Design and Development of an Airborne Biomedical Signal Device for Urgent Care Situations

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***Abstract*—As the financial cost of electronics is constantly decreasing and new electronic modules are being introduced to the market, the development of many healthcare applications becomes easier, cheaper and more prospects are created for various healthcare related fields. Some of these fields are the pre-hospital care and the telemedicine, which have a lot to contribute to modern healthcare provision. The purpose of this paper is to present the development of an electronic biomedical device that will measure and send a number of biosignals, while at the same time being lightweight enough to be transferred by an unmanned air vehicle to achieve a better pre-hospital service in case of urgent care situations. The system was built trying to keep the total cost on a low level. Finally, some measurements were taken to check the device's proper functionality and conclusions were drawn.**

***Index Terms*—urgent care, unmanned air vehicle, biomedical signals**

I. Introduction

The healthcare field comes with great opportunities for the development and application of new and already existing technologies. The introduction of these technologies targets in increasing the efficiency of the medical personnel, decreasing the time required for a diagnosis and securing medical services of excellent quality. Pre-hospital care is considered to be an extremely important field of medical services, as it tries to minimize further systemic injury and manages life-threatening conditions by ensuring patient's safety. In addition, pre-hospital care acts as an index for patients' condition before they arrival at the hospital unit, in which they will be given a proper care plan. Moreover, it contributes to the in-time preparation for the confrontation of the incident. Telemedicine, another field of equal importance, refers to the clinic care provided by distance via the application of telecommunication technologies. The combination of these fields for the development of an electronic system is the main subject of the present study.

The aim of this project is the design and the construction of an electronic device which will measure a total of biosignals and will transmit the measurements, while having the capacity to be transported by an Unmanned Air Vehicle (UAV). For the purposes of this project, we used a DJI phantom 3 Pro quad copter in order to serve multiple tasks which will contribute to achieve a better pre-hospital service. First of all, the use of the aircraft targets to a fast transfer of the medical device into a specified radius from the ground-based controller. The active radius of our application depends on UAV's technical characteristics. Secondly, assuming that there is an emergency situation, the UAV will reach the place sooner that an ambulance and as a result it could help towards an estimation of the situation, which could provide useful information to the medical personnel arriving to the place. The above assumption could be very useful for situations like road accidents or rescues on rough environments (e.g. mountains). In the case in which the medical personnel is not able to reach the place, the UAV can drop the device and the system will establish a telecommunication link between a doctor and the patient. Thus, a telemedicine activity will take place

For these reasons, a research for the existence of relevant devices took place. Additionally, the status for the flights of unmanned aircraft and all different telecommunication methods that can be used to achieve the transfer of the measured data, were studied. Furthermore, in order to facilitate the understanding of the construction part, some useful meanings were introduced. More specifically, the total of protocols which are being used by the biomedical device for the interaction between the central processing unit and the sensors were underlined. Then, each module was designed and materialized trying to keep the total cost on a low level. Finally, some measurements were taken as it was important to check if the device worked as it should; then the measurements were analysed to provide the relevant results and conclusions.

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II. Biosignal Receiving Applications

Over the last years a variety of telemonitoring medical systems have been developed. The Yale-Nasa mobile patient monitoring system was one of them; this system was developed in 1998-1999 in order to monitor the physical condition of a group of mountaineers, in real time, under tough environmental conditions on high altitude. The Yale-Nasa monitoring system used to send data via satellite link, as this was the only choice because of the high altitudes [1]. Recent applications like the open software and hardware, e-Health Sensor Shield v2.0, targeted to go in with diagnosis, the monitoring of patients who suffer from chronic diseases, the increase of prenatal controls, epidemic monitoring and the train of Colombia's medical personnel. The e-Health Sensor shield v2.0, is able to collect data of (a) Peripheral Oxygen Saturation (SPO2), (b) Galvanic Skin Response (GRS), (c) heart Beats Per Minute (BPR), (d) body temperature, (e) respiratory flow, (f) glucose blood level, (g) electromyography (EMG) and (h) electrocardiography (ECG) via a sensor network. This network communicates with the Central Processing Unit (CPU) via the Serial Peripheral Interface (SPI) bus and the collected data are sent using the LTE (Long Term Evolution) network providing an encrypted communication, which is really important considering the fact that sensitive data are transferred [2]. Another noteworthy platform is the Biosignal Igniter Toolkit (BIT). BIT is a complete toolkit as it has its own hardware, the BITalino board and a software toolkit with a variety of applications. The most important part of the software is the real time data visualization, OpenSignals. The BITalino board can be used for the measurement of ECG, EMG, Electrodermal Activity (EDA) and acceleration (ACC). However, the platform cannot be recognized as a telemedicine device without the use of an external communication system [3]. Finally, the TeleCare system is an application which aims to save time for the patient and reduce hospitalization time for patients who suffer from hypertension. The TeleCare device communicates via Bluethooth with an Android compatible device, which collects and transmits the measured data to a remote server. On a more practical level, the device is consisted of a Blood Pressure Reader (BPR) and a Beat Per Minute reader (BPM). The Android device can be used for the measurement of the environment condition and the patient's position detection. An interesting feature of TeleCare is the registration of data which can be done manually and automatically on a specified time using a variety of communication protocols, such as GSM (Global System for Mobile Communication) and LTE [4].

III. Unmanned Air Vehicles (UAVs)

An Unmanned Air Vehicle (UAV) is an aircraft which is able to fly without a human pilot onboard and can be controlled by a ground-based controller. Although UAVs have been developed years ago, their cost decreased on a significant level over the last three years, while at the same time their capabilities have increased [5]. Thus, there is a great opportunity to use UAVs for pre-hospital care and Search and Rescue (SAR) cases. On the other hand, there are some limitations regarding the UAVs flights, as the uncontrollable use of unmanned aircraft can be dangerous [6]. At this time, unmanned air crafts (like the one used in our case, shown in Fig. 1 [7]) have already been used in healthcare, for example Matternet corporation, DHL, Zipline, Flirtey and the Delft University have used UAVs in several places to transport medicines, vaccines, blood or even defibrillators [8]-[10].

Figure 1. DJI Phantom 3 PRO [7].

An existing limitation is that there is a flight control system from the civil aviation services of each state for the efficient air traffic control and the avoidance of possible accidents. Thus, the UAV pilot has to be certified as local laws define and he/she has to provide a flight schedule to the local civil aviation service in order to receive a flight permission. This procedure is essential and may differ from state to state. However, it decreases the response time on emergency situations and it must be respected for the general safety point of view.

To the best of our knowledge a low-cost biosignals UAV has not been used or tested for urgent care situations, allowing us to experiment and validate a system using existing components in a new area. Although a recent review identified cases for out-of-hospital cardiac arrest emergencies, identification of people after accidents and transport of blood samples and one used drone to improve surgical procedures in war zone in a recent review [11], however none of them offered a variety of biosignals-related functionalities to this end.

IV. Biomedical Device System

As our electronic device aims at the pre-hospital care, we chose to make use of a variety of biomedical sensors in order to make a biomedical system easy to use and serving of general purpose. As a result, the system is able to measure human body temperature, environmental temperature and humidity, SPO2, BPM, ECG and blood pressure. The results of the above measurements are depicted on a 3.5 inches TFT touchscreen and are stored in an SD memory card. For the central micro processing unit (MCU) of our system we decided to use an Arduino MEGA 2560 compatible board as it is a low cost but efficient board for our project. The maintenance of the system's total cost on a low level was one of the main aspects of our project and as a result it determined the choice of sensors:

For the body temperature sensor, the DS18B20 (Fig. 2) from Dallas Semiconductor was chosen as it maintains a descent price-reliability ratio and it is compatible with the systems MCU via One-Wire protocol. Furthermore, it turns out that the mean error for temperatures between 10 and 30 Celsius degrees (c) is equal to -0.2 (C) from the typical error curve of the sensor [12].

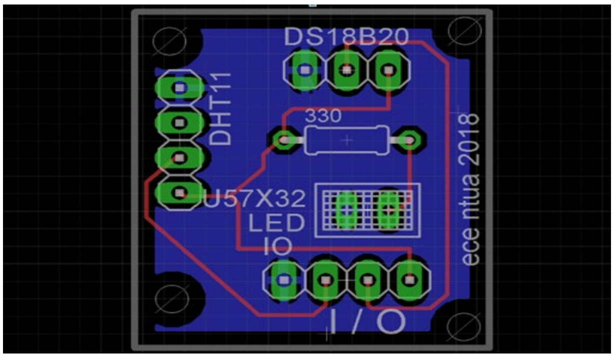

Figure 2. DS18B20 and DHT11 PCB board.

The environmental conditions are able to affect the measurements, thus the DHT11 module was chosen to achieve an evaluation of the environmental temperature and humidity (Fig. 2). DTH11 is a product of AOSONG and it uses an NTC thermistor for the measurement of temperature and a variable resistance which depends on humidity for the measurement of humidity. At this point it should be noticed that DHT11 has a 5 per cent humidity mean error and +/- 2 C mean error under 25 C of operation. This module needs 3.5 to 5.5 Volts (V) power supply and the communication with MCU is established via One-Wire protocol [13].

The SPO2 and the heart beats per minute are being measured with the use of the MAX30100 integrated circuit. MAX30100 has two light diodes (LEDs), one red with wavelength at 650nm and one infrared with wavelength at 950nm, the two LEDs are transmitting light into the human finger and the MAX30100 measures the light absorption. The sensor communicates with Arduino Mega using the Inter-Intergrated Circuit (I2C) bus and it works under 1.8 to 3.3V [14].

The Blood Pressure is measured from a CK101 BPR and the values are being transmitted to a module based on Arduino NANO 328p via Universal Asynchronous Receiver Transmitter (UART) protocol in order to convert the UART signal to two analog values for an easier signal management from Arduino Mega 2506.

In addition, the ECG module is an open hardware module base on AD8232 integrated circuit developed from Sparkfun and it is a single lead heart rate monitor. As a module it is really cost-effective and easy to use as it needs only three electrodes for the measurement of heart's electric activity. It operated under 3.3 V power supply and has an analog voltage which make the communication with MCU easy.

Finally, we chose to use for the graphic depiction of ECG and the exposure of the total of biosignals, a 3.5 inches 320x480 TFT resistive touchscreen, which is able to communicate via Serial Peripheral Interface (SPI) and I2C bus; it has also embedded an SD card slot which permits the handling of a memory card.

The complete biomedical system is shown in Fig. 3.

Figure 3. Complete biomedical system.

V. Measurements

In order to examine the correct operation of our electronic device we proceeded with measuring a total of 10 adults, choosing to exclude children as their examination demands special oriented medical equipment. The sample was formed by 5 women and 5 men. Furthermore, it should be underlined that the youngest participant was 20 years old and the oldest one was 63 years old (Table I). More details about the sample's characteristics are given at the Table II.

TABLE I. Participants Age Group

O/N	1	2	3	4	5	Median Value	Mean Value
Men	21	23	24	24	63	24	31
Women	20	23	25	25	55	25	29,6

The measurements were taken while the participant was seated and on an idle state. Additionally, a specific sequence for the placement of sensors was followed, to ensure that the participants would have the least possible constrains on their moving ability at the measurement time. Moreover, the measurements were taken at the same place for electromagnetic compatibility reasons.

TABLE II. MEASUREMENTS (1)

i/n	Sex	Age	BodyTemp (C)	Env. Temp (C)	Env. Hum. (%)	Sp02 %
1	F	20	36.25	28.00	29,00	97
2	F	23	36.44	24.00	80,00	97
3	F	25	36.25	23.00	81.00	96
4	F	25	36.65	24.00	82.00	96
5	F	55	35.88	25.00	80.00	97
6	M	21	36.00	30.00	27.00	97
7	M	23	36.88	30.00	26.00	97
8	M	24	36.69	28.00	29.00	97
9	M	24	36.5	27.00	35.00	97
10	M	63	35.5	30.00	27.00	96

TABLE III. MEASUREMENTS (2)

i/n	BPM	SYS. CK.	DIA. CK.	BPM CK.	ECG
1	84.65	94	63	88	normal
2	79.06	106	67	97	normal
3	110.3	103	65	105	normal
4	84.7	122	80	85	normal
5	77.19	109	68	87	normal
6	64.6	114	78	67	normal
7	89.72	135	93	92	normal
8	84.42	110	65	87	normal
9	72	119	69	78	normal
10	83	182	111	88	normal

TABLE IV. BPR AND ARDUINO BLOOD PRESSURE VALUES

SYS. CK. Hgmm	DIA. CK. Hgmm	SYS. ARD Hgmm	DIA. ARD Hgmm	Diff. SYS Hgmm	Diff. DIA Hgmm
94	63	97.95	68.7	3.95	5.7
106	67	11.7	69.20	9	2.2
103	65	107.4	71.20	4.4	6.2
122	80	126.9	87.95	4.9	7.95
109	68	107.9	69.45	1.1	1.45
114	78	121.7	82.95	7.7	4.95
135	93	149	96.95	14	3.95
110	65	120.7	66.7	10.7	1.7
119	69	125	75	6	6
182	111	193.7	119	11.7	8

On each participant we let the device to make ten complete measurement cycles to ensure that the system's memory has been refreshed and no garbage values are stored in memory. In Table II and Table III, the sixth measurement cycle was presented. From a statistical point of view, on the sixth measurement cycle the transition stage was over and the next measurement cycles were the same.

During the measurement procedures we noticed that the measured values from BPR's screen were different from the blood pressure values of Arduino. These differences are shown in Table IV.

VI. RESULTS

After the measurements phase, we reached certain results which had to do with the response time of the sensors and the credibility of the whole system.

Regarding the response time (Table V), it was noted that the DHT11 and the ECG sensors were the fastest as they respond almost instantly. On the other hand, the MAX30100 sensor had a bigger response time as 20 seconds passed from the time of the placement of applicant's finger and the depiction of the result. About the BPR, it was expected that it would need more time as before the reading of blood pressure values, a pump has to work in order to tighten the BPR on the applicant's wrist, the estimated time response of the BPR was 50 seconds. Finally, the biggest response time was noticed for the DS18B20 thermometer which needed 300 seconds to transit from 25 Celcius degrees (environmental temperature) to human body temperature.

TABLE V. RESPONSE TIME

System	Time
DS18B20	300 s
DHT11	-
MAX30100	20 s
BPR	50 s
ECG	-

Despite the normal operation of the system, an unexpected behavior was observed. The measured values from BPR's screen were different from the blood pressure values of Arduino, the mean values of that difference are 7.34 Hgmm for systolic and 4.21 Hgmm for diastolic blood pressure.

It should be noted that the device is light enough to be carried by a DJI phantom 3 or any other unmanned aircraft with mass bigger that a kilogram (1 Kg) and Maximum Take Off Mass (MTOM) bigger than two kilograms (2 Kgs). Thus, no problems were occurred at the time of transportation

VII. FUTURE WORK AND RESEARCH SUGGESTIONS

Some acts that may contribute to achieve a better, faster and more stable result can be attempted. On the software level, the optimization of program's code could provide better response time and the digital signal processing could increase measurement's accuracy. On the hardware level, the study of electromagnetic conductivity and filter's application would reduce noise levels on inputs. In addition, the use of common power supply between Arduino and BPR may eliminate the error between their values.

VIII. Conclusion

Appreciating the importance of telemedicine and pre-hospital care in modern healthcare systems, as well as the full and future potential of electronics and UAVs, we designed and developed a biomedical device aimed to assist urgent care incidents. To the best of our knowledge this was a first attempt for a UAV system to be used for urgent care situations. The main features of this device were the low financial cost in relation to its reliability and its capability to be transferred by an unmanned aircraft. Consequently, certain tests were conducted in order to study the specifications of the device (e.g. response time) and to verify its stable performance. The analysis of the measurement procedures verified most of our initial hypotheses, allowing us to recognize the limitations and plan our next steps towards a future trial of a related scenario

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Ioannis Panagopoulos conducted the research along with Panagiotis Katrakazas. Ioannis Panagopoulos and Panagiotis Katrakazas wrote the paper, while Dimitrios Koutsouris supervised the whole process. Panagiotis Katrakazas and Dimitrios Koutsouris corrected the draft paper. All authors approved the final version.

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