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Wireless Physiological Monitoring System for Psychiatric Patients

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Abstract —**Patients in psychiatric hospitals that are sedated or secluded are at risk of death or injury if they are not continuously monitored. Some psychiatric patients are restless and aggressive, and hence the monitoring device should be robust and must transmit the data wirelessly. Two devices, a glove that measures oxygen saturation and a dorsally-mounted device that measures heart rate, skin temperature and respiratory rate were designed and tested. Both devices connect to one central monitoring station using two separate Bluetooth connections, ensuring a completely wireless setup. A Matlab graphical user interface (GUI) was developed for signal processing and monitoring of the vital signs of the psychiatric patient. Detection algorithms were implemented to detect ECG arrhythmias such as premature ventricular contraction and atrial fibrillation. The prototypes were manufactured and tested in a laboratory setting on healthy volunteers.**

I. Introduction

Psychotic patients in psychiatric hospitals that are sedated or secluded are sometimes at risk of death or injury if they are not continuously monitored. In 1998, a number of incidents that could be linked to the restraining and sedation of patients led to the deaths of adults and children in the psychiatric setting [1]. Hartford Courant [1] subsequently commissioned a study that revealed that between 50 and 150 deaths that occur each year in psychiatric environments in the USA are due to the use of seclusion or restraints [2]. A vital signs monitor will reduce the risk of death or injury to such patients during sedation or seclusion. Such a device can assist clinicians to monitor patients continuously and more efficiently without having any physical contact with the patient. Currently a patient in seclusion is monitored using a video camera, or by visiting the patient. With the proposed device one clinician can monitor several patients from central monitoring stations and if any of the monitored vital signs are fall outside of the selected margins, an alarm will be activated to ensure that the clinician on duty can attend to that patient as soon as possible. It is proposed that the following vital signs be monitored with this device: oxygen saturation, pulse rate, electrocardiography (ECG), respiratory rate and skin temperature. Other measurements such as the motion / movement of the patient can be used to determine if the patient is moving uncontrollably, or not at all, which can also activate an alarm. The monitoring system will contribute to the safety of patients during psychiatric emergencies and reduce the considerable workload of medical staff.

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II. Concept Development

The use of the device on psychiatric patients limits the positioning of the device due to the possible aggressive nature of these patients. The measurement of certain vital signs at particular locations is also limited by the physiology at those locations. All of these factors must be considered to choose a specific practical location of the device on the patient. Four concepts (a safety cuff, safety glove, safety shoe and dorsally mounted device) were compared using a concept evaluation matrix. The dorsally mounted device showed most promise, followed by the safety glove concept. A basic electrocardiogram (ECG) and oxygen saturation monitoring were deemed necessary. To comply with this requirement the project was divided into three parts, the dorsal mounted device and the safety glove device and the central monitoring station (Fig.1).

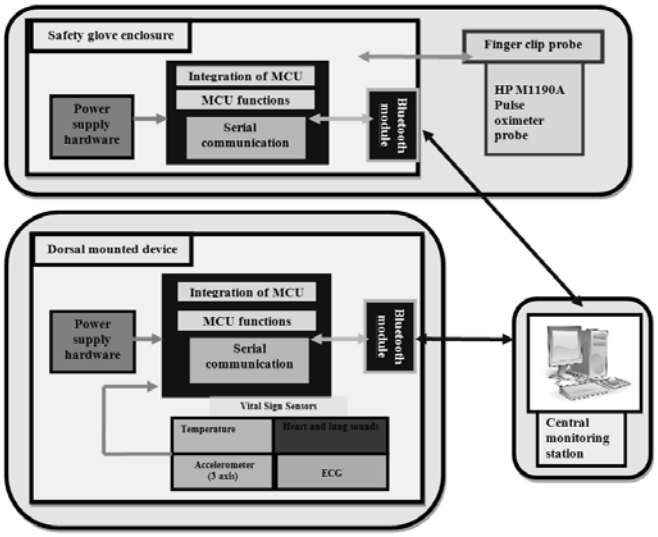


Fig.1. Diagram of proposed system

III. Dorsal Mounted Device

It was decided that the device must be mounted dorsally (on the back) of the patient to prevent the patient from removing it or damaging it. To measure variables such as ECG, heart rate, respiratory rate, motion and skin temperature, sensors must be attached to the body of the patient. A microcontroller (MSP430FG439) from Texas Instruments [3] was used to sample all the sensors and send the data using a dedicated Bluetooth connection (Parani ESD100 from

Sena) [4]. A baud rate of 115200 bps was selected for the Bluetooth connection, given that six ADC channels should be transmitted with a sampling rate of 1600 Hz each. A battery and 3.3 V voltage regulator [5] ensured that the microcontroller, Bluetooth module and other electronic components receive a stable 3.3 V supply. Each of the four sensors is described in more detail below:

A. Electrocardiogram circuit

The main component in the ECG circuit is Texas Instrument's INA322EA integrated circuit (IC), a micro power single-supply complementary metal-oxide-semiconductor (CMOS) instrumentation amplifier with a very favorable common mode rejection ratio (CMRR) of 60 dB. The design is based on a design provided in TI's datasheet for the INA322EA component and incorporates some of the design elements from a four-lead ECG system designed by researchers at MIT's Media Lab as part of the Every Sign of Life project [6].

B. Lung sound transducer circuit

The Panasonic WM-61A Omni directional Back Electret-Condenser Microphone Cartridge and a two-stage operational amplifier circuit were used to monitor the acoustic signals.

C. Temperature

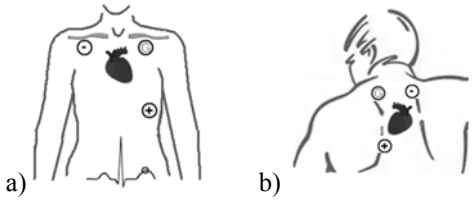
Progressive hypothermia can be prevented by early detection with a temperature probe. The Maxim DS600 analogue temperature sensor was selected due to its small size and good accuracy [7]. The probe was attached to the patients back using regular ECG electrodes.

D. Accelerometer

The accelerometer is intended to measure the motion of the patient. When the patient is moving too much, the ECG and acoustic sound data will not be transmitted, to ensure that false readings are avoided as these sensors are sensitive to movement artifacts. When this occurs, a warning message will be displayed on the screen to prompt the clinician to visit the patient. The MMA7260QT is a 3-axis accelerometer manufactured by Freescale Semiconductor [8] and offers programmable dynamic ranges of 1.5, 2, 4 and 6 g (where 1 g = 9.81 m/s^2) and a controlled sleep mode.

E. ECG Electrode placement

The three ECG electrodes are incorporated onto the dorsal mounted device. ECG electrodes are normally placed on the chest of the patient (Fig.2a). To measure the same ECG rhythm as if on the front of a patient, the placements appear reversed to obtain the same electrical vector across the heart. The placement used in the device is shown in Fig.2b.



a) b)

Fig.2. a) Chest b) Dorsal ECG placement of probes

F. CAD and prototype of electronic protection enclosure

Computer aided design (CAD) was used to design a computer model with all the design considerations discussed above. All the external components (battery, PCB and Bluetooth module) were drawn to scale and it was ensured that they fit inside the protection enclosure without interfering with the external protection enclosure, as shown in Fig.3a. The dorsal mounted prototype (Fig.3b) is placed on the back of the patient between the left and right scapula and the ECG electrodes are mounted on a spring system. The ECG electrodes will be placed to the right and left of the patient's vertebral column. To ensure that the device stays in place and to reduce the movement of the electrodes on the skin, a very strong adhesive plaster will cover the entire device and keep the device attached to the skin between the left and right scapulas.

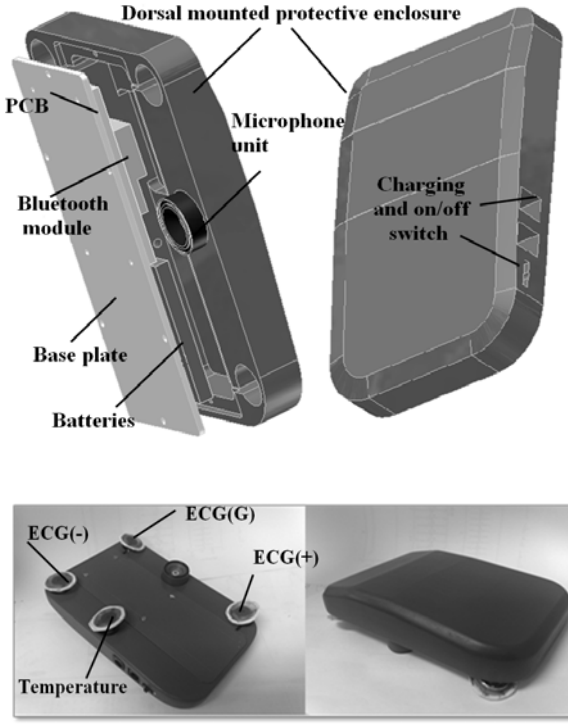


Fig.3. a) CAD model including batteries, PCB and Bluetooth module
b) Final prototype of dorsal mounted device

IV. SAFETY GLOVE DEVICE

This device will be mounted on the wrist with a finger clip probe (M1190A oxygen saturation probe from Hewlett Packard (HP) [9]) fitted to the index finger. The protective glove will be attached over the hardware enclosure and finger clip to protect the wires and the probe. This device will measure two photo plethysmography (PPG) signals and calculate the oxygen saturation ratio value from the two PPG signals (red 660 nm and infrared light 910 nm).

A microcontroller (MSP430FG439 from Texas Instruments) is used to sample the PPGs and send the red PPG signal together with the calculated ratio value using a serial communication protocol to the host system, using a dedicated Bluetooth connection (Parani ESD100 from Sena). The

main code structure for the pulse oximeter measurement was obtained from Texas Instruments pulse oximeter design application notes [10]. For this application an oxygen saturation level of less than 90% will indicate that the patient requires medical attention and an alarm will be sounded when this threshold is reached. The most common problems with PPG are due to its use of optical sensors. These optical sensors are susceptible to motion artifacts. Psychotic patients will not always be motionless during measurements, and remaining still for an extended period is necessary for accurate measurements. Thus, it is reasonable to expect that motion artifacts will be introduced. The motion can be detected with an accelerometer and will assist in knowing when to take measurements.

A final implementation of a prototype together with the proposed placement of the device to the patient is shown in Fig.4. The final prototype was used to sample the PPG signal in Fig.5.

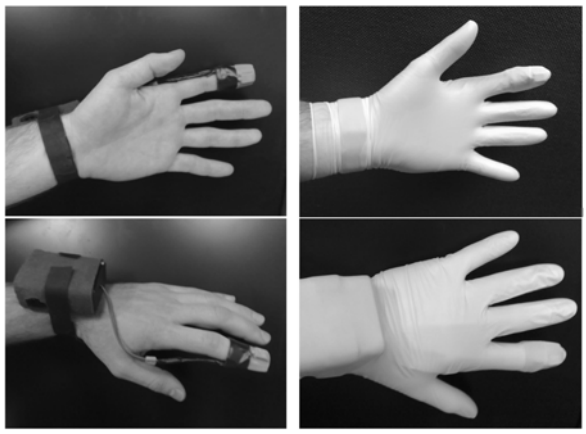


Fig.4. Final safety glove prototype

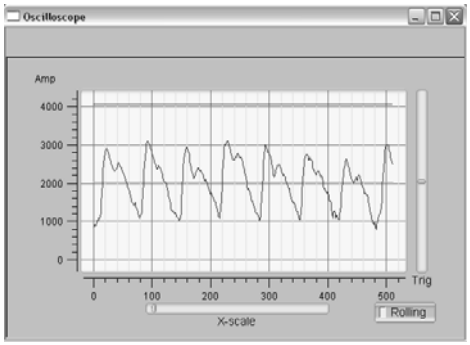


Fig.5. Measured PPG signal from safety glove prototype

V. SIGNAL PROCESSING

A. ECG

The raw ECG signal is filtered with a 10 Hz lowpass Butterworth filter to remove noise, as shown in Fig.6. A peak detection algorithm was developed to calculate the heart rate.

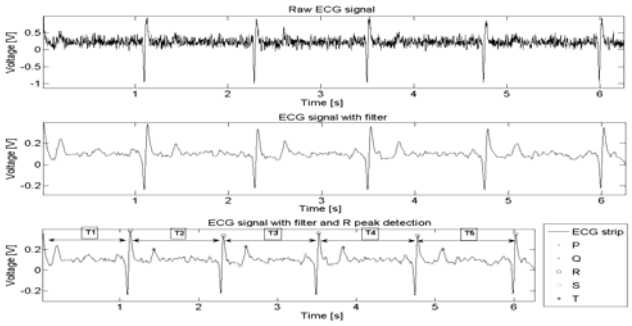


Fig.6. ECG raw, filtered and peak detection graphs

A. AF and PVC

The heart rate variability (HRV) graph is used to detect a sudden change in heart rate. If the R-R interval (which is linked to HRV) changes suddenly with more than 50 ms above the average threshold it is classified as a "missing beat" and will then be recognized by the system as a possible atrial fibrillation (AF) [11]. A Premature Ventricular Contraction (PVC) occurs when an "extra" heartbeat is detected. When the HRV curve drops below the average threshold with more than 50 ms, a possible PVC is detected, as shown in Fig.7a and Fig.7b.

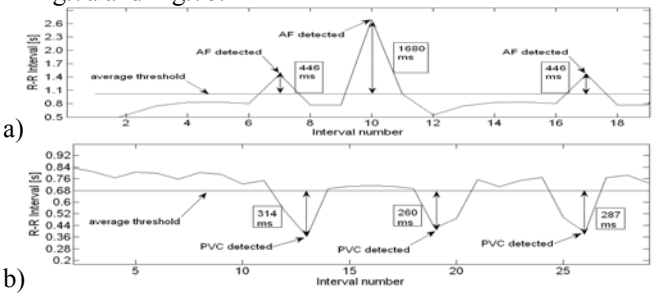


Fig.7. a) Atrial fibrillation detection using HRV graph b) PVC detection using HRV graph

B. Respiratory rate

The raw sound signal is bandpass filtered between 187 Hz and 300 Hz to filter out the heart sounds and any unwanted noise. This respiratory signal is then rectified and lowpass filtered (1Hz) to obtain an envelope of the respiration signal. The envelope signal is then used for peak detection to calculate the respiratory rate. All of these steps are shown in Fig.8.

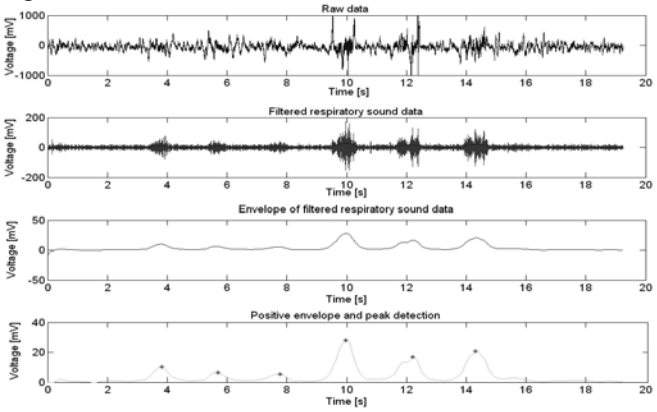


Fig.8. Respiratory rate detection using filters and peak detection

VI. RESULTS

Verification of all the sensors was done to ensure that the device was functioning as proposed. As it is difficult to measure changes in vital signs on psychotic patients in a psychiatric hospital, five healthy volunteers were asked to perform different activities to measure the changes in these variables. From Table 1 it is clear that the system can detect and calculate heart rate, respiratory rate, temperature, and oxygen saturation accurately.

Volunteer	HR Test1	HR (Polar) Test1	HR Test 2	HR (Polar) Test2	Difference HR % Test1	Difference HR % Test2
1	69	70	140	140	1.5	0.0
2	52	52	108	107	0.0	0.9
3	65	67	163	165	3.1	1.2
4	65	67	134	135	3.1	0.7
5	48	49	161	161	2.1	0.0
Volunteer	**ARR Test1**	**ARR (Counted) Test1**	**ARR Test 2**	**ARR (Counted) Test2**	**Difference ARR % Test1**	**Difference ARR % Test2**
1	19	18	41	38	5.6	7.9
2	13	12	36	34	8.3	5.9
3	15	15	48	46	0.0	4.3
4	14	14	49	49	0.0	0.0
5	15	15	30	31	0.0	3.3
Volunteer	**Temp [ºC] Test 1**	**Temp[ºC] – Test 2**		**S_aO_2 [%] – Test 1**		
1	36.8	36.9		93.6		
2	37.0	37.1		94.3		
3	37.0	37.1		92.8		
4	36.9	37.0		93.1		
5	37.1	37.2		92.9		

Table 1. Calculated heart rate (HR) values from device and Polar heart rate monitor [12]. Calculated and counted respiratory rate (ARR). Measured temperature (Temp) and oxygen saturation (S_aO_2).

VII. CONCLUSION

Two prototypes that measure the required vital signs were manufactured and tested. Both devices are suitable for use in a psychiatric patient environment. The GUI, shown in Fig.9, was developed to wirelessly receive the sensor data and continuously calculate the vital signs for medical emergencies. All the different sensors were tested and usable results were obtained as shown in Table1.

VIII. FUTURE WORK

The mechanical strength of the prototypes was not tested, since only a "proof-of-concept" design was undertaken in this project. Therefore mechanical strength tests should be done on the prototypes to ensure that the prototypes can be used with psychotic patients. The prototypes should also be tested and verified that it fulfils electromagnetic compatibility (EMC) regulations, before a commercial product can be implemented. Further research should be done on implementation of continuous blood pressure monitoring for such patients.

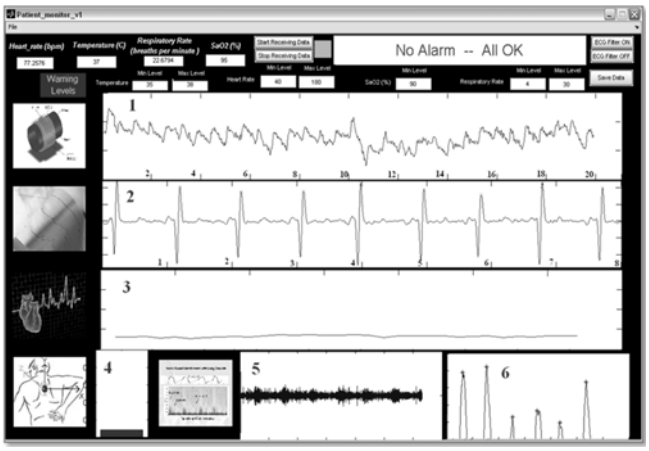


Fig.9. Matlab GUI of patient monitoring system receiving data and display and monitor the different vital signs

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