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Deployment of Assisted Living Technology Solution Platform using Smart Body Sensors for Elderly People Health Monitoring

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Abstract**—**Many of the Ambient Assisted Living Technologies (AALT) available in the market to the end-users with long term health condition have no common inter-operational protocol. Each product has its own communication protocols, different interfaces and interoperation which limits their solution reliability, flexibility and efficiency. This paper presents assisted living platform solution for elderly people with long term health condition based on wireless sensors networking technology. The system includes multi feedback sensor arrangements for monitoring, such as: blood pressure, heart rate and body temperature. Each sensor has been integrated with the necessary near real time embedded and wireless protocols that allow data collection, transfer and interoperate in ad-hoc bases. The data will be communicated wirelessly to central data base system and shared though cloud network. The collected data will be processed and relevant intelligent algorithms will be deployed to ensure certain actions taken place when health condition warnings arise. These warnings to be communicated to relevant carer, General Practitioner (GP) and health authority to take the necessary action and steps to handle such end user health condition warnings. The proposed solution system will provide the flexibility to analyse most of the health conditions based on near real time monitoring technology. It will enable the population of elderly with long term health condition to manage their daily life activities within multiple environments i.e. from their comfort home, care centres and hospitals. The data and information will be treated with high confidentiality to ensure end-users integrity and dignity have been maintained.

Keywords**—**Ambient Assisted Living Technology, Remote Healthcare, Patient Monitoring.

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I. Introduction

The raising population of seniors with long term health condition in the EU and around the world faces significant challenges in managing their daily life activities. To live independently and have a good quality of life is very challenging, since the majority of older adults have a long term health condition (LTC) which requires some interventions. This burden is replicated across health service providers throughout the EU and is shared by informal and formal care providers who play a major role in providing the point of care services and support. Furthermore, older adults are affected by a range of chronic diseases such as: cardiac infarction; stroke; macular degeneration; glaucoma; diabetes, dementia and high blood pressure.

All of which require active monitoring and intervention, failure to deliver the necessary care to this community can lead to reduced quality of life and ultimately death. 63% of all deaths in the world are within the older adult population and may have been due to one of these chronic LTC's. Out of the 36 million people who died worldwide from disease in 2008, 29% were under 60 and half were women [1]. By 2020 it is predicted that there will be more than 15 million more elderlies with long term health condition each year [2]. It is envisaged that these diseases will in the future contribute to seven out of every 10 deaths in developing countries. Many of the non-communicable diseases can be prevented by tackling associated risk factors. The cost of care and treatment of long term health condition diseases for elderly in the EU is estimated to consume over 70% of the overall Health Service (HS) provider budget [3].

The "state-of-the-art" of the current technology of daily life activities, telecare and telehealth solutions products, particularly in respect to elderly people conclude that the potential manufacturers of telecare, telehealth products and ongoing projects are: Tunstall / Bosch / Docobo …etc. These are the major market leaders across EU, with 70% of the current Telehealth and Telecare markets. These vendors have unique platforms and their system architecture differ from each other. The issue is when a certain platform has been chosen in a public or private care nursing house, the risk of system lock-in is exceedingly to happen. For example, if a system from any of the above providers were chosen for a resident area or care facility centre, it will be only deployed using software and products manufactured and supported by the supplier only. To use other products and software from different vendors, there will be a need of another system infrastructure which could impact on the system performance and service provided [4]. As

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well as carrying these installations involves a complexity and various organisations to provide these installations. Which, makes the deployment of ambient assisted living equipment expensive and complicated [5]. In some cases, systems and units are also required to be installed at home "for the end-users" the data collected has to be entered manually to the system to update the healthcare records, which results in increase in cost.

There are many efforts have been undertaken to overcome these teething issues. For example, Mirth Corporation: is an American organisation specialised in open source IT communication software aimed at multiple platforms. Their solution can listen, send and connect to ALL forms of protocols. Medway EPR: is a UK Company: Medway EPR is a family of products, built specifically for the UK health sector, which appear to cover all aspects of patient management and care, however it has been identified that there seems to be no case driven aspect to their EPR with built in alerts and monitoring solutions integrated with monitoring devices and sensors. These show that there is a serious need to develop a new approach that could enable each devices and units to communicate with each other and transfer data wirelessly without any interface technology barriers. This investigation into the current technology state of the art clarified that none of the manufacturer around the world has develop such technology.

This paper is organised as follows, Section 2 elaborates on the proposed system architecture and the assisted living platform. Section 3, describes the interoperation of the system platform. Section 4, presents the integrated system ad-hock developed devices with their principle of operations and their data reference limits. Section 5, addresses the use of the wireless technology platform developed for the entire system. Section 6, provides a demonstration of the developed user interface window with system monitoring and the alerting functions. Section 7, the execution process of the platform system followed by main windows for user interface and a conclusion.

II. Proposed Assisted Living Platform Architecture

Figure 1 shows the proposed ALT solution Platform architecture. The system has a number of sub-units. These includes array of sensors, data communication protocols, intelligent algorithms, expert system and decision making unit. It will also have an integrated intelligent self-assessment unit, to enable self-assessment of all the stages of the system hardware and software [6-8]. This is to ensure that the plugged in medical devices are performing well and if there is any sign of degradation, the necessary action can be taken to replace the device, in appropriate time, to maintain near real time monitoring. These sub-units can be clustered into three main stages: The front end part: this is to integrate different health measurement devices from different manufactures in ad-hoc interface based protocol. This is where data will be send wirelessly. The middle part: this includes all the relevant algorithms to process the received data and provide the necessary information to the end-users, main care centres and hospitals. The back end part: this is mainly a user friendly interactive interface system that will show the processed data outcomes.

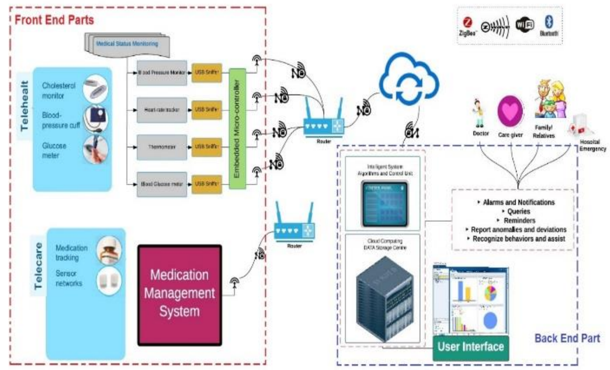

Figure 1 Proposed Assisted Living Solution Platform Architecture, includes front and back end units, processing stages and other relevant *ad-hoc* technology protocol [8]

III. Assisted Living Platform Inter-Operational Scenario

The inter-operational principle of the ALT platform is based on the principles of automatically integrate and interface any device made from any manufacturer to the ALT system in ad-hoc unit, and this is part of the main innovation of the proposed solution. The data will be collected, processed with the relevant algorithms and the outcomes will be communicated to the relevant end-users, family, general practitioner, and hospitals. This will enable individuals to monitor their vital signs, daily life and lifestyle activities. This will also help to detect any deterioration of their health or habits so that clinical decisions can be made and emergencies actions can be swiftly addressed.

IV. Assisted Living Platform design and development

A. Body Temperature Biosensor

The normal temperature level for average body is normally 37.0℃. This temperature fluctuates by 0.5℃ through the day. One of the objectives here is to keep track of the body temperature changes for elderly health monitoring. Many of the diseases associated with the body temperature changes, so it is important to keep track of this temperature variations with the physician. The following table illustrates the ranges of body temperature and their accompanied characteristics.

Table 1 Body Temperature Range Characteristics

Hypothermia	<35.0 °C (95.0 °F)
Normal	36.5–37.5 °C (97.7–99.5 °F)
Fever or Hyperthermia	>37.5–38.3 °C (99.5–100.9 °F
Hyperpyrexia	>40.0–41.5 °C (104–106.7 °F)

The body temperature biosensor will require the least amount of power of the biosensors and will take a reading of the patient's body temperature from inside their armpit upon request. The biosensor based on the Negative Temperature Coefficient thermistor (NTC). When the current run through the sensor, the microcontroller chip will convert the voltage drop across the thermistor to a resistance using the voltage divider equation. Then convert this resistance to a temperature based on the thermistor material constant obtained from the datasheet. The patient body temperature will be sent and displayed on the User Interface window.

The body temperature biosensor circuitry will consist of a 4-wire bridge to eliminate lead impedance which can create error in the temperature measurement. **Figure 2** shows the NTC thermistor circuit setup.

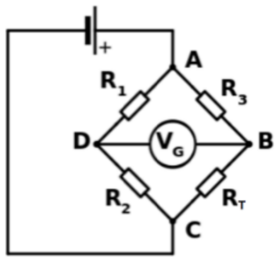

Figure 2 Temperature biosensor NTC thermistor bridge circuit

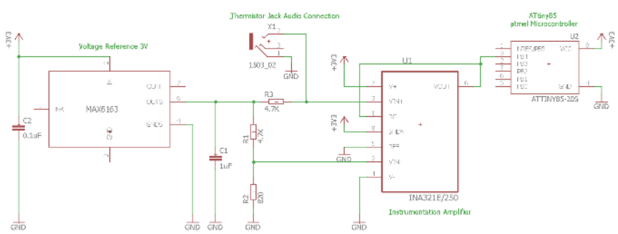

Figure 3 Body temperature biosensor circuit schematic

The biosensor circuit in **Figure 3**, is connected with a voltage reference chip for fixed 3V low power requirement and the voltage converted from the thermistor resistance is connected to the instrumentation amplifier, the output of the instrumentation amplifier is connected to the microcontroller board, this board has analogue input terminal and with the built in Analogue To Digital Converter (ADC) will be able to process and convert this signal.

The resistor values chosen for this design are R1, R2, equal to 4K7Ω and R3 is 820Ω. The resistance of the NTC thermistor will be determined by reading the voltage at node B with respect to the voltage at node D using the following relationship Equation 1.

$$V_G = \left(\frac{R_T}{R_3+R_T} - \frac{R_2}{R_1+R_2}\right) V_s \tag{1}$$

The temperature sensor will be powered by ATtiny85 microprocessor, which has 8 kilobytes of on board flash memory, and support for the Arduino bootloader. This small microcontroller can use one of its serial ports to connect the ZigBee module for wireless transmission. The data obtained and processed will be sent securely to the intelligent user interface which has the algorithms to advice on taking certain actions.

The output voltage obtained, will run the program and process the data to find the final resistance of the Resistance Temperature Detector (RTD) and evaluate the patient's body temperature by comparing the final resistance to the initial resistance. The product is model 427 reusable skin/surface probe made by Measurement Specialties. It operates under the 400 series nominal resistance response curve. Relationship Equation 2 represent the NTC thermistor response.

$$R_T = \frac{R_{25}}{exp\left[B_{25}/_{85} \cdot \left(\frac{1}{T_{25}} - \frac{1}{T}\right)\right]} \tag{2}$$

RT is the thermistor resistance, T is its temperature in Kelvin, and T_{25} is the Kelvin temperature at 25 °C (298.15 °K), T_{85} is the Kelvin temperature at 85 °C (358.15 °K). Solving Equation 1 for temperature (in Kelvin) this led to Equation 3.

$$T = \frac{B_{25}/_{85} \cdot T_{25}}{B_{25}/_{85} - T_{25} \cdot ln\left(\frac{R_{25}}{R_T}\right)} \tag{3}$$

B25/85 is the material constant, 3977 °K for the NTC thermistor surface probe. T25 is 298.1 °K. These defined parameters are deployed in the C programming software to develop the code for processing these and obtain the required body temperature with wireless communication being enabled for transmission as soon as the data is obtained.

```
float ALTBSClass::getTemperature(void)
{
    //Local variables
    float Temperature;
    float Resistance;            //Resistance of sensor.
    float gain=5.0;
    float Vcc=3.3;
    float RefTension=3.0;        // Voltage Reference of Wheatstone bridge.
    float Ra=4700.0;             //Wheatstone bridge resistance.
    float Rc=4700.0;             //Wheatstone bridge resistance.
    float Rb=821.0;              //Wheatstone bridge resistance.
    int sensorValue = analogRead(A3);

    float voltage2=((float)sensorValue*Vcc)/1023; // binary to voltage conversion

    // Wheatstone bridge output voltage.
    voltage2=voltage2/gain;
    // Resistance sensor calculation
    float aux=(voltage2/RefTension)+Rb/(Rb+Ra);
    Resistance=Rc*aux/(1-aux);
```

The specifications of the biosensor used in this platform are: accuracy: ±0.4%, resistance: 2.25 kΩ at 25 °C, time constant: 7s (sensor requires about 5 time constant for stability to read 99%) and temperature range: -40 to 100 °C.

B. Blood Pressure Sensor

Blood pressure is the pressure of the blood in the arteries as it is pumped around the body by the heart. When heart beats, it contracts and pushes blood through the arteries to the rest of the body. This force creates pressure on the arteries. Blood pressure is recorded as two numbers—the systolic pressure (as the heart beats) over the diastolic pressure (as the heart relaxes between beats).

Classification of blood pressure for adults (18+ years) is shown in **TABLE 2**.

TABLE 2 BLOOD PRESSURE CLASSIFICATION FOR ADULTS (18+ YEARS)

Classification	Systolic (mm Hg)	Diastolic (mm Hg)
Hypotension	< 90	< 60
Desired	90–119	60–79
Prehypertension	120–139	80–89
Stage 1 Hypertension	140–159	90–99
Stage 2 Hypertension	160–179	100–109
Hypertensive Crisis	≥ 180	≥ 110

High blood pressure (hypertension) can lead to serious problems like heart attack, stroke or kidney disease. High blood pressure usually does not have any symptoms, so you need to have your blood pressure checked regularly.

Figure 4 Blood pressure monitor setup connection and interface to the ALT platform solution

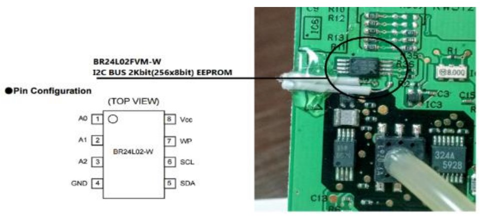

Figure 5 Blood pressure device data interface

1) *Blood pressure device EEPROM data interface*

The objective here was to get into the information measured using off shelf devices, and use the platform solution for processing these data and send them wirelessly to a main server which will hold the user interface for monitoring and making certain decision based on the results.

A Blood Pressure Monitor with memory saving capability was investigated by looking into the datasheet of the EEPROM and locating all the pins of the serial bus communication PINs as shown in **Figure 5**, pin5 and pin6 determined the serial data and serial clock for the programming execution. The required data was obtained out of the memory and interfaced to the ALT platform. The process was to connect in parallel with the serial lines and keep listening for any activity in the serial bus, once the memory button is pressed the data will move to the memory and at the same time it was possible to read these data out to the microcontroller for processing and transmission wirelessly.

2) *Interpretation of I2C data wire*

The data communication between the Microcontroller Unit (MCU) and the memory transmitted uses the Inter Integrated Circuit (I2C) communication protocol, this protocol has two wires: a serial data and serial clock. Using logic analyzer it was possible to obtain the two signals as shown in **Figure 6**.

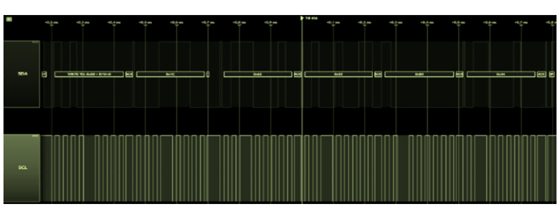

Figure 6 Logic analyzer signals display

To interrupt the signal and obtain the relevant the signal formation, it was necessary to obtain the serial data signal bus. The bus consists of start, address, data and stop with acknowledge in between. The exact structure of the serial data bus is expressed as.

Once the serial communication is enabled, the synchronisation will start then the address where the data is stored initialised followed by acknowledgement with data length has 5 bytes of data, each byte holds a specific information. The 1st byte is the address in the chip (the data storage location). The 2nd byte has 0x62 in hex means 98 in decimal and this corresponds to the values of the heart beats. The 3rd byte holds 0x53 from hex to decimal 83 which corresponds to the diastolic pressure as 83 mmHg. The 4th and 5th bytes represents the systolic pressure value. Since this type of memory holds only 256 data length in each byte and the systolic pressure goes up to 280 mmHg, so two bytes are reserved for this purpose. The 4th byte function is to check whether the value is odd or even, if the value was odd the 4th byte will be high (0x80) and the 5th byte will determine the systolic pressure in this case which reads 0x44 from hexadecimal to decimal gives 68. This reading is divided by 2, using Little Endian Byte pattern for shorting the data length. The obtained ready multiplied by 2 = 136, since the 4th byte was odd we add 1 to the result gives 137 mmHg for the systolic pressure measurement. Then we have an acknowledgement again followed by stop of serial communication between the MCU and the memory.

V. ALT SOLUTION PLATFORM AD-HOC WIRELESS PROTOCOL

To develop choose and possibly adopt suitable ad-hoc wireless network protocol, where wireless technologies involved in healthcare application is a real challenge. These includes: IEEE 802.15.1 (Bluetooth), IEEE 802.15.3A (Ultra Wide Band), IEEE 802.15.4 (Zigbee Protocol) and WLAN (Wireless Local Area Network). ZigBee is Reliable and self-healing, supports large number of nodes, Easy to deploy, very long battery life, Secure and Low cost. The motivation behind the ZigBee technology introduced by ZigBee Alliance are: Organisation with a mission to define a complete open global standard for reliable, cost-effective, low-power, wirelessly networked products addressing monitoring and control. ZigBee alliance provides: Upper layer stack and application profiles, Compliance and certification testing. Result is a set of recognizable, interoperable solutions. The table below shows a comparison of the performance between these technologies, the table clearly shows that choosing ZigBee has the advantage in the low cost and the maximum operation of their life as power profile. The transmission range of ZigBee is greater than Bluetooth, but it less compared to other technologies. Still, it is remarkable for a low power solution. While implementing any wireless health monitoring system it needs to consider security issue. The ZigBee technology provides adequate security for our platform. The security has been ensured via several steps namely key establishment, key transport, frame protection, and device authorization. The ZigBee technology has designated a full function device (i.e. coordinator) as the 'trust centre', which stores all the keys for the network. Once assigned by the 'trust centre' both originator and recipient need to share the same key to ensure secured delivery of information.

TABLE 3 COMPARISON OF ZIGBEE WITH OTHER TECHNOLOGIES [9]

Features	IEEE 802.11b	Bluetooth	ZigBee
Power Profile	Hours	Days	Years
Complexity	Very Complex	Complex	Simple
Nodes/Master	32	7	64000
Latency	Enumeration up to 3 seconds	Enumeration up to 10 seconds	Enumeration 30ms
Range	100m	10m	10-300m
Extendibility	Roaming Possible	No	Yes
Data Rate	11Mb/s	1Mb/s	250Kb/s
Stack size	100 + Kbyte	100 + Kbyte	8-60 Kbyte
Topology	Star	Star	Star, Cluster, Mesh
Security	Authentication Service Set ID (SSID), WEP WAP	64 bit, 128 bit	128 bit AES and Application Layer user defined

VI. END-USER INTERACTIVE INTERFACE

The data displayed in the back-end user interface screen will be updated in a table. An alerting indication unit will appear on the screen that display the state of the emergency. LabVIEW software has some advantages and these are: The software uses graphical icons (block Window) for ease of designing and just matter of wiring these blocks together to do a specific function. The software can handle as many as sensors connected to, through a USB or accessing a webserver from a given IP address. It has a customized front window; this window can be designed upon the user request. Helps in making the user interface more interactive with many shapes to offer. The capability of proving a high and fast data acquisition between the different sensors and the monitoring and controlling station unit. It has various tools for data analysis and data visualization and processing units. LabVIEW workbench software features as well advanced mathematical block functions, used in signal filtering for Digital signal processing. LabVIEW is a complete station for programming and designer users, LabVIEW uses spreadsheets for data storage and table lookups process in comparing and recording the upcoming new data in different files within the directory of the project created.

VII. PROPOSED ALT PLATFORM SOLUTION EXECUTION PROCESS

The execution process of the system, is initiated as soon as the front-end devices (body temperature and blood pressure) are switched on. Data will be sent/received wirelessly for processing and then displayed in the back-end part of the system i.e. user friendly interactive interface screen.

The biosensors are connected to the development board and powered through computer USB port. Both of the body temperature and the blood pressure sensors will be connected to platform shield for processing the measurements once the user or patient request a scheduled for patient eHealth data logging. These data are then transmitted to the user interface LabVIEW unit which holds all the records of every patient, based on the data received, the user interface has an intelligent system and algorithms with database which will look up and compare the data to pre-stored data as reference for alerting and making the right notification to end-users' health condition. **Figure 7** shows the body temperature biosensor integrated to the ALT platform solution.

Figure 7 Body temperature sensor integrated to the ALT platform solution and setup

A. *Body Temperature Biosensor Flowchart Algorithm*

The algorithm flowchart for body temperature biosensor is shown in **Figure 8**.

Once the system is powered and the user starts to take any measurement. The add-hoc wireless communication module protocol will be enabled and data will be send to the local data center. Where it will be processed to detect any changes and start processing these changes whether the obtained reading is higher or lower the normal body temperature level range. Once the data is processed, it will be transmitted to the monitoring user interface which holds different display arrangements upon the data for notifications and alerting the people of care to proceed with suitable actions.

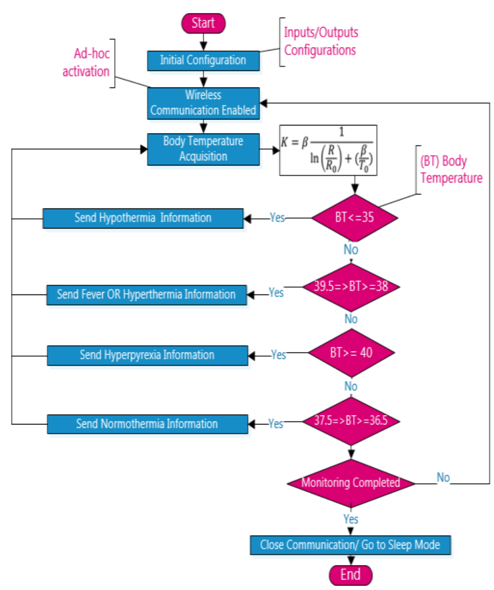

Figure 8 Body Temperature (BT) flowchart algorithm

B. Blood Pressure Monitoring Device Flowchart Algorithm

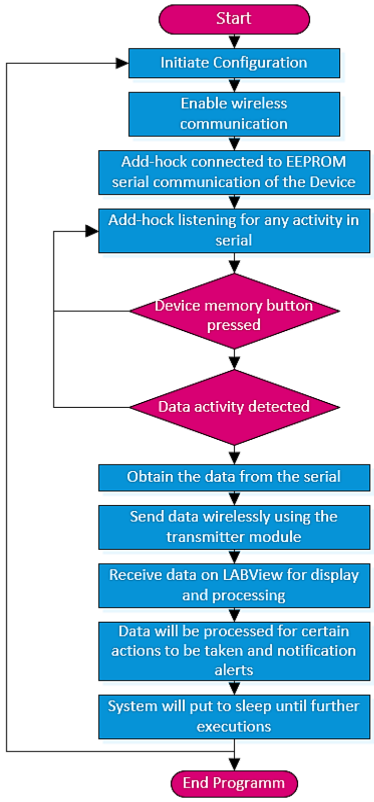

Figure 9 Blood Pressure (BP) execution flowchart algorithm

VIII. ALT Solution Platform Prototyping

The initial testing of the system functionality was carried out, by obtaining the data from the blood pressure, the heartbeats and the body temperature. **Figures 10** and **11** show the user interface window with the data received at the back-end User Interface Screen. The screen shows the monitored information of patient health condition, with level of normality or any unexpected changes that may need some attention from carer and or GP responsible for the patients.

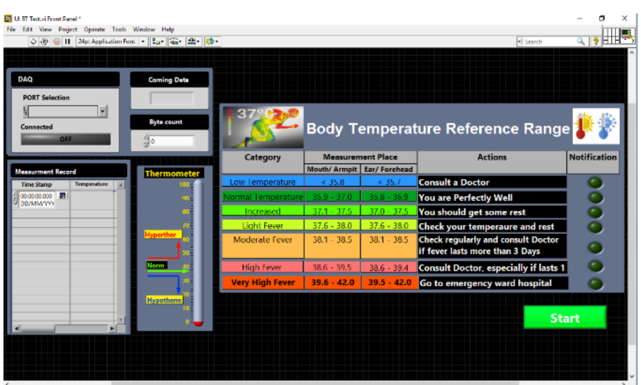

Figure 10 LabVIEW system Body Temperature monitoring user interface and results obtained using developed ALT system prototype

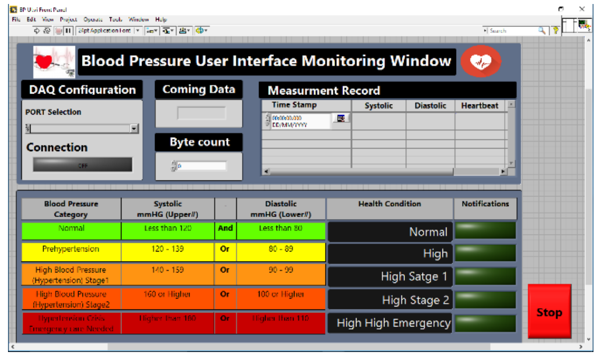

Figure 11 LabVIEW system Blood Pressure monitoring user interface and results obtained using developed ALT system prototype

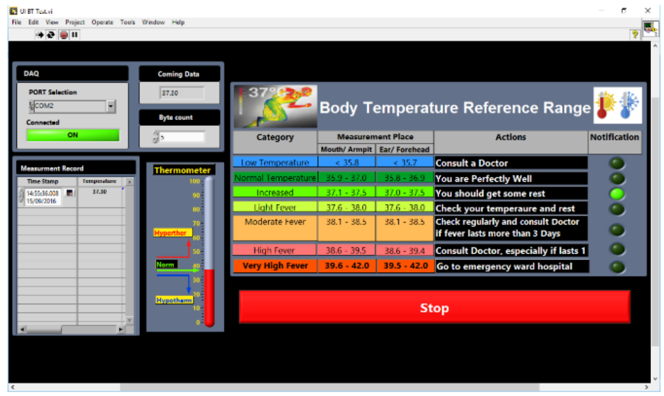

Figure 12 Body temperature user interface test simulation

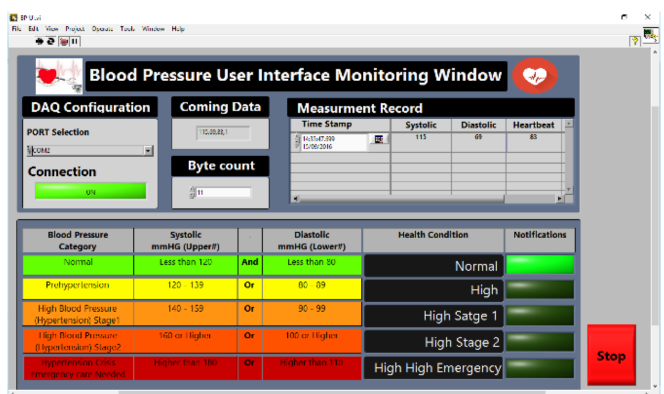

Figure 13 Blood pressure user interface test simulation

A. Developed ALT Solution Platform Testing, Results and Discussion

The testing and simulation procedure was carried with the use of LabVIEW as seen in **Figure 12**, the user interface shows the body temperature data obtained through the data acquisition and displayed the measurement record table as well an instruction is advised to be taken along notification system activated.

In this test, the body temperature was measured as 37.30º where the system shows the temperature increased a little due to physical work and the actions to be taken is to get some rest with light green LED displays the notification.

In **Figure 13**, the system was tested to record the measurement of patients' blood pressure and heart-rate. The test simulation from the user interface shows the measurement has been recorded as 115 systolic and 69 diastolic and the heart beats recorded as 83 BPM. The intelligent system correspond to this data and advised the measurement is normal with light green notification LED bar.

The proposed solution of assisted living technology platform for monitoring elderly and disabled people in monitoring their long-term health conditions from their comfort homes with the enabled wireless technology, this platform is analyzed and has the advantages from the following prospective:

1) Enabled Wireless Sensor Network Technology

The platform with multi integrated body sensors and devices is easy, simple and safe to use. The system features low cost with very low power consumption as ZigBee chosen for the wireless communications. The size of the USB integrated plug and play devices is very small with a medium range of distance between the different nodes and the main master unit. The sensors can transmit data from one node to another or as many nodes as needed for the platform.

2) Large-scale Health Care Institution Scalable

This platform can help for large scale health care institutions, where the need to increase the patients and reducing the manpower (carer givers). The use of this wireless platform system will enable any institute from managing and assisting their patients in real-time status monitoring and notifications. The system will help in providing effective management for large scale health care providers.

3) Ad-hoc Solution Platform

The proposed platform is capable of integrating as many sensors network as needed. The new compatibility feature of the platform will enable the ability to extend the platform to other care units. This is a great benefit for home automations and it can be adopted easily for smart cities applications.

IX. Conclusion

The initial prototype of an Assisted Living Technology Solution Platform for Elderly People with Long Term Health Condition Based on Wireless Sensors Network Technology is presented in this paper. The developed prototype of the system has shown the possible potential of the ALT Solution platform. A wireless communication link has successfully established between front-end devices, ZigBee modules and back-end units. The data was processed and displayed in the serial monitor using LabVIEW software user friendly interface screen. The research program at early stage and there are still a number of ongoing activities. This is mainly aiming to conclude with an integrated assisted living technology multi-functional case driven wireless ad-hoc management system for elder adults using smart sensors and actuators, 3D-video, audio, radio frequency identification and wireless technology, combined with secure cloud and semantic data technology.

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