A Preliminary Study on a Voided Volume Measuring Method Using Noncontact Temperature Sensors under the Toilet Seat

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Abstract

Some systems to measure voided volume and flow rate have been developed. Clinically, urination parameters are measured using uroflowmeters that have special receivers such as cups or bowls. Since these uroflowmeters were developed for clinical use, home use is difficult and inconvenient. Many of these devices require equipment cleaning; additionally, most are too expensive for home use. To address these problems, we developed a method to measure voided volume by noncontact matrix temperature sensors that are installed under a toilet seat. The basic concept is as follows. Urine is excreted at core temperature of 37°C. The heat radiated from urine during excretion is measured by noncontact matrix temperature sensors, and the measured radiated heat is converted to urination volume. A preliminary study was conducted to estimate the voided volume using an actual toilet bowl. The noncontact matrix temperature sensors simultaneously measure the temperature of falling water at 37°C in 16 areas using a matrix of four lines and four rows. Four noncontact matrix temperature sensors were installed at the front, rear, left and right of the underside of a toilet seat. The toilet seat equipped with the four sensors was installed on a toilet bowl. The position of the falling water was fixed at 120 mm from the front sensor. Water volumes of 100, 200 and 300 ml were passed vertically at flow rates of 10, 20, 30 and 40 ml/s. As a result, the surface of the toilet bowl was slightly heated from the heat of the falling water, and the toilet bowl retained the heat after the water had fallen. To eliminate overestimation of heat from the toilet bowl, we proposed two analytical methods: a bias temperature elimination method and a time limitation method. For all four flow rates, the variation of $U$ with a proportional volume obtained by the time limitation method was smaller than that by the bias temperature elimination method.

Keywords: voided volume, toilet seat, noncontact, temperature sensor.


1. Introduction

Uroflowmeters are used clinically to evaluate urination parameters such as voided volume. Primarily, three types of uroflowmeters are available: gravimetric, dipstick and spinning disc [1]. These uroflowmeters utilize equipment that comes into contact with the voided urine. To avoid infections, it is necessary to clean or use disposable equipment. Since they require user cooperation, these uroflowmeters are not suitable for home use.

Several methods have been developed to evaluate urination volume in daily household toilets to address the above problems and to improve healthcare. Yama-koshi [2] developed a urination monitoring system with weight sensors installed under the toilet floor to evaluate body weight, urine weight and feces weight. Toto Co., Ltd. (Fukuoka, Japan) developed a toilet system that includes a water level-sensor in the drain pipe for clinical use [3]. These systems estimate the volume of excrement without any contact with the excrement, but large renovations of the toilet are required to install the devices. In another study, Hitt et al. [4] investigated the potential of obtaining urinary flow measurements from acoustic signatures of the urine stream produced by impact on a liquid-free surface. Isomura et al. [5] developed a voided volume estimation system for males that installs a camera on a urinal. Since these methods record sounds and images during excretion in the toilet, i.e., in a private space, whether people will accept these measurement devices in household toilets remains questionable.

The ideal uroflowmeter for use in household toilets requires (1) no contact of the measuring device with excrement for infection prevention and easy maintenance, (2) maintaining privacy during excretions, and (3) easy...
installation in household toilets. We study the potential of obtaining urinary flow measurements from the heat radiated by urine. Urine from the body is discharged at the core temperature of 37°C. We assume that the integral of temperature in both space and time represents the amount of urine if the falling urine retains the core temperature. In this preliminary study, we investigated the relationship between the integral of the radiant heat from falling water and the amount of radiant heat. The radiant heat of the falling water was measured by four noncontact matrix temperature sensors installed under a toilet seat.

2. Methods

2.1 Experimentation

In this study, the temperature of 16 areas, 4 lines × 4 rows, was simultaneously measured using a noncontact matrix temperature sensor (D6T-44L, Omron Corp., Kyoto, Japan). The sensor had viewing angles of 44.2 degrees and 45.7 degrees in the X and Y directions, respectively. We employed a microcomputer (SPP-NANA-D01B, Symphodia Phil Co. Ltd., Yonezawa, Japan) incorporating the matrix temperature sensor and a Bluetooth unit. Sixteen temperature datasets were transmitted every 250 ms to a PC via the Bluetooth connection. Four matrix temperature sensors were installed under a toilet seat (TCF116 #NW1, TOTO Ltd.) at the front, rear, left and right. Figure 1 shows the layout of the four sensors and the ID number of each sensor. The toilet seat that was equipped with the four sensors was installed on our laboratory toilet bowl (CS230B, TOTO Ltd.). The position of the falling water was fixed at 120 mm from the front sensor (Fig. 1, right). This position was determined anatomically by the position of the female external urethral meatus.

Varying amounts of water (100, 200, and 300 ml) were passed vertically into the toilet bowl at low rates of 10, 20, 30 and 40 ml/s using funnels. The flow rate was determined by changing the diameter of the exhaust hole simulating the urethral meatus. Room temperature and the temperature of the falling water were controlled at 25.5 ± 1.0°C and 37.0 ± 1.0°C, respectively. The temperature of the sump of the toilet bowl was 22.5 ± 1.0°C. These experiments were performed in triplicate. In our preliminary experiments, we found that the temperature of the toilet bowl surface was slightly heated by the 37°C falling water. To prevent the heat of the falling water from conducting to the toilet bowl, the toilet was flushed every time after the water was passed.

2.2 Principle

The principle from temperature measurement to volume estimation is shown in Fig. 2. We suppose the urine flow forms a cylinder. The temperature sensor measures the temperature difference before urination and during urination obtained from the area of the rectangle projected from the cylinder. Therefore, the area (m²) is proportional to the temperature (°C). Next, to obtain the volume of the cylinder, if the temperature difference is raised to the power of 3/2, the value proportional to the volume is calculated.

2.3 Analysis

The matrix temperature sensors measure the temperatures of the 16 areas before and during passage of the water through the funnel. To eliminate the background temperature, the temperature difference $Td$ is calculated by equation (1):

$$ Td_{ch}(t) = Temp_{ch}(t) - Temp_{ch}(0) $$

where $Temp_{ch}(t)$ is the temperature of channel $ch$ at time $t$. $Temp_{ch}(0)$ is the temperature of $ch$ immediately before the water is passed.

The falling water has a volume that is proportional to the cube of length. However, the matrix temperature sensor measures the average temperature of the object surface, i.e., the measured temperature is proportional to the square of the length. Therefore, if the measured temperature is raised to the power of 3/2, the surface tem-

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**Fig. 1** Bottom views of the toilet seat. Left: layout and ID number of the sensors; Right: Position of falling water (X). Units of distance are mm.

**Fig. 2** Principle from temperature measurement to volume estimation. $Td$: Temperature difference before urination and during urination.
temperature can be converted to volume dimension. Instantaneous surface temperature difference $S(t)$, with a proportional volume, is calculated by equation (2):

$$S(t) = \sum_{ID=1}^{4} \sum_{ch=1}^{16} [T_{ID,ch}(t)]^{1/2}$$

(2)

where $ID$ is sensor ID. Flow rate proportional $P(t)$ is calculated by equation (3):

$$P(t) = \frac{S(t) - S(t - \Delta t)}{\Delta t}$$

(3)

As mentioned above, we found that the surface temperature of the toilet bowl increased slightly by the falling water. The falling water warmed the toilet bowl, resulting in bias heat. Because of the bias heat of the falling water, the value $S(t)$ did not return to zero within a short time after water passing into the toilet was completed. Therefore, we proposed two analytical methods to obtain $U$, which is the time integral of $S(t)$ with a proportional volume as described below. Figure 3 shows the outline of those methods.

A) Bias temperature elimination method:
To eliminate the bias heat, $U_{be}$ is calculated by equation (4):

$$U_{be} = \sum_{t=tp37s}^{t=tp37e} S(t) - S(tp37),$$

(4)

$$S(tp37s) = S(tp37e),$$

$tp37s < tp < tp37e$

where $tp37$ and $tp37e$ are the times at 37% of maximum $S(t)$, and $tp$ is the time at maximum $S(t)$.

B) Time limitation method:
To eliminate overestimated heat from the toilet bowl, $U_{tl}$ is integrated with $S(t)$ in time until the time decreases to 37% of maximum $S(t)$ value. $U_{tl}$ is calculated by equation (5):

$$U_{tl} = \sum_{t=0}^{t=tp37e} S(t).$$

(5)

3. Results
A typical example of $Td$ change for each channel of falling water at a flow rate of 20 ml/s and a volume of 200 ml, is shown in Fig. 4. All sensors responded to the falling water. In particular, $Td$s in the central vertical channels (channels 5 to 12) showed the effect of falling water. The falling water flows from front to back because of the toilet bowl shape. Therefore, channels at the low positions (channels 7, 8, 11, 12) for ID = 1 and ID = 4 showed large responses. Since ID = 2 and ID = 3 were arranged facing each other, these temperature changes were almost the same in all the channels.

$Td$s in the side channels from 1 to 4 and 13 to 16 also increased slightly temporarily. Since the falling water at 37°C heated the surface of the toilet bowl, $Td$s at the lower two channels 8 and 12 did not return to zero within a short time after the water was passed into the toilet. Similar phenomena were obtained at the other flow rates, and the effect increased at lower flow rates and larger amounts of water. The error was largest at 10 ml/s flow rate and 300 ml of water.

Typical examples of $S(t)$ are shown in Fig. 5 and Fig. 6. At a flow rate of 20 ml/s, maximum $S(t)$ increased significantly as the amount of the falling water increased (Fig. 5). At 200 ml of falling water, the duration of $S(t)$ increase resulting from the falling water became shorter as the flow rate increased.

The $U_{be}$ and $U_{tl}$ obtained by the bias temperature elimination method and the time limitation method are shown in Fig. 7 and Fig. 8, respectively. All the $U_{tl}$ were larger than the $U_{be}$. Regression lines are shown in each figure. From the regression lines, averaged slopes for $U_{be}$ and $U_{tl}$ were $22.3 \pm 4.3^\circ C/ml$ and $28.4 \pm 2.9^\circ C/ml$, respectively. The ratios of the mean and standard deviation of the slope were 0.19 and 0.10, respectively.

4. Discussion
In this preliminary study, we proposed a method of measuring voided volume using noncontact temperature sensors. Because there are few air conditioned toilets in Japanese homes, the room temperature in toilets varies with the season. Thus, the background temperature may change. In this preliminary study, the air temperature of the location of the toilet seat was set at almost constant. We proposed flow rate proportional $P(t)$ and $U$ that has a proportional volume. To determine the flow rate and voided volume, a conversion coefficient that should be a function of the background temperature is required. If the background temperature is the same as the temperature during urination, no difference is obtained in equation 1. Therefore, it is theoretically impossible to obtain both the flow rate and the voided volume. Toilet seat
equipped with a heater is increasing being used in recent years. The heater will warm the environmental air. The extent to which the toilet heater affects the estimated voided volume in a feasibility test will be reported in the near future.

There are gender and individual differences in the urination position. The output of temperature sensor increases when the heat source is close to the sensor. We employ four temperature sensors to complement each other, with the expectation to minimize gender and indi-
Individual differences. The maximum flow rates of urination in healthy males and females are 30 ml/s and 50 ml/s, respectively [6]. The average flow rate of urination in healthy males depends on age, and varies from 7.7 to 16.0 ml/s [7]. In patients with benign prostatic hyperplasia, the maximum flow rate of urination is slow (approximately 11 ml/s) and the voided volume is approximately 190 ml [8]. In these patients, the required urination time is at least 17 s. This means that the toilet bowl is heated by urination for a long time. Radiant heat from the surface causes overestimation of $P(t)$ and $U$. Therefore, a method to avoid overestimation is required to obtain the precise voided volume.

We proposed two analysis methods to obtain $U$ in proportion to the amount of falling water. $U_{tl}$ was always larger than $U_{be}$ at all the flow rates and all the flow volumes tested. Both parameters showed a good linear relationship to the volume of falling water, for all the flow rates. However, the ratios of mean and standard deviation of the slope in was smaller for $U_{tl}$ than for $U_{be}$. From these results, the time limitation method was suitable for obtaining $U$.

Previous research has reported uroflowmeter that requires major modification of the toilet [9]. However, our system is easily installed if the toilet seat is equipped with sensors. Since the measuring device does not make contact with excrement, our method is effective for prevention of infectious diseases. Additionally, the noncontact temperature sensors can solve privacy concerns for methods using a camera.

5. Conclusion
An instrument for measuring voided volume which is easy to install in household toilets is required for health monitoring at home. We developed a method to evaluate the value of $U$ that is proportional to the voided volume from urine radiant heat. This method does not make contact with excrement and maintains privacy.

The sensors were installed directly under the toilet seat, and the volume of falling water at 37°C was estimated using the actual toilet bowl. The variation of $U$ obtained by the time limitation method was smaller than that obtained by the bias temperature elimination method. For future research, we are planning to develop an integrated device with a built-in sensor and communication functions to facilitate installation in existing toilets.

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Conflict of Interest
We have no conflicts of interest relationship with any companies or commercial organizations based on the definition of Japanese Society for Medical and Biological Engineering.

References


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