A Real-Time Infant Health Monitoring System for Hard of Hearing Parents by using Android-based Mobil Devices

Faruk AKTAS[1], Emre KAVUS[1], Yunus KAVUS[1]

[1]Kocaeli University, Department of Biomedical Engineering, Kocaeli, Turkey
faruk.aktas@kocaeli.edu.tr, emrekavus@gmail.com, yunuskavus@gmail.com

Abstract: *In this study, a real-time infant monitoring system by using android-based mobile devices is developed and implemented in order to be used especially for hard of hearing parents. An Arduino Leonardo board has been used in the system design along with body temperature sensor, sound detection sensor, finger heartbeat detector, and humidity sensor. In order to notify alarm conditions to the parents, an android-based application has been developed. It is observed that the data collected from the sensors are monitored in real-time and the alarms are set off successfully when abnormal conditions occurred.*

Keywords: *Infant monitoring systems, hard of hearing parents, microcontroller and android-based application.*

1. Introduction

Recently, with the development of technology, home healthcare and remote monitoring of physiological data have gained importance. It is a popular implementation to track home healthcare of patients, particularly babies.

An infant monitoring system basically includes sensors and a microcontroller. A biomedical sensor device is capable of sensing several vital physiological and physical data (ECG, body temperature, SpO_2, heartbeat, blood pressure, wetness etc.) from human bodies or environment and sending them to the microcontroller by using analog or digital outputs. It is important that the monitoring system generates alarms in abnormal conditions. Various wireless infant monitoring systems were previously proposed for different purposes [1-13].

One of the most important physiological data to track in such monitoring systems is body temperature, i.e. infant fever. Changes in body temperature of babies have a key role in the diagnosis and treatment of diseases. In particular, rapid febrility in babies can cause vital damage. Therefore, the body temperature should be continuously monitored. The inability to adjust the temperature of the environment may cause excessive perspiration or cooling for premature or weak-born babies. The maximum body temperature range should be 36-38 ^{o}C for these babies. Another crucial parameter to track is heartbeat rhythms. Cardiac arrhythmia can cause sudden deaths of infants [4], so continuously monitoring of the infant's heartbeat rhythm may be required. A finger heartbeat sensor is a low-cost, noninvasive and user-friendly device for monitoring heartbeat rhythms. It is also important to monitor bedwetting and perspiration of babies. When the parents are too late to intervene to bedwetted babies, intertrigo problems may emerge. In this case, the baby may be unrestful, sleeping disorders and febrility may occur. Excessive perspiration may cause the infant be dehydrated, resulting in illness or exacerbation of existing disease. In all of those cases, the sound level of baby crying is a kind of natural alarm. In particular, the detection of a baby crying is therefore very important especially for hard of hearing parents.

The major advantage of homecare systems for infant monitoring is that these systems can automatically collect physiological data without the requirement for parents to constantly check infants, and can generate an alarm for abnormal conditions. It is easy for healthy parents to react immediately to those alarm conditions. However, it may not be possible for hard of hearing parents to react a baby crying or a voice alarm instantaneously. Therefore, alarm notifications must be visual or vibrant for those parents.

In this study, a real-time infant monitoring system by using a microcontroller and android-based mobile devices is developed and implemented in order to be used especially for hard of hearing parents. With the developed system, the physiological signals collected from an infant body are continuously monitored, and an alarm is generated in abnormal conditions. An Arduino Leonardo board has been used in the system design along with a body temperature sensor, a sound detection sensor, a finger heartbeat detector, and a humidity sensor. In order to notify alarm conditions to those parents, an android-based application which is executable on all Android-based smartphones has been developed. Notification of alarm

Received on: 05.02.2017
Accepted on: 14.03.2017

situations has been successfully provided via a vibrating smartwatch, SMS, and LEDs (Light Emitting Diode) using Arduino board and android-based applications. The experimental studies show that the developed system provides a time-saving implementation for home care infant monitoring systems.

The paper is organized as follows: In section 2, components and architecture of the developed system are explained, and the design and implementation of the system are presented in section 3. The paper is concluded in section 4 with final remarks.

2. System Architecture

The real-time infant health monitoring system for hard of hearing parents has been designed and implemented by using Arduino Leonardo boards and android-based mobile devices. The developed system includes sensors, an android-based smartphone, a vibrating Smartwatch for those parents, and a microcontroller that evaluates the received data from the sensors and generates an alarm when emergency conditions occur. It is important to note that an the android-based application namely "Infant Monitoring" has been developed in order to send alarm events to Smartwatch. The architecture of the system is illustrated in Figure 1.

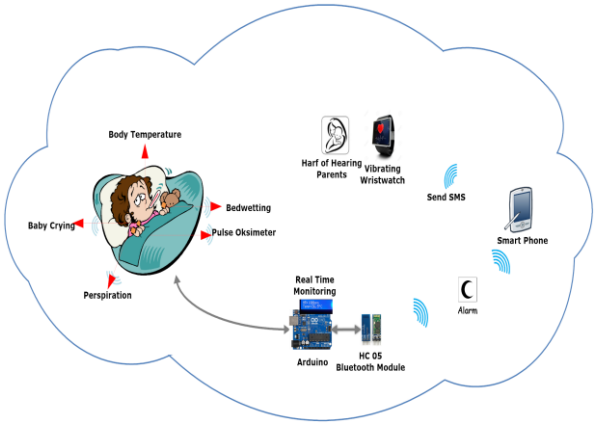

Figure 1. Infant monitoring system for hard of hearing parents

In the following, components of the developed system are explained in detail.

2.1. Components of the System

The system consists of several components;

- Atmega32u4 microcontroller on Arduino Leonardo board
- LCD screen
- Android smartphone
- Vibrating smartwatch
- HC-05 Bluetooth module
- Body temperature sensor
- Finger heartbeat sensor
- Humidity sensor

The Arduino Leonardo development board have been used to collect data from the sensors and evaluates these data to create cases which trigger the alarm. It is a microcontroller board based on the Atmega32u4. It has 20 digital input/output pins (of which 7 can be used as PWM outputs and 12 as analog inputs) which enable to collect and process many physiological data [14].

In order to monitoring body temperature of the infant, a waterproof version of the DS18B20 temperature sensor have been used [15]. The analog body temperature raw data collected from the sensor is converted into the actual temperature data using a microcontroller.

The KY-039 finger heartbeat sensor compatible with Arduino boards has been used to monitor the infant heartbeat. The sensor consists of two components, namely an infrared phototransistor (sensor) and an infrared LED (IRLED). The heartbeat is obtained according to the amount of light passing through the finger between the IRLED and the sensor [16].

The T1592 humidity sensor has been used for wetness sensing. This sensor can be used to monitor both infant bedwetting and perspiration.

The KY-037 sound detection sensor has been used in order to detect baby crying. Sound detection sensor has two outputs: Analog output (A0) is real-time microphone output port. D0 port generates a high and low-level signal when the sound volume reaches the threshold. The threshold-sensibility can be adjusted via the potentiometer on the sensor.

Bluetooth is a wireless standard (IEEE standardized Bluetooth as IEEE 802.15.1) for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices. The HC-05 Bluetooth module has been used for the notification of alarm situations to send wireless to the parents via the android-based smartphone [17].

Smartwatch has been used to inform parents with a vibration alarm. This device is able to communicate with the android-based smartphone via Bluetooth technology. Before using this device, "Bluetooth notice" (BTNotification) application is required to be installed on an android-based smartphone in order to automatically synchronize the device. Smartwatch has a user interface to display "message" and "remote notice" from a smartphone. Additionally, it is able to receive notification of each application or send a reminder, including SMS alerts, and other messages/reminders. The Smartwatch can be charged via micro USB and can standby time up to 120 hours. This low-cost device with vibration features is an ideal choice in the notification of the parents.

3. Design and Implementation

We now present experimental studies the developed system by using aforementioned components and the android-based application. Experimental studies of infant health monitoring system for hard of hearing parents have been carried out in a laboratory environment and physiological data was collected from an adult.

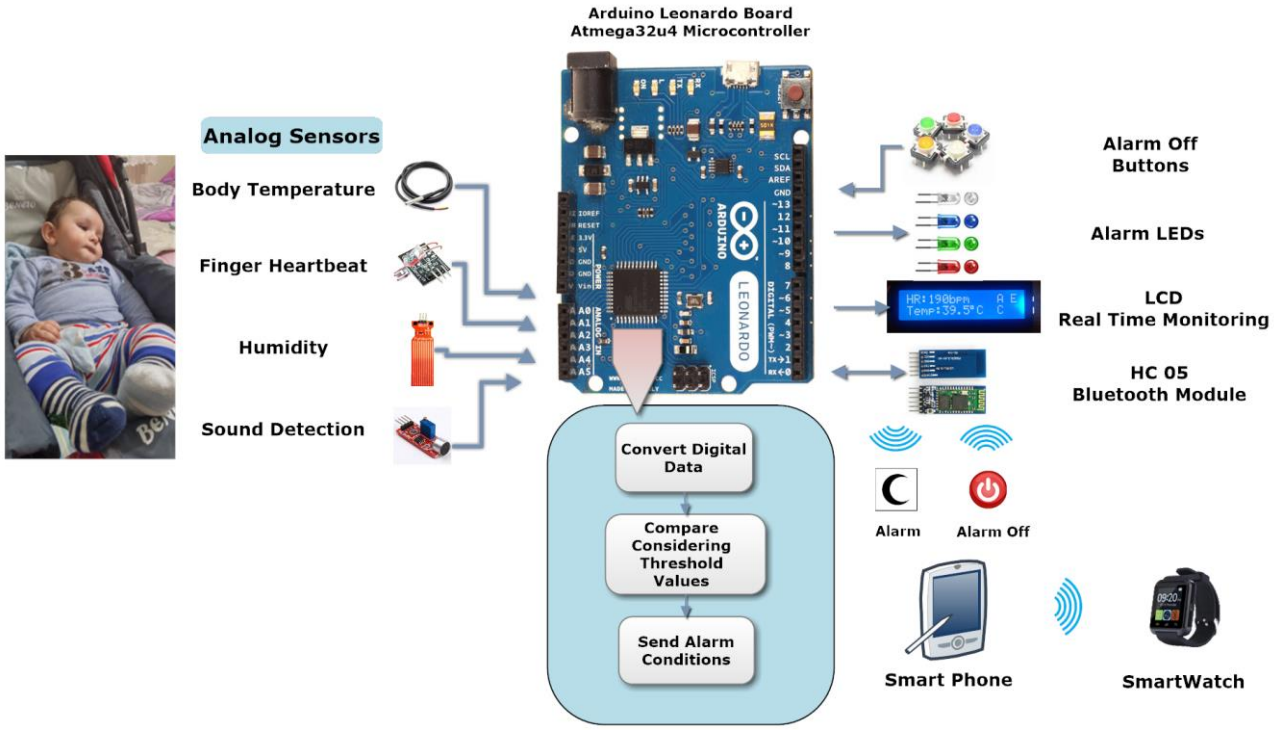

Figure 2. Hardware connection diagram

3.1. Hardware Design

The microcontroller performs three important functions; converting the physiological data collected from the sensors to digital raw data, generating an alarm using digital raw data according to the determined conditions, and providing notification to the parents. In this context, the hardware connection diagram and microcontroller process procedure of the developed system are depicted in Figure 2.

As shown in Figure 2, the sensors (i.e. body temperature, finger heartbeat, humidity, sound detection sensors) are connected to the Arduino Leonardo board via analog inputs. Body temperature sensor is attached either to the armpit or finger of an infant for accurate measurement results. The humidity sensor can be used for two purposes; detecting bedwetting or perspiration. It is placed in the infant's nappy for bedwetting detection, and on the back of infant for perspiration detection. Heartbeat data is collected by attaching the finger heartbeat sensor to the infant's finger. Sound detection sensor is placed at a distance to the infant for baby crying detection.

In the microcontroller firstly the physiological data collected from the sensors are converted to digital raw data using analog-digital converter (ADC) module. ADC module resolution is 10 bits in the Atmega32u4 microcontroller. The raw data collected from the sensors displayed on the LCD screen are normalized considering real values. For example, while the infant body temperature is 36 degrees, the raw data values obtained from the sensor is 75. By the normalization process, the raw data value of 75 is converted to the real value of 36 degrees.

The process after conversion of the analog data to normalized digital data is the determination of the alarm conditions. Special alarm conditions have been determined according to the data collected from sensors in order to alert the family in abnormal situations. The digital data is compared with the corresponding threshold values for alarm conditions. A character code has been assigned for each alarm condition. The codes, cases, and conditions of the alarms are given in Table 1.

Table 1. Alarm codes and alarm conditions

	Alarm code	Alarm Causes	Alarm Condition
1	A	High heartbeat	>135 bpm
2	B	Low heart beat	<80 bpm
3	C	High body temperature	>38 °C
4	D	Low body temperature	<34 °C
5	E	Bedwetting or perspiration	Wetness
6	F	Baby crying	Threshold value exceeded 15 times

It can be seen from Table 1 that alarm conditions are generated if the infant's fever reaches 38 °C (alarm code "C") or falls below 34 °C (alarm code "D"). Alarm conditions for the data obtained from the finger heartbeat sensor have been determined for high heartbeat (alarm code "A") or low heartbeat (alarm code "B") in accordance with the age range of infants. For example, the 0-5 month baby's heartbeat is 100-160 bpm (bit per minutes), 6-12 months baby's heartbeat is 80-140 bpm [2]. In this study, the boundary values are

chosen 80-135 bpm (1-3 years age) bpm for alarm conditions. The alarm thresholds have been determined under different conditions in the detection of bedwetting and perspiration. An alarm is generated when the wetness level reaches different threshold values for bedwetting or perspiration detection (alarm code "E"). For baby crying detection, a sound level threshold is prescribed. If this threshold is exceeded continuously (e.g. more than fifteen times) in a specified time duration (e.g. 10 sec), an alarm is generated (alarm code "F"). This mechanism avoids any false alarms in case of short duration and/or low-level sound changes.

The last process performed by the microcontroller is to notify the alerting cases to the parent. In the event of an alarm, both the related LED blinks and the related alarm code is displayed on the LCD screen. At the same time, alarm information is sent to the android-based smartphone via Bluetooth module to notify the vibrating Smartwatch. The parents can manually turn the alarm off by pressing a related button. Figure 2 shows the LCD screen for a high heartbeat, high body temperature, and bedwetting or perspiration alarm conditions.

In the next section, the developed android-based application for notification of alarm cases to those parents is introduced and explained in detail.

3.2. Android-based Application

We now introduce the android-based application, an important component of the developed system. Android is a mobile operating system developed by Google, based on the Linux kernel and designed mainly for touchscreen mobile devices such as smartphones and tablets. In this study, a user interface on the android-based application has been developed that performs several functions to notify the parents of alarm conditions. The android-based application was developed in the App Inventor web application. The prime advantage of the developed application is that it can work on all Android phones and not only just on a special phone. App Inventor for Android is an open-source web application originally provided by Google and now provided by the Massachusetts Institute of Technology (MIT) [18]. The android application is connected to Arduino Leonardo board via Bluetooth module. When it receives alarm information from the Arduino, the android application sends an SMS containing alarm information to the parents. At the same time, the phone vibrates and gives an alarm message for a second. The application user interface is shown in Figure 3.

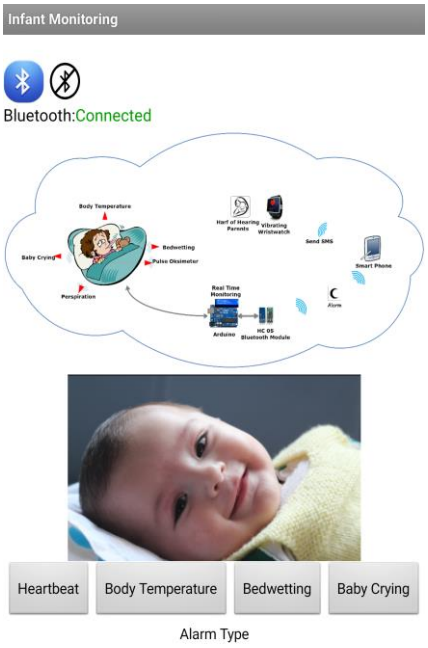

Figure 3. Android application user interface

As shown in Figure 3, there are two buttons on the user interface of application related to the Bluetooth connection. Bluetooth connection defaults to "Not Connected". When the Bluetooth button (blue icon) is clicked, active Bluetooth devices in the vicinity of the smartphone are listed. After the HC-05 Bluetooth module is selected, Arduino Leonardo, is connected to the smartphone via Bluetooth and "Connected" is displayed (green text color) on the application screen. If the disconnect button (black-white icon) is clicked, the Bluetooth is disconnected and "Not Connected" is displayed (red text color) again on the application screen. With "BTNotification" application, it is possible to synchronize smartphone with smartwatch via Bluetooth. So when there is a notification on the smartphone, the smartwatch vibrates.

In the event of any alarm, the microcontroller system sends an alarm code to the android-based application via Bluetooth. When this code is received, the alarm notification procedure is activated in the application. A "Message Dialog Box" notification is generated according to the incoming alarm code and the smartphone vibrates for one second. The corresponding alarm information is displayed in the message box. At the same time, an SMS (containing the alarm condition) is sent to the previously defined (parents') phone numbers. The SMS provides a vibration by creating a notification on the smartwatch synchronized to the smartphone via Bluetooth. The android-based application and smartwatch screen for baby crying and bedwetting alarm is shown in Figure 4 and Figure 5, respectively.

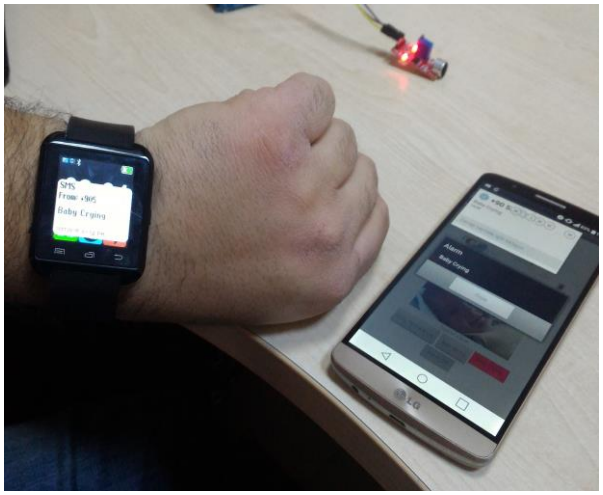

Figure 4. Smartphone and smartwatch screen for baby crying alarm

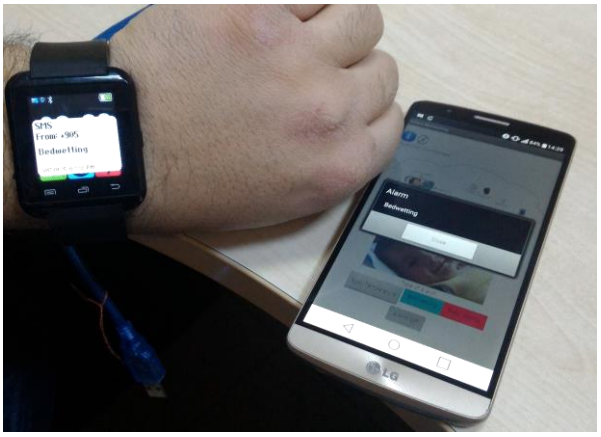

Figure 5. Smartphone and smartwatch screen for bedwetting alarm

As shown in Figure 4 and Figure 5, in the case of an alarm, the related button background color changes in the "Alarm Type" section, and the previously invisible "Alarm Off" button becomes visible. When the "Alarm Off" button is clicked, information related to closing the alarm is sent to the microcontroller via Bluetooth and the alarm is deactivated and the related led is turned off. In the application, the related button returns to the previous state and the "Alarm stop" button becomes invisible again. The aim of the notifications is to inform the parents in case of any alarm. According to the alarm, the parents can either treat the baby themselves or take it to a medical center.

4. Conclusions

In this paper, we have presented a real-time infant monitoring system for hard of hearing parents, consisting of sensors (finger heartbeat, body temperature, humidity and sound detection), a microcontroller and android-based mobile devices (smartphone and smartwatch). In particular, a system has been developed that monitors both physiological data collected from infants and creates alarms for abnormal conditions.The designed and implemented system, developed on the Arduino Leonardo board, has been used in order to data collect data from the sensors and to create alarm cases by evaluating these data. Low-cost vibrating Smartwatch compatible with android-based smartphones has been used for notification of alarms to the parent. From the implementation results, it is observed that the data collected from the sensors are monitored real-time and that the alarms determined when abnormal conditions occur are notified successfully.

The implemented system is designed as an open system for improvement and other desired sensors can be easily added to the system. This study can be used not only for hard of hearing parents but also for healthy parents. In addition, the developed system, which is suitable for monitoring adult patients, can be used for general purposes. We remark that it would be useful to have some usability tests including an average of measurements (e.g. from 10 babies) for the purpose statistical evaluations of the proposed system, which will be considered as a future work.

5. Acknowledge

We thank all the reviewers for their invaluable comments.

6. References

[1] H. Cao, L-C. Hsu, T. Ativanichayaphong, J. Sin, J-C Chiao, "A non-invasive and remote infant monitoring system using CO2 sensors", in *IEEE Sensors 2007 Conference*, Atlanta, USA, 2007, pp. *989-992.*

[2] E. Saadatian, S. P. Iyer, C. Lihui, O. N. N. Fernando, N. Hideaki, A. D. Cheok, A. P. Maduapperuma, G. Ponnampalam, Z. Amin, "Low-Cost Infant Monitoring and Communication System", in *2011 IEEE Colloquium on Humanities, Science and Engineering Research (CHUSER 2011)*, Penang, CHINA, 2011, pp. *503-508.*

[3] S-H. Cheng, J-C. Huang, C-J Lin, "A real-time Location and Infant Monitoring System Based on Active RFID", in *Proceedings of the 2012 International Conference on Machine Learning and Cybernetics*, Xian, CHINA, 2012, pp. *1844-1849.*

[4] W. Lin, R. Zhang, J. Brittelli, C. Lehmann, " Wireless Infant Monitoring Device for the Prevention of Sudden Infant Death Syndrome", in *11th International Conference & Expo on Emerging Technologies for a Smarter World (CEWIT)*, New York, USA, 2014.

[5] S. Mohajerani, S. A. H. Moosavi, R-A. Rihawi, B. Ahmed, A. N. Bhat, R. Y. Kamal, "A Cloud-Based System for Real-Time, Remote Physiological Monitoring of Infants", in *IEEE International Symposium on Signal Processing and Information Technology (ISSPIT)*, Abu Dhabi, UAE, 2015, pp. *565-569.*

[6] H. Zhou, B. Goold, "A Domestic Adaptable Infant Monitoring System Using Wireless Sensor Networks", in *IEEE 34th International Performance Computing and Communications Conference (IPCCC)*, Nanjing, CHINA, 2015.

[7] A. G. Ferreira, D. Fernandes, S. Branco, J. L. Monteiro, J. Cabral, A. P. Catarino, A. M. Rocha, "A Smart

Wearable System for Sudden Infant Death Syndrome Monitoring", in *IEEE International Conference on Industrial Technology (ICIT)*, Taipei, TAIWAN, 2016, pp. *1920-1925.*

[8] P. Kumari, P. Goel, S. R. N. Reddy, "PiCam: IoT based Wireless Alert System for Deaf and Hard of Hearing", in *International Conference on Advanced Computing and Communications*, Coimbatore, INDIA, 2015, pp. *39-44.*

[9] M-J. Wu, S-F. Shieh, Y-L. Liao, Y-C. Chen, "ECG Measurement System Based on Arduino and Android Devices", in *International Symposium on Computer, Consumer and Control*, Xian, CHINA, 2016, pp. 6*90-693.*

[10] H. Deng, S. Chen, "Design and implementation of Android-based health and healthcare system", in *International Wireless Communications and Mobile Computing Conference (IWCMC)*, Paphos, CYPRUS, 2016, pp. *164-169.*

[11] S. Agezo, Y. Zhang, Z. Ye, S. Chopra, S. Vora, T. Kurzweg, "Battery-Free RFID Heart Rate Monitoring System", in *IEEE Wireless Health (WH)*, Bethesda, MD, 2016, pp. *136-142.*

[12] V. Wahane, "An Android Based Wireless ECG Monitoring System for Cardiac Arrhythmia", in *IEEE Healthcare Innovation Point-Of-Care Technologies Conference (HI-POCT)*, Cancun, MEXICO, 2016, pp. *183-187.*

[13] P. S. Chowdary, S. Aruna, "Infant Monitoring System", *International Journal of Computer Science and Communication*, vol. *2*, no. *2*, pp. *501-503*, July-December, 2011.

[14] www.arduino.cc/en/Main/ArduinoBoardLeonardo

[15] http://datasheets.maximintegrated.com/en/ds/DS18B20.pdf

[16] http://www.zoebachman.net/itp/?p=190

[17] https://www.itead.cc/wiki/Serial_Port_Bluetooth_Module_(Master/Slave)_:_HC-05

[18] http://appinventor.mit.edu/explore/

Faruk Aktaş received his B.S. and M.S. degrees in Electronic and Computer Education from Kocaeli University, Turkey, in 2008 and 2012, respectively. He is currently pursuing his Ph.D. degree in Biomedical Engineering at the Kocaeli University. His active researches are wireless body area networks, internet of things, microcontrollers and embedded devices.

Emre Kavuş currently pursuing his B.S. degree in Biomedical Engineering at the Kocaeli University. His interests include medical technology, biosensors, medical imaging and wireless networks.

Yunus Kavuş currently pursuing his B.S. degree in Biomedical Engineering at the Kocaeli University. His interests include medical technologies and device design, biosensors and medical imagin