Arduino based System for Indoor and Outdoor ECG Monitoring
Functions and Extended User Model Ontology

Carmelo Pino and Alfio Costanzo
Department of Electrical, Electronics and Computer Engineering,
University of Catania, Viale Andrea Doria 6, Catania, 95125, Italy

Keywords: Health Monitoring Systems, Arduino Shields, ECG Sensors, General User Model Ontology.

Abstract: In this paper a system for monitoring the environment and biometric parameters like ECG for cardiac patients is presented. Monitoring Health Environment can be considered important like monitoring the patient in direct way. In this paper we propose an architecture consisting of a sensors network to monitor the patient environment in conjunction with other biometric parameters like ECG with the aim to control the health status in outdoor and indoor conditions. The monitoring system makes use of different sensors such as: oxygen level, air quality, humidity, temperature, ECG, integrated with an Arduino controller. The observed data are sent via GPRS or Wi-Fi to a server to activate the regulation of the environment conditions. Patient environment and health status can be monitored in remote way by mobile thanks to a specific App.

1 INTRODUCTION

Nowadays monitoring the patient during its daily activities represents an essential tool in order to understand her/his health status (Cho, 2010), (Gargiulo, 2010). Some typology of patients spends most of the day at home, and consequently monitoring the environment conditions can be useful to enrich the set of information about the patient status.

Patient status depends on different factors dealing with the specific pathology, but often environmental conditions could affect the patient health too.

Usually in the telemedicine applications (Xie, 2010), each patient is monitored by a specific sensor to collect data and by a communication module to send the biometric data to a remote center. Data received are passed to a doctor to check if the patient conditions are critical and to plan the required intervention.

Often a first intervention can be done by simply modifying the environmental conditions (e.g., improving the oxygen concentration, modulating the room temperature, humidity or light conditions, etc.). For this reason, in the telemedicine projects we find an increase of systems for remote patient monitoring, portal equipment and specific homecare devices (Cho, 2010).

The idea behind this work is related to the creation of a system that allows us to carry our an indoor monitoring of the patient health status by using the proper biometric and environment sensors with the aim of regulating the environment conditions when needed. Also, patients in outdoor condition are monitored to plan first aid rescue or to suggest suitable actions in case the patient status is becoming critical. In the latter case, we will take into account weather and traffic conditions so that the patient decisions or the external interventions may take into account of both the patient ambient and the urban context in which s/he is located.

Although the methodology may be used to monitor the patient affected by any pathology, in the paper we take into account cardiac patients since they represent a suitable field of application of the proposed approach. The system architecture to monitor the environment temperature, humidity, air condition and oxygen concentration has been developed by using an Arduino controller provided with the appropriate set of shields and it is described in a companion paper, whereas the sensors in order to measure the patient ECG in both indoor and outdoor conditions are illustrated in this paper.

The requirement of accessing the user data from any remote computing system to plan the right

Pino C. and Costanzo A..
Arduino based System for Indoor and Outdoor ECG Monitoring - Functions and Extended User Model Ontology.
DOI: 10.5220/0004762203310335
In *Proceedings of the International Conference on Physiological Computing Systems* (PhyCS-2014), pages 331-335
ISBN: 978-989-758-006-2

interventions is fulfilled by using a suitable extended user ontology, named GUMO+, proposed in (Costanzo, 2013) consisting of all the personal and context data useful for supporting the needed health assistance systems in either indoor and outdoor conditions. In the next section, details about the system architecture and functionalities are given, whereas in sect. 3 hardware materials and the implementation methodology are pointed out. Sect.4 briefly describes how the mentioned extended user model ontology may be used for implementing the open and interoperable data organization needed for an effective ubiquitous health assistance system. In the concluding remarks, a comparison with similar works is done and ideas for future developments are given.

2 SYSTEM ARCHITECTURE AND MAIN FUNCTIONS

The proposed system is based on a network of sensors connected to an Arduino controller. The set of sensors has been chosen to monitor the environmental conditions and the cardiac patient conditions. For this aims we have used:

- Sensors for biometric data acquisition, in particular for ECG acquisition (Celler, 2003). The ECG is acquired through specific electrodes connected to the patient in order to retrieve pulsation and possible critical situations (e.g. Tachycardia, arrhythmia, etc.). The electrodes are connected to a module that can be brought by the patient in a pocket. Data collected by the ECG sensors are transmitted via GPRS or Wi-Fi to a server.
- Sensors for environmental data acquisition, in particular for: oxygen concentration, air quality, temperature, and humidity. This set of sensors is positioned in different room of the patient house.
- Actuators: the actuators are used to interact with the devices present into the patient house, in particular we recognize the actuator for aeration conductors, heating boiler, and dehumidifier.

The architecture supports indoor and outdoor scenarios:

- Indoor: in this first scenario we assume that the patient is at home and the information about the ECG are combined with information coming from the other environment sensors positioned in each room.
- Outdoor: in this second scenario we assume that the patient is outside the home, and then only the data about ECG are considered, whereas a GPS module is used to identify the position and relative speed of the patient. In the outdoor scenario not only this information to understand the correlation between the patient speed and number of pulse is used but also the car traffic and weather data stored on the city server to better plan the patient rescue.

Data collected from the sensors with an Arduino module (fig. 1), are stored in a micro SD according to the mentioned GUMO+, i.e., the user ontology, named GUMO (Heckmann, 2005), powered by a mobility ontology, e.g., (Faro, 2003), and successively sent to a microcontroller that works like a Web Service (WS) (see fig. 2).

The Web Service receives the data and returns the response to the actuators drawn in fig. 2 to modify the environment conditions. In particular, the data coming from the sensors S1, S2 and S3 dealing with humidity, temperature and luminosity are collected by the Arduino (ATMEL 2560) and sent to the WS through the GPRS module. Each home device influencing the environment conditions (e.g., radiator, dehumidifier, air conditioner) is actuated when needed.

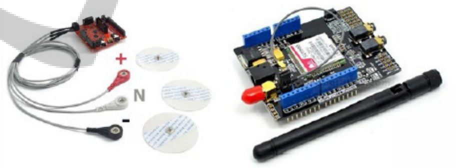

Figure 1: ECG with the acquisition shield (left) and the GPRS shield for data communication (right) used in the implementation.

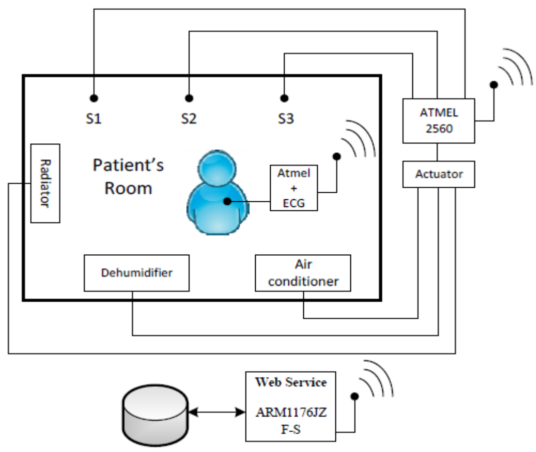

Figure 2: Indoor Monitoring System Architecture.

Different combinations of data coming from the sensors can be considered as critical conditions. With the term “critical conditions” we mean all the situations in which a patient could be in hazardous health conditions. Indoor and outdoor thresholds to delimit the normal conditions are as follows (Basilakis, 2007):

Indoor - a) Relaxation State: 100 bpm with a speed less than 10 Km/h; b) Sustained Activity: 150 bpm with a speed greater than 10 Km/h.

Outdoor - a) Humidity: 100 bpm and humidity greater than 30%; b) Oxygen concentration: 150 bpm and oxygen concentration less of 18%. c) Temperature: if temperature is greater than 26 C° and the pulse is less than 80 bmp.

When one of the thresholds is exceeded an SMS or an alert message is sent to relatives, doctor or hospital first aid service that may access the Web Service to evaluate the situation.

3 HW MATERIALS AND SW IMPLEMENTATION

The architecture consists of different hardware and software modules. HW modules are as follows: a) Arduino Mega 2560, a microcontroller based on ATMEGA2560, b) E-Health Shield is an Arduino compatible board that allows us for health monitoring. It’s has different types of sensors such as pulse, oxygen in the blood, respiration, body temperature, ECG, glucometer, pressure, patient position, c) GPRS and GPS Shields, and d) Raspberry Pi single-board computer with a 700 MHz processor and a GPU.

The software modules implement the functionalities illustrated in the previous sections, i.e.: a) Software for ATMEL 2560 implemented on the Arduino Mega for the acquisition of the data coming from the sensors and for controlling the environmental devices, and b) Software for ECG to collect the data coming from the ECG sensors that are worn by the patient. The acquired data are sent by a GPRS module to the Web Service.

The Web Service has been developed to offer a suitable processing data service due to the low processing capabilities of the Arduino mega shield. The data coming from the Arduino mega shield are sent in JSON format to WS where they are stored in XML/RDF format as shown in fig. 3 so that the patient data base could interoperate with other authorized applications. Also, the Web Service is able to process the data in order to automatically change the environment conditions and manage any critical cardiac situation.


```
{ "DATE": {       "HOUR": "9",
                  "MINUTE": "12",
                  "SECONDS": "55",
                  "DAY": "19",
                  "MONTH": "6",
                  "YEAR": "13" },
"POSITION": {    "LATITUDE": "3731.5928",
                  "LAT": "N",
                  "LONGITUDE": "1504.4885",
                  "LON": "E"
                  "ANGLE": "357.27",
                  "ALTITUDE": "110.50"  },
"INDOOR": {      "HUMIDITY": "22",
                  "OXYGEN": "18",
                  "TEMPERATURE": "24"   },
"OUTDOOR": {     "SPEED": "0.63"    },
"ECG": {          "PULSE": "132"  } }
```


Figure 3: Example of JSON code for both Outdoor and Indoor scenarios.

Smartphone APPs allow the patient to monitor her/his health status and the doctor to monitor the patient at distance using a mobile. Fig.4-left shows the APP interface that allows the user to visualize the data coming from each sensor and to fine control the environment conditions.

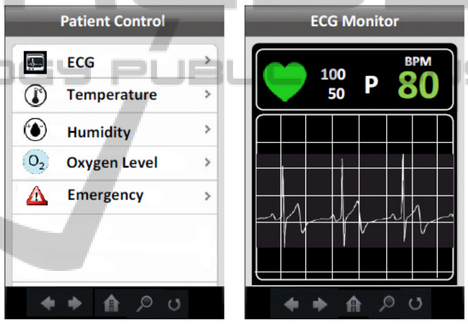

Figure 4: APP functions (left) and ECG displayed on mobile.

The circuit used by the Arduino system to measure the environmental conditions is illustrated in a companion paper (Costanzo, 2014), whereas the ECG may be displayed on the mobile as shown in fig.4-right using a specific APP visualization procedure.

4 EXTENDED USER MODEL ONTOLOGY FOR E-HEALTH

All the data coming from the Arduino based sensors are coded in JSON. However, to allow the collected data to be used by any remote software applications it is necessary to adopt a standard codification system and an agreed ontology, i.e., a shared semantics about the terms used in the e-health application and their properties. For this reason, the data are converted into XML/RDF format and are organized according to the general user model ontology (GUMO) shown in fig.5.

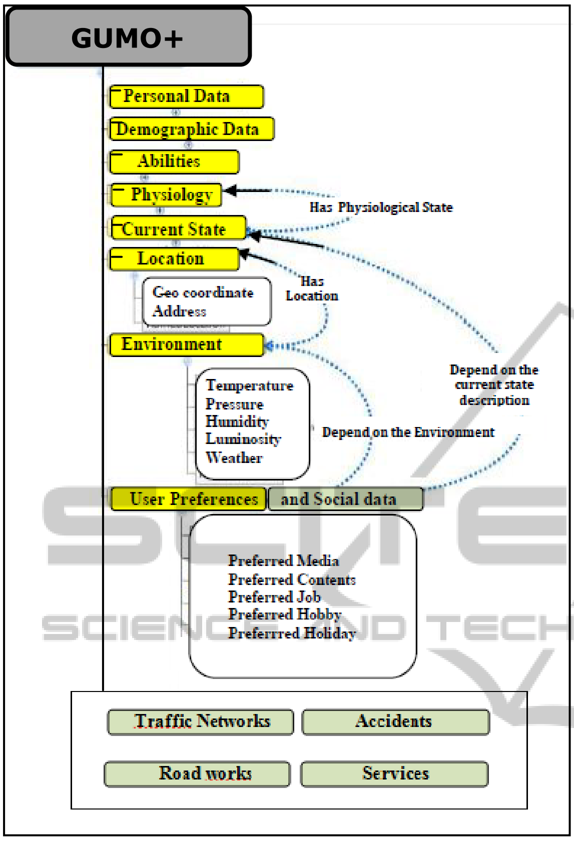

Figure 5: Extended user model ontology GUMO+.

In particular the biometric data follow the terminology of the *physiology* section, whereas the indoor and outdoor environment data are coded according to the section *environment*. Other GUMO sections of interest of our e-health application are the *current state* and *location*. The former to know how the status of the user (current task, activity and possible disease) evolves over the time, the latter to know in which road s/he is driving/waking or in which room s/he is located.

However, the need of mobility information to implement an effective user health assistance, implies that the GUMO sections should be extended to include information about the car traffic and the available health services at urban scale such as hospitals, and first aid centers. For this reason, further sections were added to GUMO dealing with *Traffic* and *Services* as illustrated by the extended GUMO, named GUMO+, drawn in fig.5.

Fig.6 shows a sample of representation of data of user interest in XML/RDF format according to the mentioned GUMO+ sections. Therefore, after collecting the user data according to proprietary protocols and formats, the monitoring systems should convert them in real time in standard formats so that all the collected data may used by the software processes resident on other computing systems to suggest to the users the most suitable actions depending on the *current state* and to plan the right first aid *services* in case of sudden illness.


```xml
<health>
  <datetime>
    <hour>9</hour>
    <minute>12</minute>
    <second>55</second>
    <day>19</day>
    <month>6</month>
   <year>13</year>
  </datetime>
  <ecg>
    <heart_pulse>132</pulse>
  </ecg>
  <environment>
    <indoor>
      <humidity>22</humidity>
      <oxygen>18</oxygen>
      <temperature>24</temperature>
    </indoor>
    <outdoor>
      <humidity>26</humidity>
      <oxygen>16</oxygen>
      <temperature>20</temperature>
    </outdoor>
  </environment>
  <position>
    <lat>37.540698</lat>
    <lng>15.128675<lng>
  </position>
  <traffic_condition>
    <link>
    <name>etnea-sout</name>
    <travel_time>125</travel_time>
   </link>
  </traffic_condition>
  <urban_services>
  <hospital>
    <name>Ospedale Cannizzaro</name>
    <address>Via Messina, 829</address>
    <phone>0957261111</phone>
  </hospital>
  </urban_services>
</health>
```


Figure 6: XML/RDF representation of data for e-Health.

Figure 7: Optimal path to be followed by an ambulance for timely rescuing a people.

In this way, any mobile software may access the data that will be provided to the users by using

Google maps based applications to display the nearest hospital to the patients which are able to drive or to walk, otherwise, the health assistance software should send the best path for the patient rescue, as illustrated in (Faro, 2008-2011), to the ambulance if the patient is in critical conditions as shown in fig.7. We plan to integrate the proposed system in the city information architecture named Wi-City (Costanzo, 2013) to offer a complete assistance to mobile people.

6 CONCLUSIONS

In this work a simple and cheap system to monitor at distance the cardiac status of a patient during her/his daily life has been presented. The system is provided with wearable sensors for cardiac data detection (ECG) (Costanzo, 2014). Correlating data from multiple sources allows the system to identify the more appropriate actions for the patient health status. Before activating the interventions of the rescuers, the system regulates the indoor environmental conditions by using sensors to measure indoor conditions and domotic equipments.

In the paper we taken into account only cardiac sensors, but other wearable sensors have been added to the proposed architecture, thus increasing the pathologies the system can manage, e.g., in the mentioned companion paper, a similar system to measure blood pressure and respiration rate with a portable system is illustrated.

In the future the proposed e-health assistant will be able to monitor other types of relevant information e.g. emotional status that will be identified with specific wearable sensors, such galvanic skin response, and by recognizing facial features by computer vision techniques (Faro, 2006), (Radhakrishnan, 2013) even in noisy context (Cannavò, 2006), (Crisafi, 2008).

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