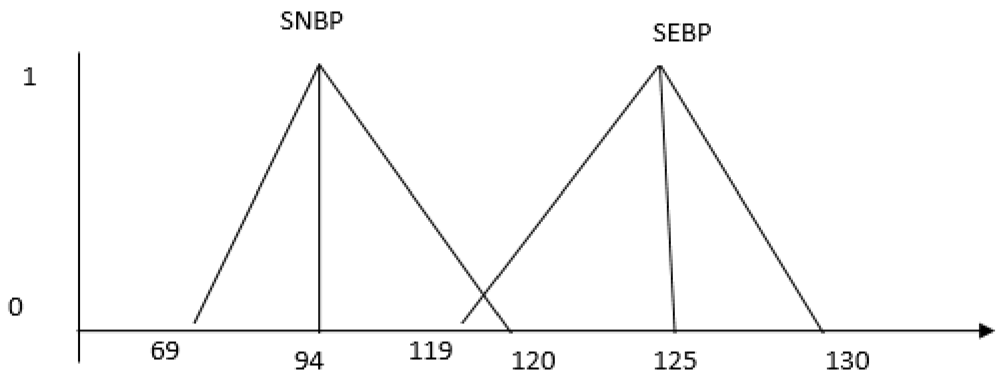

Figure 1.12: Fuzzification of Systolic Pressure Crisp Input (source: Author)

Using the Triangular Membership Function as depicted above:

µSystolic-pressure (120) SNBP = $\{\frac{MFmax-Crisp}{MFmax-MFcenter}$

0

= (120 – 120)/(120 – 94)

= 0

µSystolic-pressure (120) SEBP = $\frac{Crisp-MFmin}{MFcenter-MFmin}$

0

= (120 – 119) / (125 -119)

= 1/6 = 0.1667

Hence, µSystolic-pressure (120) = {0,0.1667}

RULE-BASE AND ITS OPERATION

After the fuzzification of the input variables into the membership functions MF, all the elements of the different MFs interact following rules (usually provided by expert knowledge) to help determine the membership of the fuzzy output. The rule base is programmatically represented using the IF … THEN construct. Different combinations of MFs in the universe of discuss constitute the IF section while the output MF constitute the THEN section of the program. The output of the rule base provides a set on which the strength of the fired rules is extracted (the complete rule base listing is available at the appendix).

Example:

IF systolic-pressure is SNBP and Diastolic-pressure is DNBP and Heart-rate is NHR and Temperature is TN

THEN Health-status is OH.

IF systolic-pressure is SHyper1 and Diastolic-pressure is DHyper1 and Heart-rate is HHR and Temperature is THF

THEN Health-status is E.

The rule base can also be represented in a tabular form; because there are more than two input variables, there will be more than one table. Each table of 1.6, depicts the interaction between two different input variables with respect to the MFs of the output.

Table 1.6(a): Systolic and Diastolic Interaction for Output MF (source: Author)

		Systolic-	Pressure				
		SLBP	SNBP	SEBP	Shyper1	Shyper2	Scrisis
Diastolic	DLBP	SD	SD	SD	E	E	E
Pressure	DNBP	SD	OH	GH	E	E	E
	Dhyper1	E	E	E	E	E	E
	Hhyper2	E	E	E	E	E	E
	Dcrisis	E	E	E	E	E	E

Table 1.6(b): Systolic and Heart Rate Interaction for Output MF (source: Author)

		Systolic-	Pressure				
		SLBP	SNBP	SEBP	Shyper1	Shyper2	Scrisis
Heart	LHR	E	SD	SD	E	E	E
Rate	NHR	SD	OH	GH	E	E	E
	HHR	E	SD	SD	E	E	E

Table 1.6(c): Systolic and Temperature Interaction for Output MF (source: Author)

		Systolic-	Pressure				
		SLBP	SNBP	SEBP	Shyper1	Shyper2	Scrisis
	TCD	E	SD	SD	E	E	E
Temperature	TCL	SD	GH	GH	E	E	E
	TN	SD	OH	GH	E	E	E
	TLF	SD	GH	GH	E	E	E
	THF	E	SD	SD	E	E	E

Table 1.6(d): Diastolic and Temperature Interaction for Output MF (source: Author)

		Diastolic-	Pressure			
		DLBP	DNBP	Dhyper1	Dhyper2	Dcrisis
Temperature	TCD	E	SD	E	E	E
	TCL	SD	GH	E	E	E
	TN	SD	OH	E	E	E
	TLF	SD	GH	E	E	E
	THF	E	SD	E	E	E

Table 1.6(e): Diastolic and Heart Rate Interaction for Output MF (source: Author)

		Diastolic-	Pressure			
		DLBP	DNBP	Dhyper1	Dhyper2	Dcrisis
Heart	LHR	E	SD	E	E	E
Rate	NHR	SD	OH	E	E	E
	HHR	E	SD	E	E	E

Table 1.6(f): Heart rate and Temperature Interaction for Output MF (source: Author)

		Heart Rate		
		LHR	NHR	HHR
Temperature	TCD	SD	SD	SD
	TCL	SD	GH	SD
	TN	SD	OH	SD
	TLF	SD	GH	SD
	THF	E	SD	E

DEFUZZIFICATION PROCESS

From the fired rules (in most cases more than one rule) in the rule base, different values of the set are generated. These values undergo defuzzification following a defuzzification method that best fits the application. For this thesis, the Mean of Max (MoM) defuzzification method is employed. Here, the mean of all crisp output values within the highest membership values are computed, in order to get the final crisp output value for the health-status.

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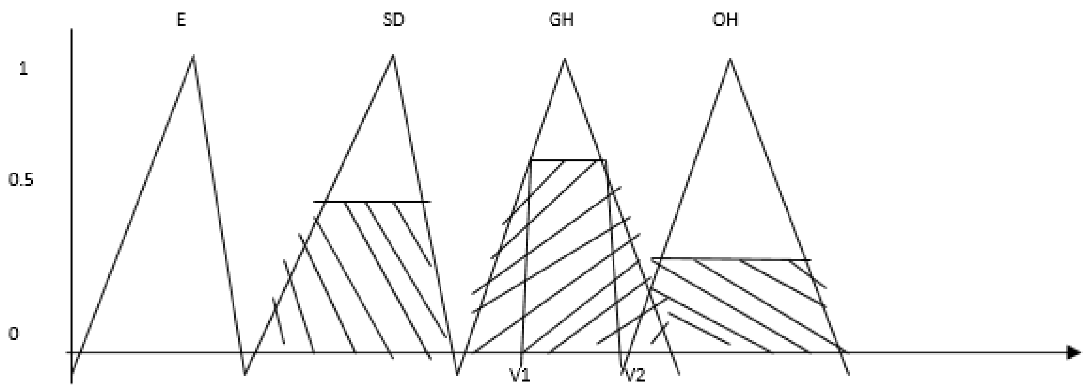

Figure 1.13: MoM Defuzzification (source: Author)

Let the data set supplied by FIS to defuzzifier be {µy1, µy2, µy3, µy4}

Where µy1 = health-status (E)

µy2 = health-status (SD)

µy3 = health-status (GH)

µy4 = health-status (OH)

MoM will compare µy1, µy2, µy3 and µy4 and pick the one with the highest membership value. Then it will compute the mean and return it as final result; from figure 3.17 MoM result will be (V1 + V2)/2.

HARDWARE BEHAVIORAL DESIGN

Figure 1.14 shows details of the behavioral use case of the device which is derived from the execution of the firmware. User activities with the device will manifest, when the system setup operations, takes readings, calculation and extraction of data, update the LCD and transmit data.

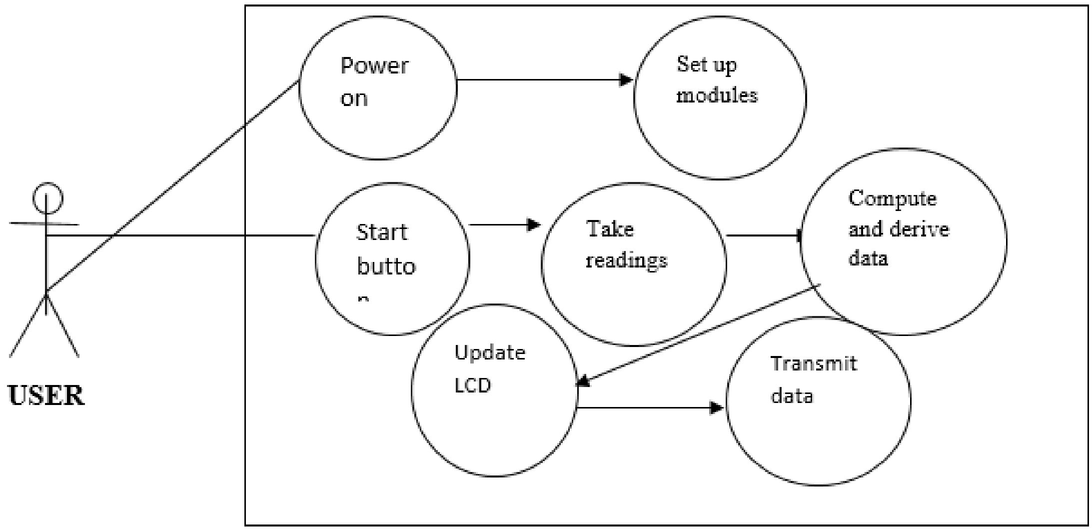

Figure 1.14: Behavioral Use Case Model Diagram (source: Author)

DEVICE SIMULATION AND TESTING

Voltage measurements were carried out at the output of the sensors to ensure the system is receiving the 5volts current to work with. The measured voltage showed that the sensors are working well. See samples of device prototype and App emulation screenshots in figure 1.15.

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B) Sample Snapshots of the proposed system interfaces are shown below:

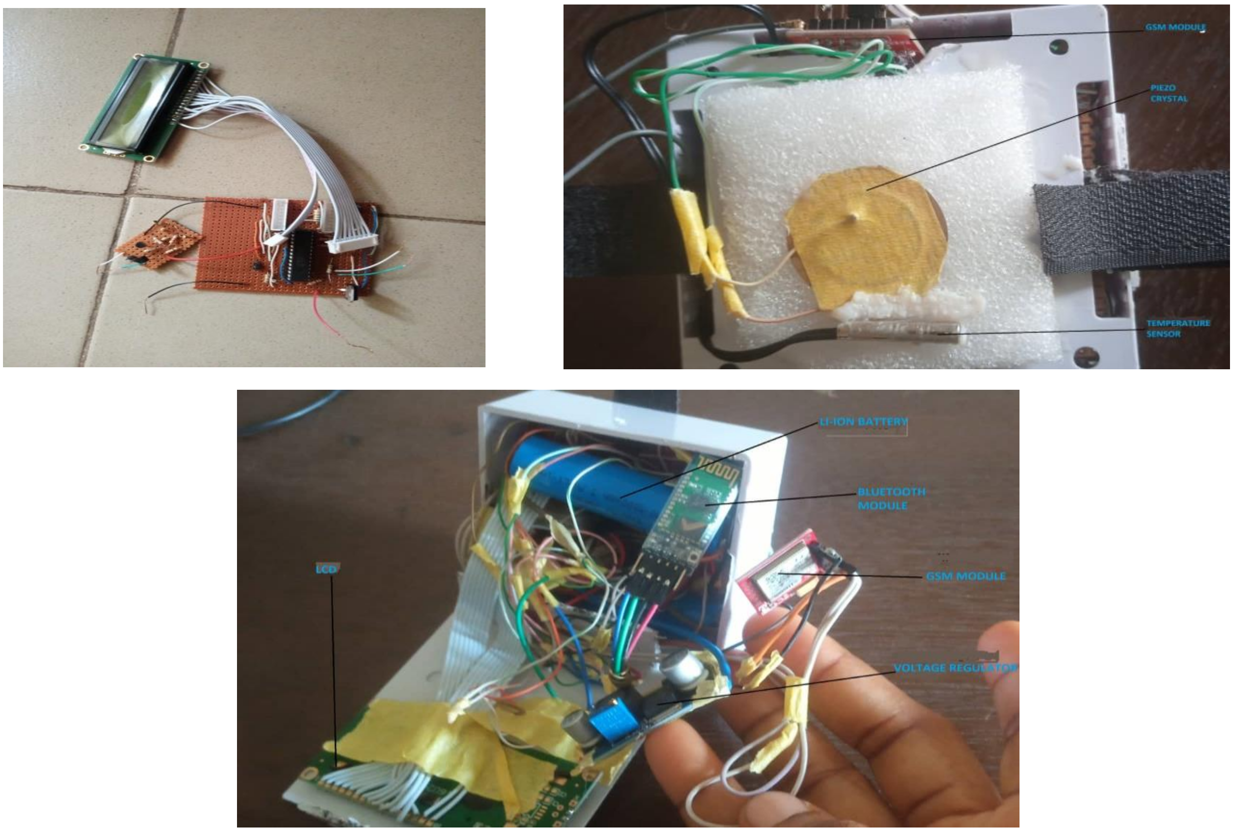

Figure 1.15a: Snapshots of the Proposed Wearable Device Hardware development in process- the Microcontroller was detached from the Ardiuno board and fixed on the Vero board to fit in the vital component of the proposed system (source: Author)

Figure 1.15b: Wearable Device LCD display during Test (source: Author)

Figure 1.15c: The VIS App on an Android phone and Wearable Device connected to MTN Network (source: Author)

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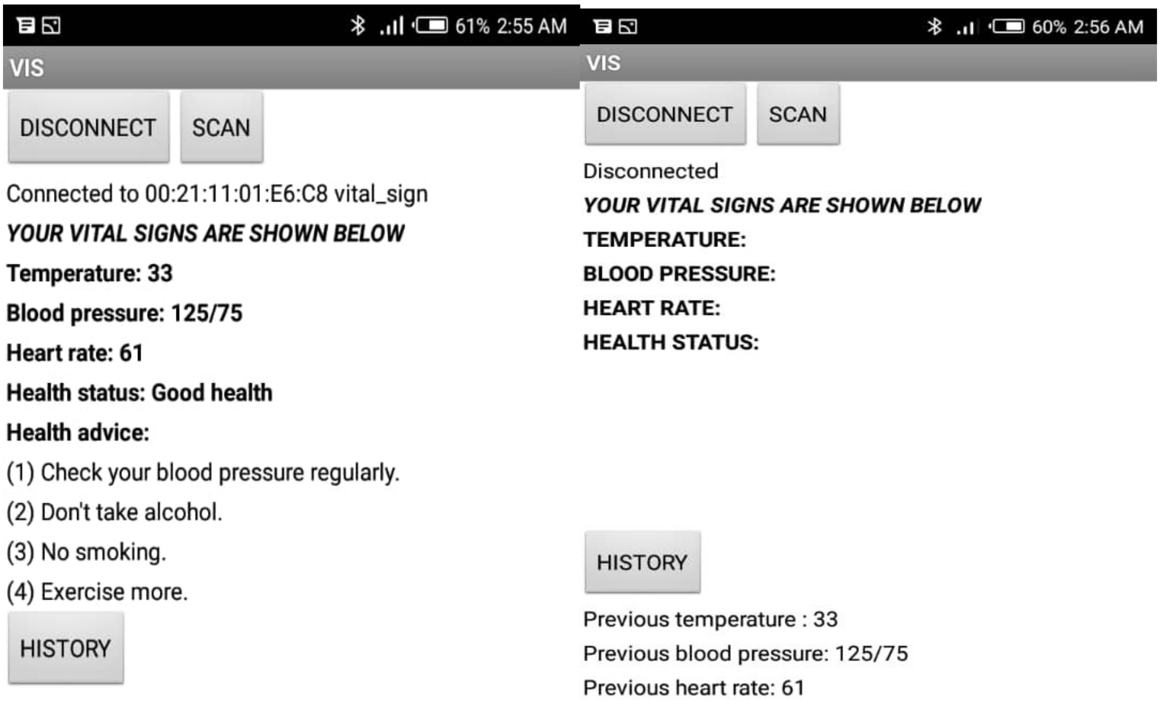

Figure 1.15d: The VIS App interface during emulating and testing (source: Author)

IMPROVEMENT VALIDATION

The following features and performance criteria of the system were used for performance validation. They include multiple vital sign measurement, computational accuracy, real time monitoring, cost effectiveness, ease of use, processing speed, result interpretation and device adaptability. The Figure 1.20 below shows the improvement in the system features and performance over the existing wearable vital devices (such as upper arm band monitors).

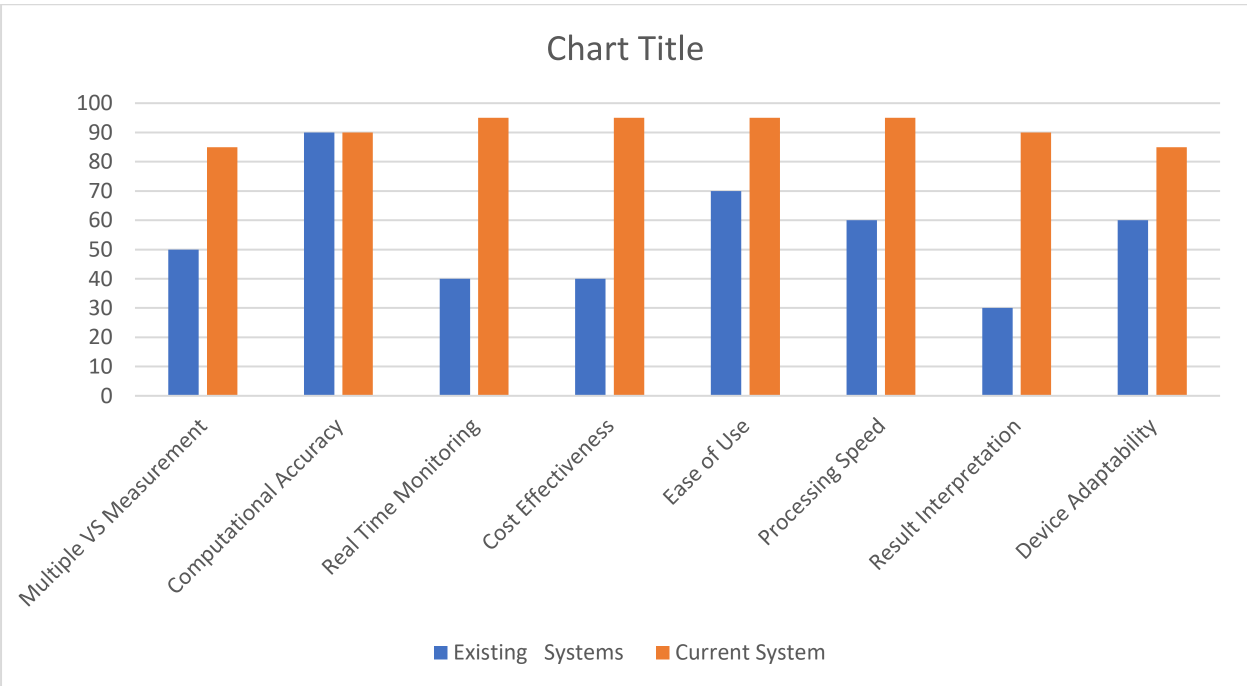

Figure 1.16: Chart on improvement of the Current vs Existing systems (source: Author)

3. SUMMARY OF SYSTEM TESTS

A summary of all the tests carried out and validations are shown in the table 1.7 below:

Table 1.7: Summary of System Tests, Results and Remark (source: Author)

Area Tested	Result Obtained	Remark
Hardware Tests	The various parts of the hardware worked effectively	Hardware operation is satisfactory
App Functionality	The various features of the App worked effectively	App operation is satisfactory
System Cost	Cost incurred in developing both vital sign Hardware and App is ₦168,950	Cost incurred is moderate
System Improvement	Various parameters and features of the system is improved over the existing systems	There is significant system improvement

4. CONCLUSION

The problems inherent in Vital Sign Monitoring devices and equipment which showed systems that mostly measure one vital sign, inconsistent monitoring systems, systems that are not cost effective, systems that do not alarm for emergency situations and systems that does not interpret measured data, this research work set out to upgrade the design of the logical input output modules and employ fuzzy logic in the computational analyses of input parameters in other to develop a real-time smart monitoring system, that will improve system mobility and adequately interpret and report the results of user's vital signs .

C++ Programming language was deployed in implementing the algorithms developed for the hardware in other to ensure a hybrid system. Also, the MIT app inventor tool allowed for a seamless App development. The cost incurred in developing this device is moderate. This means that if an organization should decide to mass produce it, the cost of the final product will become cheaper than most wrist strap devices like smart watches and this will encourage wider adoption of the device. Conclusively, the objectives of this thesis were fulfilled as this wearable vital sign device outperforms the previously existing systems as shown in figure 1.20.

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