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Research Article

Internet of Things in the Bathroom: Smart Health-Monitoring Bidet System

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The Internet of things (IoT) helps our everyday lives such as by monitoring objects and tracking behaviors in various settings, but studies on enhancing the bathroom experience are rare. This article describes full details about development and implementation of a smart health-monitoring bidet based on our study published previously in the conference. A smart bidet system is designed to monitor the users' health through several contact-type sensors, such as pressure, oxygen, and thermometer. The system is equipped with a built-in artificial intelligence software platform and is designed to detect anal and spinal diseases. The attached sensors normally operate under waterproof conditions: we tested their performances under X6 international protection marking conditions. These devices were designed to operate properly even in extremely waterproof conditions. The temperature, pressure, and oxygen sensors of the bidet system had error rates of about 4.1, 0.6, and 1.1 percent, respectively.

1. Introduction

When it comes to confusing and ever-changing terminology, nothing really comes close to digital technology. From dongles to routers, smart hubs to podcasts, the technology world certainly has no shortage of jargon. However, one phrase might just be worth knowing, that is, IoT. It is certainly one of the more unusual turns of phrase, but WLAN (wireless local area network) or WPAN (wireless personal area network) enabled products could end up in every home in the world, by monitoring objects and tracking behaviors in various settings. However, studies on enhancing the bathroom experience are rare. Based on our previous publication in the conference proceedings [1], this article describes the development and implementation of a smart health-monitoring bidet with full details including additional and new contents we did not report earlier.

Bidets are used to clean and maintain the perianal area of a toilet seat. They are generally attached to the seat's heating and cooling components [2]. The first bidet system was introduced in France in the seventeenth centuries [3]. Today, these electronic devices are used for various purposes, such as cleaning, heating, and drying [4]. The seat is attached to an electric powered nozzle that is designed to clean both male and female anus areas [5]. Electronic bidets are usually equipped with a mechanical or two-pronged mechanical nozzle on one or both sides of the toilet [6, 7].

In basic bidets, a high-pressure water jet is utilized to clean the anus and genital areas. However, in recent models, the jets can also function autonomously. The latest energy-saving technology for electronic bidets is a device that automatically warms up once a user approaches it [8].

Several patents about electronic bidets have been registered. One of these includes a system that uses an internal camera to locate and identify the users' lower body orifices; afterwards, an electronic bidet can automatically adjust the settings based on the user's weight and orifice location. It can also detect the exact size of the water droplets and adjust the temperature and pressure [9]. Another electronic bidet has a remote controller that is powered by a series of microforce sensors [10]. However, these bidets have not yet applied with the Internet of Things.

The IoT has the potential to improve the efficiency and effectiveness of healthcare systems by helping prevent and manage chronic diseases of the aging population [11], and the IoT is a network of devices that are connected through machine-to-machine (M2M) communications. This technology enables the exchange of data and enables the collection of big data and automation within a wide range of industries. In addition, conventional bidets are being substituted with electronic bidets that use various sensors and a remote controller to provide additional convenience. The electronic bidet manufacturer Novita recently collaborated with LGU + to control bidet functions via smartphone [12]. However, this bidet cannot receive biometric information or big data; in fact, the various types of biometric information acquired from the sensors are not stored in a memory but only displayed once and then disappear. By combining existing conventional electronic bidets with IoT technology, the collected biometric information can be potentially applied to the health care field [13]. IoT provides the opportunity to develop smart wearable applications in health sectors and to grow the existing wireless capabilities (i.e., mobile devices, interactive sensors, and actuators) [14].

The early prediction of diseases can help prolong people's lives by allowing timely treatments. Within this context and goal, we developed an electronic bidet that can be easily accessed in everyday life and predict possible early-stage diseases. This new type of bidet (i.e., "medical bidet") has integrated IoT sensing technologies and various types of sensors (i.e., pressure, oxygen, and thermometer sensors). In this paper, we describe the application of the medical bidet to smart health care: it collects and analyzes personal biometric information in a nonrecognition and nonrestraint way, within the daily-used space of the bathroom. Section 2 describes the construction of several sensors that can be fitted in the smart health-monitoring bidet toilet seat. Section 3 shows the results obtained from the sensors under waterproof International Protection Marking (IP) X6 conditions. Section 4 presents the concluding remarks.

2. Materials and Methods

Figure 1 shows a schema of our smart health-monitoring bidet end-to-end architecture. A smart health-monitoring bidet uses various sensors (pressure, oxygen, and thermometer) to detect potential and actual early-stage diseases. The raw data collected from these sensors were automatically processed by our dedicated software. There have six pressure sensors at lower side of the toilet seat, and these can be used to calculate resistance variance by measuring the difference between the force-sensing resistor layer and the active spot [15]. Pressure sensors can also be used to diagnose spinal deformities and guide users to correct their body posture. Oxygen sensors can be used to measure the amount of hemoglobin (Hb) in the blood for checking physiological data, instead of using the photodiode method [16, 17]. Thermometer sensors can be used to monitor the body temperature, a vital sign that can also be combined with additional information to evaluate user's health status [18]. The biological information collected through these various sensors can be transferred to the network system through communication channels (Bluetooth or Wi-Fi).

2.1. Pressure Sensor Module. Sitting for long periods of time can lead to improper posture and worsen the conditions of the spine [19]. This issue can be prevented by using pressure sensors positioned on the lower part of the toilet seat (Figure 2(a)), which could help avoid spine deformation by stimulating posture correction.

Figure 2(b) shows the possible sensor detection positions: they operate based on algorithms that describe center-of-gravity movements within nine virtual blocks to determine posture deviations. The calculation of the center-of-gravity position in a two-dimensional space (coordinates Xi and Yi) (Figure 2(b)) is described by the following equations and is shown in Table 1.

$$CoPx = \frac{\sum_{i=1}^{4} F_i X_i}{\sum_{i=1}^{4} F_i}, \quad (1)$$

$$CoPy = \frac{\sum_{i=1}^{4} F_i Y_i}{\sum_{i=1}^{4} F}. \quad (2)$$

The pressure sensor measurements are based on changes in the resistance values derived from the pressure force in the corresponding contact area between the active area and the force-sensing resistor layer. The real-time resistance information is then transformed into an analog voltage output. The analog voltage data obtained from the pressure sensor are transferred to a 10 bit analog-to-digital converter (ADC) through Bluetooth, using a universal asynchronous receiver transmitter (UART). Finally, these data are stored in a smartphone application. Figure 3 shows a block diagram of the module used by the pressure sensors: the sensor signal needs to be amplified by the operational amplifier and then converted into a digital signal by the ADC. Finally, the weight data are transferred to a smartphone through Bluetooth, in combination with date, time, and position data.

2.2. Oxygen Sensor Module. Oxygen sensors were utilized to assess oxygen saturation, which offers a value of the Hb amount [16]. The oxygen sensor measures Hb bonded with oxygen; in fact, when Hb is not attached to oxygen, it has a different wavelength [20]. Two different light-emitting diode (LED) wavelengths (660 nm and 940 nm) were used because a 660 nm LED has a much higher absorption coefficient ratio than a 940-nm LED does [21]. The oxygen saturation level at various absorption coefficient ratios could be estimated from the ratio between the pulsatory motions, applying the Beer–Lamber law [22].

Figure 4 shows a schematic diagram of the oxygen sensor module. The pulse oximetry circuit (MAX30120, Maxim Integrated, San Jose, CA, USA) was used to scan the oxygen saturation data, which were then processed through software algorithms. The measurement module circuit in the bidet

Figure 1: Smart health-monitoring bidet end-to-end architecture.

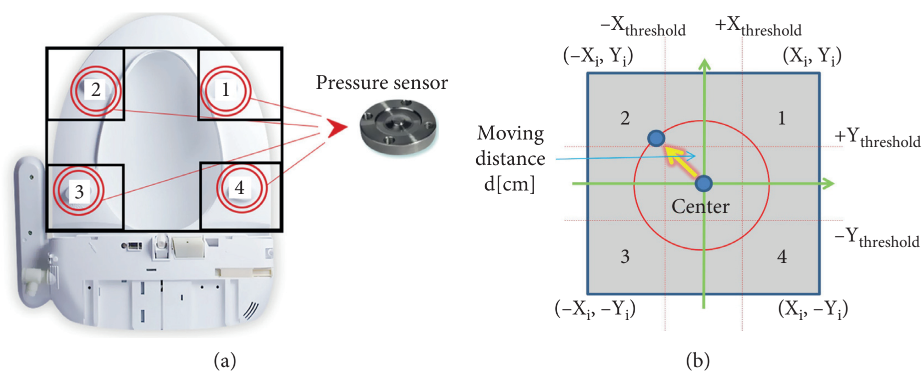


Figure 2: Pressure sensor system. (a) position of four numbers; (b) the pressure sensors can detect positions within the nine virtual blocks defined by the dashed red lines.

Table 1: Center-of-gravity movements within the virtual blocks.

Block	CoPx	CoPy
1	$CoPx < -X_{threshold}$	$CoPy > Y_{threshold}$
2	$\lvert CoPx \rvert < X_{threshold}$	$CoPy > Y_{threshold}$
3	$CoPx < X_{threshold}$	$CoPy > Y_{threshold}$
4	$CoPx < X_{threshold}$	$\lvert CoPy \rvert < Y_{threshold}$
6	$CoPx < X_{threshold}$	$\lvert CoPy \rvert < Y_{threshold}$
7	$CoPx < X_{threshold}$	$CoPy < -Y_{threshold}$
8	$\lvert CoPx \rvert < X_{threshold}$	$CoPy < -Y_{threshold}$
9	$CoPx < X_{threshold}$	$CoPy < -Y_{threshold}$
5	Default	Default

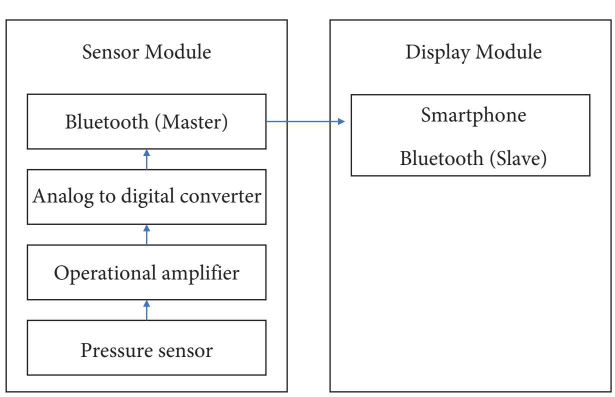


Figure 3: Schematic diagram of the pressure sensor and display modules.

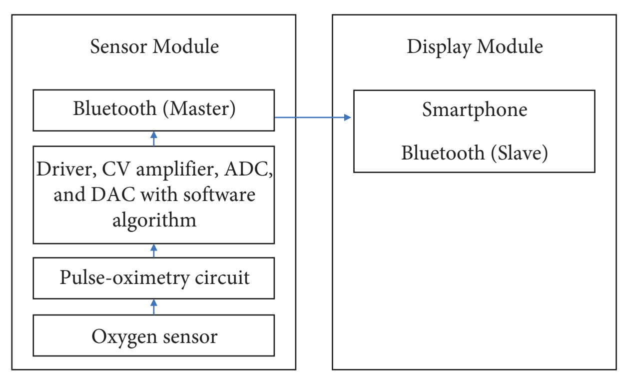


Figure 4: Schematic diagram of the oxygen sensor system.

control board was designed to measure oxygen saturation. Moreover, the driver circuit within was designed to convert the voltage level to the current level and control the intensity of the light using the LED driver board. Furthermore, a differential current-voltage (CV) amplifier was needed: the received signal was converted by aligning the human finger into infrared (IR) and red LED current using an ADC and a DAC (digital to analog converter). A microcontroller was used to change the current controlled by the DAC (i.e., the LED current). A low pass filter was also utilized to remove unwanted ambient noise signals [23]. Next, measured physiological signals were transferred to a smartphone application through Bluetooth. Finally, the signals reflected from the LED lights and the blood oxygen saturation (SpO2) data were converted by first-in-first-out (FIFO) algorithms and sent to the smartphone [24].

2.3. Thermometer Sensor Module. A thermometer sensor measures the body temperature; then, raw data were processed through our designed algorithm. The body temperature is a physiological index of vital signs and supplementary information related to women's health, such as menstruation, ovulation, and gestational period [25]. The thermometer sensor was attached to the top of the bidet cover, as shown in Figure 5.

2.4. Communication Module. The data collected by the devices were transmitted to a smartphone using Bluetooth communication protocol. The goal was to detect potential diseases and monitor physiological symptoms (fever and scoliosis) [26].

The developed smart health-monitoring bidet system employed an STM32F103RCT6 microcontroller unit (MCU). This MCU contained an ARM Cortex-M3 32 bit RISC core (operating at 72 MHz), embedded memories, and extensive input/output and peripheral ranges connected to two advanced peripheral buses (APBs) [27]. This component can offer three 12 bit ADCs and four 16 bit timers with two pulse width modulation (PWM), with both standard and advanced communication interfaces [28]. UART0 and UARAT1 were used as debug and Bluetooth ports, respectively, for interworking with the smartphone. In order to obtain valid physiological signals from the sensors (thermometer, oxygen, and pressure sensors), we adopted a communication method suitable for the sensor characteristics and connected it to the MCU: the MCU was designed to communicate with one temperature sensor through a system management bus (SMB), with four pressure sensors through a serial peripheral interface (SPI), and with one oxygen sensor through an interintegrated circuit (IIC). The DC input and output voltages in the low-power mode were 5 V and 1.8 V, respectively, while they were equal to 3.3 V in the high-performance mode.

Bluetooth is a wireless technology that enables devices to connect to each other over short distances [29]. The communication module, shown in Figure 6, is an integral part of the smart health-monitoring bidet. It enables the user to control the bidet's sensors through a smartphone [30].

The data obtained from various sensors were transmitted to the device ID and to the MCU in the HEXA format. The data obtained by the sensors were treated in the following way. First, the sensor which provided these data was identified by the MCU based on its ID: "0 × 00" indicates a pressure sensor, "0 × 01" a thermometer sensor, and "0 × 02" an oxygen sensor. Then, the data are transmitted from the MCU to a smartphone through Bluetooth and converted into a decimal number that can be displayed by the user. The sensor data format has a header (indicating the start of the text [STX]), a tail (indicating the end of text [ETX]), and a space used to delimit or separate between

Figure 5: Smart health-monitoring bidet cover with the thermometer sensor.

different series of sensor data. The typical sensor data structure format and an example of thermometer sensor data format (for a temperature of 35.6°C) are shown in Figure 7.

3. Results and Discussion

3.1. Pressure Sensor Module. Figure 8 shows the positions of the four pressure sensors and their wiring connectors connected to a device for accuracy check purposes.

The weight data and the correspondent error difference, calculated by each pressure sensor (at positions 1, 3, 7, and 9, as shown in Figure 2(a)), were considered to evaluate the pressure sensor capabilities. Table 2 shows the error rates of four pressure sensors in different weight settings. The measurements were conducted using push-pull gauges in a digital force gauge machine for weights between 10 and 50 kg (in 10 kg interval steps). The average error of the four pressure sensors was within 4.1%, which is a very low percentage of errors for the pressure sensor attached at the bottom of the bidet.

3.2. Oxygen Sensor Module. The diode-emitting red infrared light in the oxygen sensor, attached to the left side of the bidet, was used to determine the accuracy of performance by targeting 10 times the same skin portion (Figure 9(a)); then, the average measurement value was calculated as shown in Figure 9(b). A set of 10 repetitive measurements was conducted every minute. Within 3 minutes, the accuracy of the oxygen sensor had reached 100%. The value and the average accuracy differed by 0.6%.

3.3. Thermometer Sensor Module. Body temperature as a vital sign was obtained using the thermometer sensor. The accuracy performance of the thermometer sensor embedded at the top section of the bidet toilet seat was checked 10 times (Figure 10(a)). The average accuracy was then calculated as

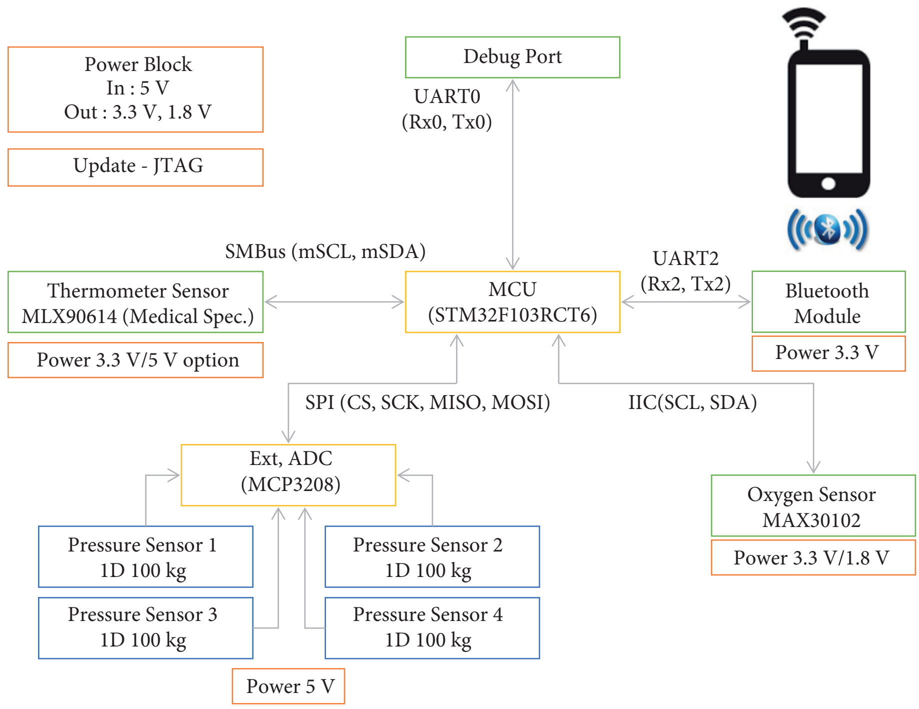
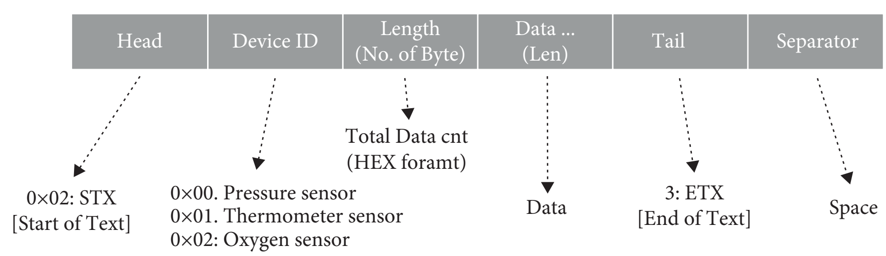


FIGURE 6: Block diagram of the smart health-monitoring bidet system communication channel.



(a)

Head	Device ID	Len	Data[0]						Tail	Separator
STX	Thermometer sensor	1	3	6	.	5	SP	ETX	SP
0×02	0×01	0×01	0×31	0×36	0×2E	0×35	0×20	0×03	0×20

(b)

FIGURE 7: (a) Sensor data structure format. (b) Example of thermometer sensor data format for a temperature of 35.6°C (body temperature).

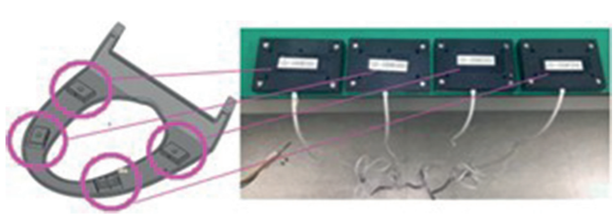


FIGURE 8: Positions of the pressure sensors (on the lower side of the bidet toilet seat) and their wiring connections.

shown in Figure 10(b). After 3 minutes, the average temperature was 32.39°C, corresponding to the average body temperature difference of 0.35°C (1.06%).

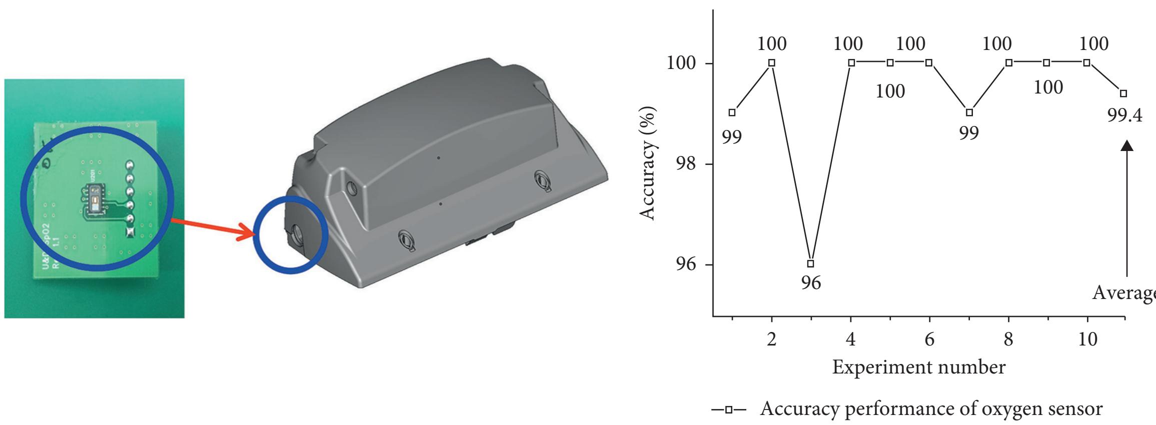
3.4. Smart Health-Monitoring Bidet System. Figure 11 shows the Bluetooth terminal installed on a smartphone, the main MCU, the embedded MCU, as well as all interfaces of the thermometer, oxygen, and pressure sensors. The measurement data obtained from each pressure, oxygen, and thermometer sensor were converted into weight, SpO2, and temperature data, respectively. Then, these data were sent to a smartphone by Bluetooth and saved in a phone application.

Figures 12(a) and 12(b) show the 3D models of the thermometer and pressure sensors, situated on the lower side of the smart health-monitoring bidet toilet seat. Figure 12(c) shows the sensors attached to the bidet system.

Table 2: Percentage and average errors of each sensor for different measurements.

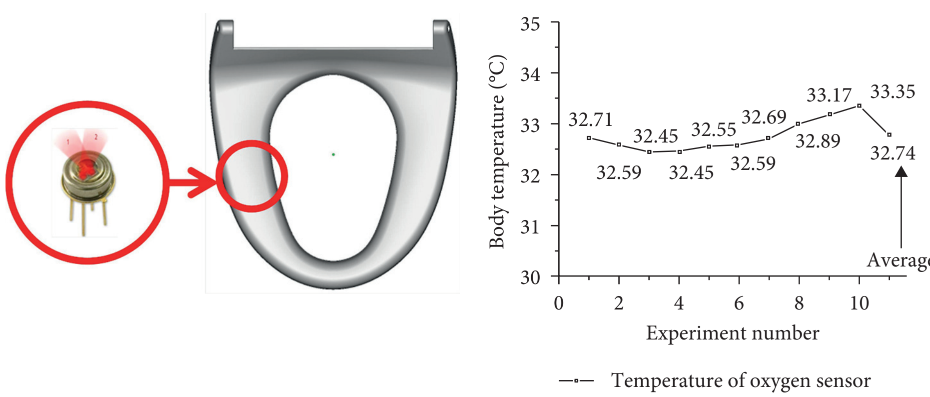
	Error (%) for 10 kg	Error (%) for 20 kg	Error (%) for 30 kg	Error (%) for 40 kg	Error (%) for 50 kg	Average error (%)
Sensor 1	7.780	4.600	2.480	0.625	0.488	3.195
Sensor 3	6.620	0.180	1.967	4.650	6.704	4.024
Sensor 7	4.420	4.420	0.880	0.005	1.952	2.335
Sensor 9	0.130	1.640	1.207	0.130	4.006	1.423

*The sensor numbers (1, 3, 7, and 9) refer to the positions of the pressure sensors. The percentage and average errors were calculated considering weights of 10, 20, 30, 40, and 50 kg.



(a) (b)

Figure 9: (a) Oxygen sensor and its position on the smart health-monitoring bidet. (b) Accuracy performance test of the oxygen sensor attached to the left side of the smart health-monitoring bidet.



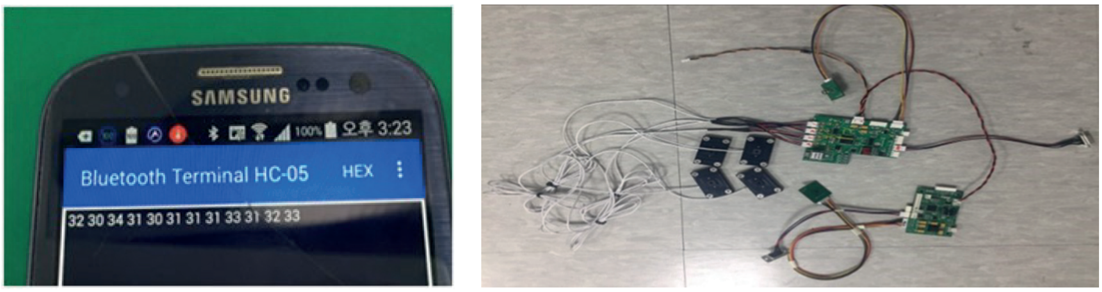
(a) (b)

Figure 10: (a) The thermometer sensor and its position on the smart health-monitoring bidet. (b) Accuracy performance test of the thermometer sensor.

The toilet seat of the bidet system is always used in the presence of water; hence, it is essential to make the system waterproof in order to protect the sensors and the MCU.

Because the smart health-monitoring bidet needs to work properly in the presence of water, its waterproof capability was experimentally tested. The smart health-monitoring bidet, equipped with thermometer, pressure, and oxygen sensors, achieved an IPX6 waterproof rating: all the sensors were functional after being sprayed with water from all directions for 3 minutes. Figure 13 shows the experiment conducted to verify the waterproof capability of the smart health-monitoring bidet. Therefore, the performances of the pressure, thermometer, and oxygen sensor functions were checked after 3 minutes of water spray to prove the IPX6 capability of the developed smart health-monitoring bidet.

3.5. Application Software. The goal of this project was to develop an application that can receive and send data using wireless communication (Figure 14). It could collect bio-



(a) (b)

Figure 11: (a) Bluetooth terminal installed on a smartphone. (b) Entire interfaces of the smart health-monitoring bidet system, including the main and embedded MCUs, as well as the thermometer, oxygen, and pressure sensors.

(a) (b) (c)

Figure 12: (a) Thermometer sensors on the lower side of the smart health-monitoring bidet toilet seat. (b) Pressure and oxygen sensors on the top and to the back of the toilet seat. (c) Photograph of the bidet with all the sensors attached.

Figure 13: Experiment conducted to verify the waterproof capability of the smart health-monitoring bidet system.

signals related to a disease and relay them to a mobile device. It could also provide information on the severity of the disease that can be inferred. In the future, all bio-signals collected by a device will be stored in a server and used to build big data. This will be extended to an artificial intelligence software technology that collects and informs users about their health.

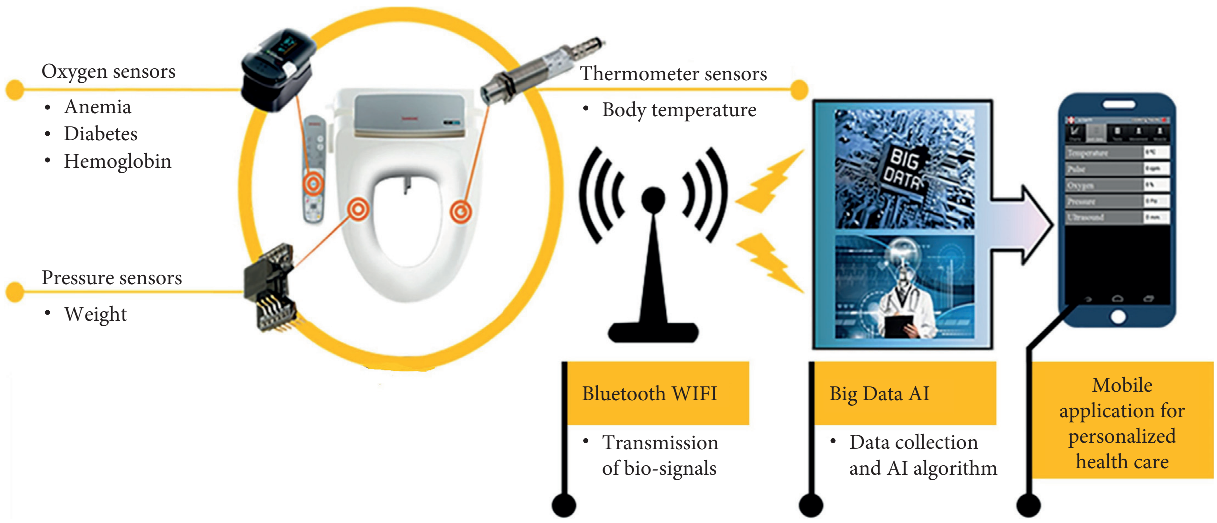


FIGURE 14: Mobile application for the smart health-monitoring bidet system.

4. Conclusions

This paper proposed a smart health-monitoring bidet system that uses various contact sensors such as thermometer, pressure, and oxygen. The performance of these sensors was tested under IPX6 conditions. The pressure, oxygen, and thermometer sensors revealed error rates of approximately 4.1%, 0.6%, and 1.1%, respectively, indicating excellent precision. The data collected by these sensors were then transferred to a smartphone application using Bluetooth communication protocol. Our smart health-monitoring bidet system can monitor various physiological data that can detect health problems.

Currently, solutions using the IoT are changing the world significantly. It has become very clear that more IoT devices will appear, which are developed to facilitate routine processes by assisting mankind in a vast range of actions. The smart bathroom is among recent IoT solutions that are very soon to be implemented. In this paper, we have calculated various health indicators by measuring and analyzing bio-signals in a nonconstrained, unrecognized environment through a health-monitoring bidet using contact sensors, noncontact sensors, wireless communication, and artificial intelligence software technology. Further studies will be needed that develop this smart bidet system into a Clinical Decision Support System (CDSS) for patients with health problems and conduct research to test the clinical effectiveness of the system.

Data Availability

The data that support the findings of this study are available from the first author (spheo@gwnu.ac.kr) upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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