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Original Research

Smart Portable Ice Bath Monitoring System for Athlete

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ABSTRACT

After athletic injuries, cold techniques are used commonly, with clear physiological effects. The main theory about the advantages of immersion in cold water is that it decreases skeletal muscle inflammation. This study was to design the electronic part of smart portable ice bath monitoring system for the athletes to use after their exercises. The design can capture cold water temperature reading and heart rate precisely during the therapy. The readings also were used to give out notifications and alarm to prevent cold related diseases. Various of components were listed and only the most compatible with the design were chosen. The criteria of the components are small, light in weight and the most important is waterproof. To have the portable design of cold-water immersion easy to use and understand, a smartphone application was created by using MIT App inventor, thus giving the athlete a platform to monitor their heart rate data and aware of the benefit and disadvantage of cold-water immersion. Three independent subjects' heart rates were recorded and compared to test the hypothesis that there is a significant difference in heart rate readings between the heart rate sensor and the Amazfit GTS 2. While three tests on the temperature of cold water were used to test the hypothesis that the temperature readings produced by temperature sensor and mercury thermometer had a significant difference. Response of the data from both tests were analysed by using a t-test. The results of both experiments revealed that the hypothesis was rejected, indicating that the heart rate sensor and temperature sensor are adequate for monitoring heart rate and cold-water temperature. They were displayed on the LCD display and the MIT app inventor application in a smartphone. The notification alarm is also effective. In conclusion, the study's objectives have been achieved, and the design can be applied in cold water immersion therapy.

INTRODUCTION

Cold treatment or ice bath is a well-established technique for treating severe soft tissue injuries. Cold is also used to minimize recovery time as part of the rehabilitation programme for both acute and chronic injuries. Cryotherapy has also been shown to reduce pain effectively in the post-operative period following reconstructive joint surgery. Cold raises the threshold for discomfort, viscosity, and plastic tissue deformation, but reduces motor efficiency. Cold tends to be safe and harmless, and few complications or side effects are recorded following the use of cold therapy. However, prolonged use at very low temperatures should be avoided as this can cause severe side-effects, such as frostbite and nerve injuries (Swenson, Swärd and Karlsson, 1996).

Cold treatment is easier to be done if it comes with a smart device. Smart devices are objects that can interact and calculate, ranging from basic sensor nodes to household devices and smartphones (Stojkoska and Trivodaliev, 2017). In smart devices, the notion of connectivity refers to creating a connection to a network of any scale. Often the primary aim may be to obtain internet access, other times it may be to exchange information with other devices. A few references to smart devices have suggested autonomous task efficiency. Zhang et al. (2013), explored the variables that play important roles in

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multitasking situations, requiring smart phones to have some computing abilities and to perform background tasks.

To make the smart cold treatment portable, wireless technology is used to exchange data and information between two points that are not connected directly. Technologies such as Bluetooth, Wi-Fi, Zigbee and Near-Field Communication utilize radio frequencies between two points to communicate. Data can be exchanged on a long-range, fast and secure with wireless technology (Chhabra, 2013). Therefore, this Final Year Project 1 is based on the combination of ice bath and smart portable device mechanism to obtain an easier way for athlete to make their cryotherapy.

Cold-water immersion (CWI) has appeared lately as one of the most common treatments to avoid delayed onset muscle soreness (DOMS) and facilitate post-exercise recovery. It is becoming popular among amateur athletes. People immerse themselves right after exercise in cold-water baths that range from custom built temperature-controlled spas to large containers filled with ice and water. Also in practice, there are major differences in the CWI protocols used in terms of immersion length, temperature of the water, and volume of submerged body parts. Sellwood (2007) recorded that there were three cycles of practice among "high-level sports in Australia," each comprising a one-minute immersion in ice water at about 5°C water temperature, followed by a one minute out, started after exercise. Even so, several clinical trials have used longer application times of 15 minutes (Banfi 2008; Vaile 2008a) and higher water temperatures of 15°C, respectively (Vaile 2008b).

There was a study by Kioumars and Tang (2011), where they made wireless network for health monitoring to measure heart rate and temperature. The Arduino microcontroller hardware and software, a TMP36 temperature sensor, a heart rate sensor, an XBee radio, and a wireless communication protocol form the system's core. They encrypt the heart rate and body temperature data and send it through an XBee network to a remote PC. The coordinator is connected to a computer that is running a programme that monitors and processes the data that comes in. The research presented has laid the groundwork for such a healthcare monitoring environment. The designed sensors can detect the average body temperature as well as the heart rate. A remote computer could acquire real-time data, execute analysis, and visualise the results using the wireless network. However, it is hard for them to run the test anywhere because they need to have a computer to receive all the data from the sensors. Nowadays, most athletes did cold water immersion for 15 minutes and 15°C therefore, a monitoring system that can read low temperature with an alert or notification features should be implemented in the therapy to improve the safety during the therapy. Hence, this project aims to design electronic part of smart portable ice bath monitoring system for athlete to use for their recovery, to develop a monitoring system that able to read optimum temperature of ice bath and alert the user when it is below 15 °C during the therapy and to determine and monitor the user's heart rate for the ice bath by using smartphone.

MATERIALS AND METHOD

Based on Figure 1, smart portable ice bath monitoring system electronic circuit was designed with Arduino uno as its main processor. It is ideal for making a design demo because it can be connected via USB cable to a computer and can simply upload programs to it. Arduino software runs on operating systems such as Windows, Macintosh OSX, and Linux thus it is compatible with any computer and laptop. Next, waterproof 1-wire Ds18B20 sensor was added to the circuit's breadboard with its wire temperature sensor DS18B20 DQ connected to Arduino Uno pin 2. DS18B20 VDD was connected to the BUS POS and have a 4.7K Ohm resistor connect within the leg and DS18B20 DQ leg. DSI18B20 GND connected with the BUS ground. The sensor to dip in the cold water had its DS18B20WP DQ leg inserted in the Arduino uno pin 4. It also connected with a 4.7K Ohm resistor and jumped to the DSI18B20WP VDD and direct it to the Bus POS. The last leg, DSI18B20WP GND was inserted in the Bus GND. One Wire library was installed in the Arduino IDE library. The codes were uploaded, then Arduino IDE Serial Monitor was open at a 9600 baud rate and the temperature displayed was in Celsius.

Next a pulse sensor to measure heart rate of the athlete was installed in the circuit with its SIG leg connected to the Arduino uno pin A3 and, VCC to the Bus POS and GND to the Bus GND. A light in the pulse sensor module supported in calculating the pulse rate. The light reflected changed when the finger was put on the pulse sensor, depending on the amount of blood within the capillary blood vessels. After that, a waterproof and small piezo buzzer CPE-243 were installed. Buzzer POS was connected to Bus POS and buzzer neg to TSBC377C or the NPN transistor's collector leg. The base of NPN transistor leg was connected to 1K Ohm resistor and direct to the Arduino uno pin 2. The emitter leg was attached to the GND. Cold water immersion recovery process took about 10 to 15 minutes at 20ºC to 15ºC. The buzzer sounded an alarm when the CWI process exceeds 15 minutes or below 15ºC to prevent the patient from getting a hypothermia. It also gave out alarm when the heart rate is rated lower than 60BPM to prevent bradycardia. The next step

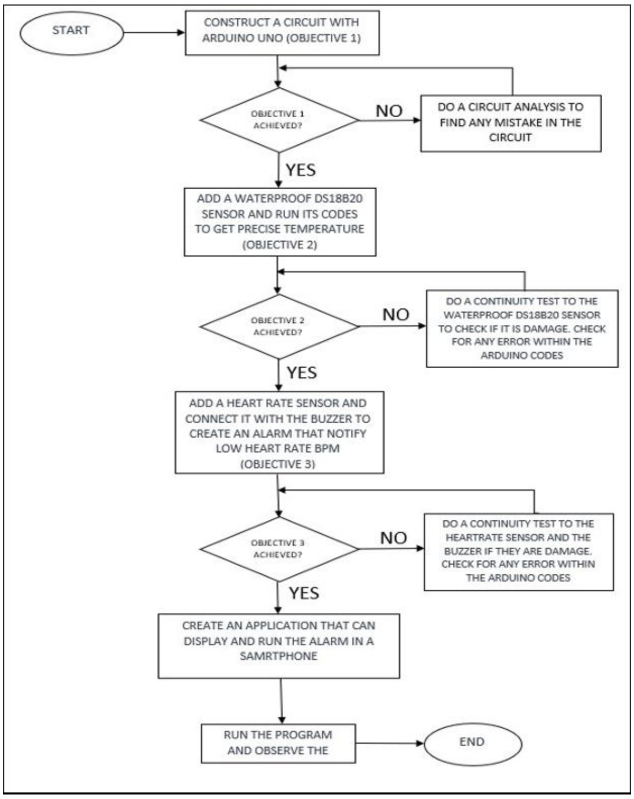

Fig 1 Project Flowchart

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was inserting the LCDs to display the cold-water temperature and heart rate BPM. LCD's SDA port was connected to Arduino uno A4 input while the SCL port connected to the A5 input. The VCC of the LCDs was placed in the Bus POS for its power supply and GND port connected to the Bus GND. Dual cell Lithium polymer DTP603450 battery were used in the design and they were rechargeable. The Lithium polymer DTP603450 battery needs to be connected to the Vin of the Arduino uno. Bluetooth module HC05 was also added to be used with an application from a smartphone. The transmitter pin was connected to pin 10 and receiver pin to the pin 11 of Arduino Uno. With all the components assembled, the design still small in size, light, and easy to carry.

Codes for the smart portable ice bath monitoring system electronic circuit were written in Arduino Integrated Development Environment or called as Arduino Software (IDE) version 1.8.13. IDE contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions, and can upload the codes to the board. The language used in the Arduino IDE is C++ with abstraction built in it, so it was simpler to write the codes and the circuit design for the Smart Portable Ice Bath Monitoring System for athlete is shown in Figure 2.

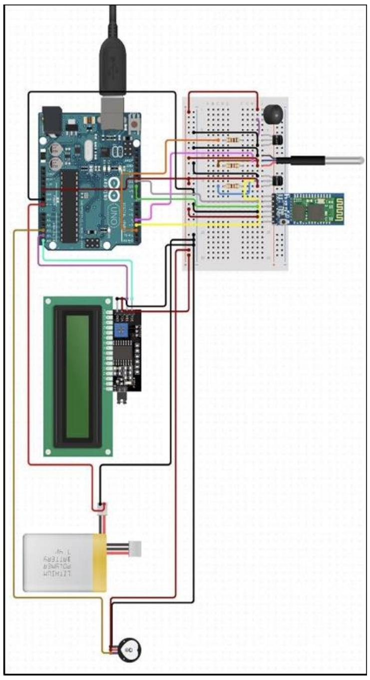

Fig 2 Smart Portable Ice Bath Monitoring System for athlete circuit design.

To use the application in a smartphone, there are two options that can be used. First, the MIT A12 Companion application can be downloaded from the google play and scan QR code in the Application inventor designer by using the MIT A12 Companion application. The mobile application will appear and can be used within the MIT A12 Companion application. Another method is by saving the apk file of the mobile application from the Application inventor designer then transfer it into smartphone to be installed. From the application created, user can connect the application via Bluetooth and monitor the heart rate data and CWI temperature. It also will give out alarm when the temperature is below 15ºC, time for the ice bath is more than 10 minutes and heart rate measurement is below 60BPM.

Heart rate sensor test procedure

The heart rate sensor test was done with three different subjects. The subject was asked to sit and remain calm. Amazfit GTS 2 smartwatch was worn by the subject and the heart rate sensor was placed beside the smartwatch. Next, Arduino Uno and Arduino IDE were turned on. Figure 3.12 shows the main screen of the Amazfit GTS 2. The smartwatch was then set to a free training mode. In this mode, the smartwatch will take the heart rate data of the user and the data will be save in Zepp App, which is the official mobile application for Zepp and Amazfit branded devices. Heart rate sensor was placed beside the smartwatch and was wrapped to prevent it from moving. Next, Tera Term software was turn on and pick the serial port 6. The Tera Term software will start taking heart rate data from the Arduino as the heart rate sensor was placed on the arm. Select log and write the wanted save data with .csv so that the data will be save in an empty Microsoft Excel. Start the test by pushing the "GO" button on the smartwatch and the reset button on Arduino Uno simultaneously and let both sensors collect the data for 10 minutes. The data taken by the heart rate sensor can be seen on the LCD display during the test. After the test was finished, next subject will follow the heart rate test procedure and new test was done.

Temperature sensor test procedure

Different with heart rate sensor test, there is no subject in this test. A container with 3-litre cold water was set. the Arduino was turn on and temperature sensor was left outside of the container therefore it was reading the room temperature. A mercury thermometer was also left outside of the container, and it read the room temperature. Next, Tera Term software was turn on and it will obtain the data from Arduino serial monitor which is the temperature readings from the heart rate sensor. Next, push the reset button on Arduino Uno and start immersing the temperature sensor and mercury thermometer simultaneously. Temperature sensor and mercury thermometer were placed oppositely in the container and not touch each other. The temperature reading from the mercury thermometer was taken every 10 seconds. Temperature reading from the temperature sensors was saved by the Tera Term software in Microsoft Excel. After the test finish, the temperature sensor and mercury thermometer were picked out. After both reach the room temperature reading, the second test for temperature sensor test was done and followed by the third test.

Data accuracy testing

The accuracy of the heart rate sensor and temperature sensor data were obtained. Some formulas have been used. Precision result formula was used to get the precision of heart rate in BPM for both heart rate sensor and Amazfit GTS 2 smartwatch. The result from both devices will be compared. The means of heart rate data from both devices were then compared using a t-test statistical procedure. The outcome was used in hypothesis testing to see if there was a significant difference in the heart rate data collected from the subject. Average deviation for both

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monitoring device needs to be calculated. To calculate the average deviation, summation of all values subtracted with the mean value then divide it with the total number of data values.

Hypothesis

Table 1 Hypothesis of the project

Parameters	Null hypothesis (H_0)	Alternate hypothesis (H_a)
Heart rate sensor and Amazfit GTS 2 heart rate reading.	There is a significant different between heart rate sensor and Amazfit GTS 2 heart rate readings.	There is no significant different between heart rate sensor and Amazfit GTS 2 heart rate readings.
Temperature sensor and mercury thermometer temperature reading.	There is a significant different between temperature sensor and mercury thermometer temperature readings.	There is no significant different between temperature sensor and mercury thermometer temperature readings.

Statistical analysis

The null hypothesis in this study is that for heart rate sensor test, there is a significant difference between heart rate sensor and Amazfit GTS 2 heart rate readings, and for temperature sensor test, there is a significant difference between temperature sensor and mercury thermometer temperature readings. In contrast, there is no significant difference between heart rate sensor and Amazfit GTS 2 heart rate readings, and no significant difference between temperature sensor and mercury thermometer temperature readings in the alternative hypothesis. A Type I error takes place when the null hypothesis is rejected when it is true, and the p-value is equal to 0.05.

RESULT AND DISCUSSION

Heart rate (BPM)

The precision results in Table 2. for heart rate sensor and Amazfit GTS 2 tested on all subjects show that both sensors manage to obtain the heart rate (BPM) within the normal reading of an adult's normal resting heart rate ranging from 60 to 100 beats per minute.

Table 2 Precision results of heart rate sensor and Amazfit GTS 2

Subject (n = 3)	Heart rate sensor (BPM)	Amazfit GTS 2 (BPM)
1	86.53 ± 10.68	91.80 ± 4.37
2	79.35 ± 6.07	84.20 ± 2.4
3	78.35 ± 5.50	75.60 ± 3.25

The average deviation, precision result, and t-test are calculated after all the required graphs have been obtained. The t-test obtained from all subjects' heart rate (BPM) mean taken with both sensor is more than $p = 0.05$. As $p = 0.45 > p = 0.05$, we reject the Hnull. Therefore, there is no significant different between heart rate sensor and Amazfit GTS 2. Thus, proving that there is no significance difference between both sensors. With that, heart rate sensor is suitable to be used to detect the heart rate of the athlete during the ice bath therapy.

Temperature (°C)

Based on Table 3, the t-test was obtained from the mean of temperature sensor and mercury thermometer in test 1, test 2 and test 3 is $p > 0.05$ ($p = 1.08$), thus proving that there is no significance difference between both sensors. With that, temperature sensor is suitable to be used to read the cold-water temperature during the ice bath therapy.

Table 3 Error percentage of temperature sensor and mercury thermometer.

Test (n = 3)	Temperature sensor (°C)	Mercury Thermometer (°C)	Percentage of Error (%)
1	132.51	153.5	13.68
2	133.26	154.5	13.74
3	139.39	160.5	13.15

Based on the results, the heart rate sensor and Amazfit GTS 2 shows inconsistence reading as expected since both sensors are different. This is because the Amazfit GTS 2 has the PAI Health Assessment System features, which uses an advanced algorithm to analyze data from the user's heart rate and other complicated health statistics and show the user's physical state as a simple, single-value score. The heart rate data from subject 2 and subject 3 were within the normal resting heart rate range, from 60 BPM to 100 BPM, but the result in subject 1 showed that there were several times that the data was exceeding the normal resting heart rate range. However, the heart rate readings with the Amazfit GTS 2 showed the consistent results that were always in the normal resting heart rate range. This might be affected by the vibration or slight movement of the heart rate sensor during the data were taken. Based on Table 2, the precision results for heart rate sensors by all subjects were higher than the heart rate precision results with Amazfit GTS 2. Even though the results were not consistence by comparison, the data still can be used to detect heart rate as the hypothesis obtained that there is no significant different between heart rate sensor and Amazfit GTS 2.

The result for temperature sensor and mercury thermometer shows the consistence reading. In every test, the temperature sensors always showed lower temperature result as compared to mercury thermometer. The pattern for all three tests is also the same because based on Table 3, the percentage errors for all tests are almost the same. Moreover, the t-test prove that the hypothesis stated in this study is rejected which is there is no significant different between temperature sensor and mercury thermometer. The surrounding factors like temperature and light did not affect the result of the tests. As precaution, the alarm system was turned off for temperature lower than 15°C because it will cause the temperature sensor to pause from taking the temperature reading. The alarm system will be turned off during the heart rate sensor test to prevent the heart rate sensor to stop working if the heart rate data is less than 60 BPM. Lasty, the buzzer will also give out alarm if the Arduino is run for 15 minutes.

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CONCLUSION

This study could design an electronic smart portable ice bath monitoring system that is portable and affordable to be used in aiding athletes in their recovery. The device is light in nature and easily used without the need of professional training. It is equipped with a small heart rate sensor and waterproof DS18B20 temperature sensor. The device can record any heart rate (BPM) readings from the user hand and able to alert the user if the heart rate is lower than 60 BPM. It also able to record temperature from -55°C up to 125°C. The alarm also will sound when the temperature is below 15°C therefore cold related disease can be prevented. Following that, the heart rate (BPM) of the athlete and the temperature (°C) of the ice bath can be revealed with the equipped LCD display.

The system includes a mobile application that is easy to manoeuvre by all group of people and contain information regarding the ice bath therapy. The mobile app also shows real time heart rate (BPM) and temperature (°C) reading from the device. The device can be easily connected to the mobile app via Bluetooth and easily indicated by the connection label. The application itself does not require a lot of memory storage (10.54MB). Hopefully, the development of this system able to contribute to facilitating athlete recovery.

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