Sweat Sensing Technique for Wearable Device Using Infrared Transparency

Masa Ogata[1], Masahiko Inami[2], and Michita Imai[1]

[1] Graduate School of Science and Technology, Keio University,
3-14-1 Hiyoshi, Kohoku, Yokohama 223-8522, Japan
{ogata,michita}@ayu.ics.keio.ac.jp
[2] Graduate School of Media Design, Keio University,
4-1-1 Hiyoshi, Kohoku, Yokohama 223-8526, Japan
inami@inami.info

Abstract. Wearable devices that are worn on the hand and display information are rapidly becoming pervasive. However, acquiring and displaying a user's own data, such as the amount of sweat flowing and the required amount of water for a particular activity, on a wearable device remains difficult. We propose a technique that senses the amount of sweat flowing from the human body. The technique, which is implemented in a wearable device, utilizes infrared transparency via a sponge that can hold the sweat. We selected sponge as the material to hold the sweat because it enables repeated measurement of the amount of sweat flowing from the human body. Consequently, we also outline the development and testing of a prototype device that actualizes the proposed technique and discuss its efficacy and feasibility.

Keywords: Sweat, Wearable device, Sensing, Photo transparency.

1 Introduction

Sporting activities are beneficial to human health for numerous reasons [12], [16]. Human beings maintain control over their health and improve their ability to keep their temperature stable when they exercise. Exercise also provides spiritual stability and physical flexibility. In recent times, particularly in urban areas, people tend to spend longer hours doing office work and sitting on chairs while working. Besides office workers, persons who work at home, and self-employed persons who use computers and sit on chairs need suitable exercise. This trend and change in the work environment increases the need for exercise. Therefore, humans have to obtain and allocate sufficient time for exercise. Hence, sporting activities including light exercise such as walking are becoming popular. Light exercise is beneficial for calorie consumption even if one exercises at night. From elementary school to high school, physical education is included as part of the education curriculum. Exercise is regarded as an elemental curriculum for developing a basic part of humanity and physical foundations.

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Although there are many benefits for engaging in sporting activities, caution needs to be exercised in several areas. People can experience temporary disorders from over-exercise and are injured if they are not careful. One of the reasons for experiencing illness and disorder during exercise activities is hydration; which is associated with excessive sweating and heat disorder. Thermal fatigue is also caused by dehydration. Sweat contains water and electrolytes. Prolonged heating and sweating of the human body induces water loss. In extreme cases, it can result in loss of electrolytes from the body via vomiting. It is well known that water leaves the body via our breath, urine, and sweat. During physical activities, the perspiration that automatically flows to cool the body is the largest amount of water that leaves the body. Sweat is emitted from all parts of the body except for the palm of the hands and the soles of the feet. Consequently, it is possible to detect and measure the state of sweat on various parts of the body. A number of researchers have conducted studies associated with sweat detection [2], [3], [4], [13]. Some of these studies attempt to determine the pH level of the sweat. However, to the best of our knowledge, detection of the amount of outgoing sweat with a wearable device that can be removed easily has not been proposed. Of the many applications supported by wearable devices, functions that are specialized for sporting activities appear to be most in demand. Initially, wearable devices were conceptualized for entertainment use, such as listening to music while running. However, concomitant with miniaturization and improvements in sensing technology, it became possible to measure and sense health status and condition during sporting activities and to quantify and visualize the data. Notwithstanding, research into new technologies and techniques for sensing during sporting activities is needed to enhance the lives of human beings.

In this paper, we propose a durable sweat sensor that uses photo reflective sensing via a sponge material that holds the water. The sensor and sensing techniques are implemented in a wearable device that a user uses during sporting activities and is easy to put on before starting the activities. Infrared has already been used in several related studies [9], [10] and has proved useful for decoding many kinds of units such as distance, density, pressure, and transparency via certain materials. By incorporating it into a sweat sensor device, it will help to augment sporting activities, which are elemental for human beings. With miniaturization, improved markets, and the increasing pervasiveness of mobile devices, wearable devices are increasingly being developed and gaining in popularity. Some of the applications available for wearable devices also focus on sports and exercise use. The functions implemented in wearable devices augment human activities in sports. For example, armband-type devices such as Fitbit Flex [5] provide data collection for health care, record time-series data by mobile application, and provide recommendations. Wearable cameras that enable users to capture various sights during their sporting activities, such as skiing, swimming, and cycling, are also available. Further, a variety of wearable devices are available for every type of sport.

2 Related Work

2.1 Augmenting Sport with Technologies

Higuchi et al. [7] conducted a study in which they used a camera aboard an unmanned aerial vehicle (UAV) to capture a user's rear view. The research focused on using the third person view afforded by the UAV to allow the user to see his/her own body image and thereby improve his/her training technique. Tracking is done by detecting the color of the user's clothing and continuously tracking thereafter.

Swimoid [14] is an underwater robot for swimmers that provides a display on top of the robot showing the user's body. The robot is automatically controlled and moves in concert with the user's position in the water in order to keep the display in view of the user. This enables swimmers to recognize their own body movements and swimming form via the display, which is captured and processed while using a colored band on the user's body to aid in tracking.

Kurihara et al. [8] augmented kinesthetic sensation using a mechanical structure. Their idea improves the user experience during push-up activities by effecting vivid sensations according to the user's movements. Mechanical feedback against the arm movement produces a rotary switch feeling. They plan to develop a virtual reality application based on this idea.

2.2 Activity Sensing

In addition to sports, human activity is supported from several perspectives nowadays. Sensing the everyday status of human activity is beneficial for self-monitoring by a patient or remote monitoring by doctors. Guo et al. [6] invented a disappearing sensor that is installed in the textile of cloth and is unseen by users and third parties. Their idea is to use conductive textile to sense the breath rating from reading the voltage change during breathing. Installing the sensor in cloth is a simple design and technique to measure the activity. From our perspective however, because sensing sweat should be continuous and the sweat amount changes over time, we have to select a device that can be attached to the body and removed conveniently, besides being easy to clean.

Velloso et al. [15] created a weight lifting application that achieved qualitative activity recognition by predicting the user's activity from data sent from several accelerometer sensors attached to the body and barbells. They implemented the system in such a way that it can deduce the user's status using both model-based and sensor-based techniques.

Bächlin et al. [1] developed an assistance system for swimmers by providing actuating LED in their goggles, a vibration motor, and audio feedback. Sensing is achieved using several accelerometers to capture the continuous swim performance. They configured suitable feedback and conducted experiments with the developed device using 22 participants.

2.3 Sweat Sensing

A chemical method for sensing sweat has been proposed by Benito-Lopez et al. [3]. Their proposed method focuses on detection of the pH balance in sweat using ionic liquid polymer gel. Their expected application is also for wearable systems utilized in sporting activities. The sensor is small enough to be attached to the human body; the purpose however, is not to detect the amount of sweat but to determine the ingredients secreted in sweat.

Salvo et al. [13] proposed a method for measuring the rate of sweat. They used a gasket with two humidity sensors and compared the difference between the sensors to deduce the sweat rate. The two sensors are placed at different distances from the surface of the skin. The gasket is glued to a layer on the skin to keep it at a distance from the skin surface. Their work improves the cost and size of such wearable devices besides rendering the sensing technique inexpensive and easy to use for wearable applications.

Coyle et al. [3], [4] proposed a wearable chemosensor that analyzes body fluids using the chemical reaction of a pH indicator. Their test device is designed for continuous sensing during experimental activities in the laboratory. It is wearable and small enough to be attached to the waist and wrapped in textiles. Sensing is accomplished by color sensing of a pH indicator and an absorbent material behind the pH indicator allows sweat to go through the pH indicator and new sweat liquid to flow into it.

3 Sweat Sensing Infrared Transparency

Sensing the status of sweat is an important factor of human health in sporting activities. Because our focus is on wearable methods, we selected photo sensors and infrared LEDs to detect the amount of sweat stored in the sponge. The sponge is placed between the LED and photo sensor and the sensor detects the infrared emitted from the LED and measures the amount of water in the sponge. The sensor, LED, and sponge are positioned and, for this implementation, placed in a pipe (Fig. 1). The pipe has a hole that allows water to enter and permeate the sponge.

The infrared ray goes through the sponge and is diffused by the structure of the sponge. Sponges that primarily comprise plastic polymers have non-uniform structures. When diffused reflection occurs, the amount of infrared going through the sponge decreases. Thus, the amount detected at the photo sensor will also decrease. Water functions as a transparency material in the sponge. It easily transmits the rays and reduces diffused reflection by decreasing the reflection ratio of the sponge. Consequently, it decreases the number of rays leaving the sponge, which further results in a corresponding increase in the number of rays received at the photo sensor.

Our method leverages the above characteristics of rays in sponge and water. Using this technique, the amount, and percentage of water stored in the sponge can be measured. Infrared rays are usually used to detect water by actually absorbing them in the water. To make the sensor small, the water is turned into a transparent material and helps the rays to be transmitted into the sponge.

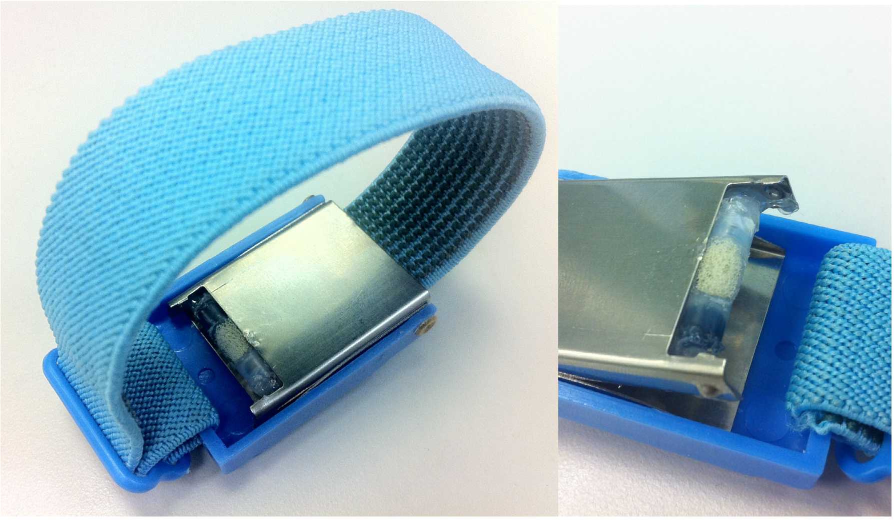

Fig. 1. Prototype of our wearable device with sweat amount sensor using infrared transparency. A tube is installed on the underside of the armband and makes contact with the skin. The tube contains a photo diode, an infrared LED, and a piece of sponge. The electronic devices are combined using glue and insulated.

3.1 Hardware

The hardware consists of an armband and sensing components including an LED, a photo diode, a piece of sponge, and a tube. The device is designed to be worn and used during sporting activities. To make the device waterproof, the sensor is stored in the tube and bonded with glue. By using armband, the sensor can gather the sweat flowing on the body and measure the amount of sweat flowing over time. The diameter of the tube is 4.5 mm, and the length of the sensor tube is 16 mm.

3.2 Experimental Results

We tested the sensing technique actualized using the above hardware. The circuit was developed using simple components: photo diode, infrared LED, tube, sponge, resistors, and a microcontroller connected to a PC. We utilized the following procedure to ensure correct measurement of the amount of water:

1. Prepare wet sponge.
2. Place sponge in the tube.
3. Measure the transparency.
4. Remove a very small amount of water by sucking it up using a square of absorbent paper.
5. Repeat Steps 3 and 4 until all the water is completely removed.

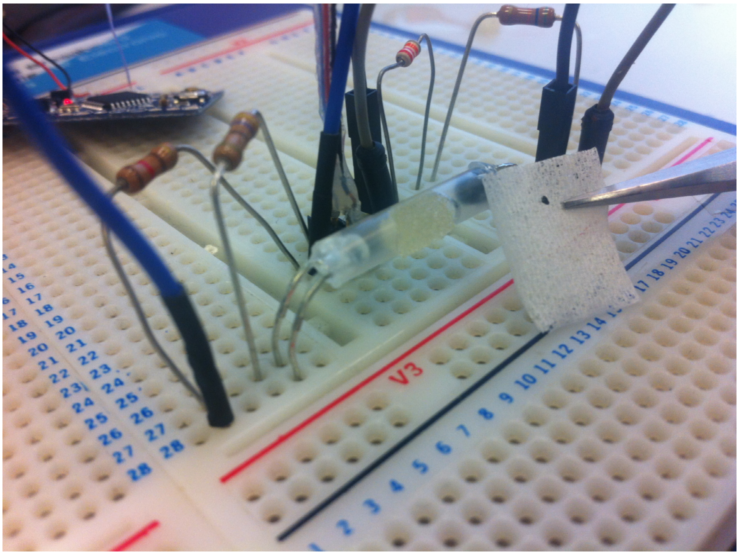

Fig. 2. Circuit and configuration of the experimental apparatus. We used a 95 Ω resistor on the LED side and a 76 kΩ resistor on the photo diode side to facilitate precise control of the infra-red ray emitted.

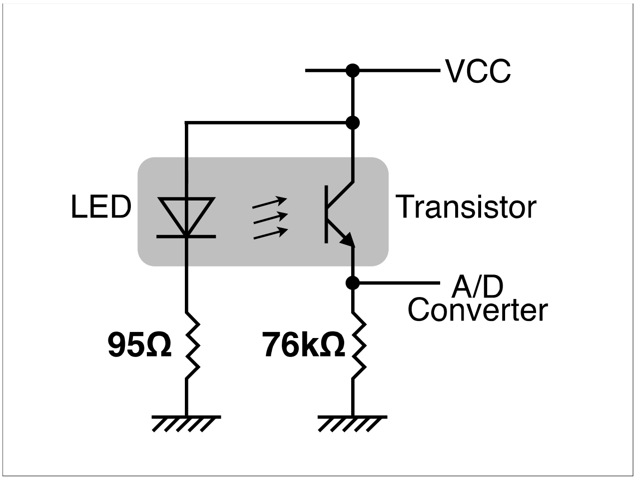

Fig. 3. Configuration of the photo sensor and diode electric circuit. The values of the resistors are not simply taken from the labels on the resistors but from actual measurements using a tester. The A/D converter is one of the functions of the microcontroller that converts the analog voltage value to a digital number.

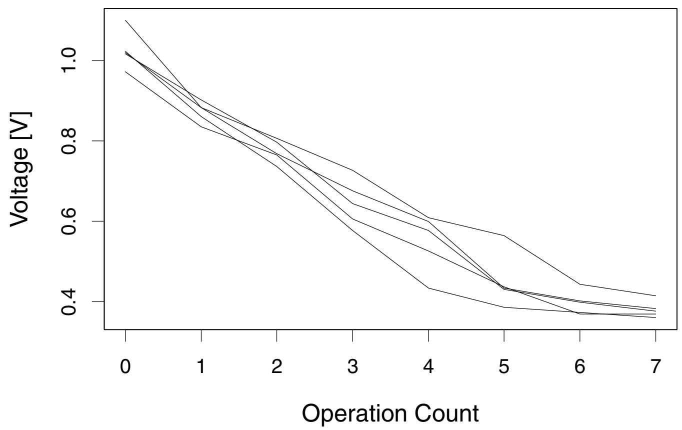

Fig. 4. Plots of voltage versus operations (five curves). Index zero on the x-axis represents the original state of the sponge. The values on the x-axis signify the number of operations, in which a small amount of water is absorbed by the paper, completed. The value on the y-axis is converted to voltage level from the digital value. The highest voltage of the microcontroller was 3.3 V.

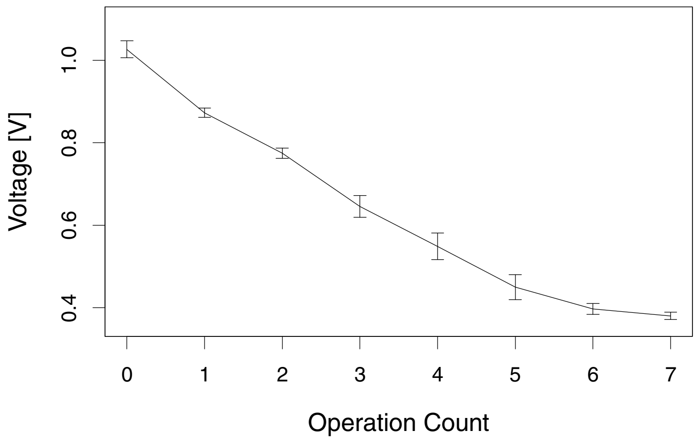

Fig. 5. Mean graph of Fig. 4 and standard deviation of five operations. Each standard deviation is indicated as a vertical line over the mean point.

To ensure that the measurement of the amount of water in the sponge was done correctly, we used tissue paper squares, each 10 mm in size. We counted the number of operations it took in each experiment for the water to be completely removed. The paper squares were sufficiently small and easily absorbed a small amount of water from the sponge. We put the paper on the sponge by means of a pair of tweezers and removed it when the paper had been evenly saturated. The configuration of the apparatus and the operation are illustrated in Fig. 2. The circuit used is depicted in Fig. 3.

Figures 4 and 5 show the results obtained in the experiments plotted on a graph. It can be seen that the plots of the third through to the fifth operation have larger standard deviations than the other operations. It appears that, during the activity of water removal using the paper, the sponge had uniform water and air distribution in it, which resulted in the larger deviations at intermediate counts. However, the mean value of each operation and deviation are sufficiently separated and the plots drawn decrease monotonically with water absorption.

4 Discussion

4.1 Limitations

To facilitate wearability, we used a small tube that can be utilized during sporting activities to detect the sweat in our design. Therefore, there are some limitations, and incomplete tasks that must be addressed before our device can be considered for actual use. First, the sponge needs to be stored inside the tube instead of sticking out from the tube as it does currently. The second issue is that of the battery. Because we are using both a LED and a diode, more electricity is required than with a simple wearable sensor. By reducing the electricity used by these apparatuses, the amount of energy, and therefore the size of the battery required can be kept small. Finally, the sponge can be improved by selecting and comparing among many types of materials, sizes, and textures.

4.2 Future Work

Using a sponge is actually only one method of implementing this system; it can be improved by experimenting with other materials and mechanisms. Further, the hardware configured with the sponge and tube can be used with other types of wearable devices such as those worn around the neck.

5 Conclusion

In this paper, we proposed a technique for detecting and measuring the amount of sweat flowing from the human body during sporting activities. We used a sponge to hold the sweat for detection over time and to facilitate the sensing of the sweat with a wearable device. The idea of photo transparency is to leverage the random reflection caused by the structure of the sponge to measure the amount of water it contains. We developed and tested a prototype device with a tube containing an LED, a photo diode, and a sponge via several water absorption operations. We found that the changes in photo transparency decreased monotonically with water absorption and that the device is sufficiently convenient for sensing sweat and small enough for wearable use.

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