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User Health Information Analysis With a Urine and Feces Separable Smart Toilet System

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ABSTRACT In this paper, the integration of Internet of Things (IoT) regarding recent technology is discussed in a healthcare perspective. Various healthcare devices have emerged in recent years, allowing individuals to diagnose and manage their health conditions easily at home. However, the diagnostic utilization of IoT healthcare services is not yet fully integrated with the Internet. For this reason, people still have to go, for example, through a hands-on sampling process to self-analyze their urine, which is the same for inspectors in hospital labs. Therefore, with the exception of people suffering from certain diseases (e.g., diabetes), there are only a few who check their own health status due to the inconvenience. In this paper, sensor-based urine and feces separating toilet proposes a categorizing method for the user's toilet, which applies various scenarios and analyses of the urine components using long-range wireless communication technology to transmit data from the smart toilet to the user.

INDEX TERMS Applications, healthcare, Internet of Things (IoT), sensor networks, urine analysis, urine strip, urine and feces separable toilet.

I. INTRODUCTION

Science Walden, named after Thoreau's essay and Skinner's novel, is now attempting to bring a new order into our society by using two concepts: feces standard money and spontaneity. Feces standard money is not meant to substitute the currency in use but as a parallel one to supplement it, economically and socially. The flush toilet has been called, from the perspectives of sanitation and the environment, one of the greatest and worst inventions in our scientific history, respectively. With further scientific developments, we now have the opportunity to move beyond the flush toilet, which could bring important changes still unknown. Thus, in this study, we hope to bring new value from the experience of using a smart toilet instead of a conventional flushing one and to reach a new horizon for our communities and through the world's networks [1].

As the first step of a new movement, Science Walden aims to generate renewable energy through waste from the surrounding living environment. For example, the toilet, which is essential to people's living space, is the most well-known renewable resource waste site from Science Walden's point of view. Many previous studies have studied finding a way to regenerate such waste into bioenergy or fertilizer via the use of anaerobes [2]–[7]. However, many of these prior studies did not progress further than the laboratory level and were mostly uncommercialized. We assumed that a lack of an economic ripple effect of such renewable energy in society was the main factor why these developments remained at the laboratory level [1]. Hence, we thought that increasing the efficiency of renewable energy from these studies would naturally increase its economic value. So, to increase the efficiency of renewables produced by anaerobic microorganisms from human defecation or food waste, we used the traditional toilet for our study and experimentation.

Using the traditional toilet for our investigation, however, brought various challenges [8], [9]. First, traditional toilets cannot separate feces and urine, which is of importance to increase the yield of renewable energy as these have to be stored separately. Second, less water should be used for each toilet flush. Main reason to limit the water use—with the goal of producing more energy—is to minimize the storage space required for the feces and anaerobic microorganisms and to avoid diluting the material too much [10]. To solve these two main problems at the same time, we suggested a different type of toilet than the traditional one. As such, the newly-designed toilet, shown in Figure 1, has many features aimed to resolve

FIGURE 1. The Science Walden toilet that can store urine and feces separately by using a vacuum pump, which also promotes a low level of water usage.

these problems, such as internal structures to store feces and urine separately, vacuum suction pumps to reduce the used flush water by more than 90% compared to the standard toilet, and ultraviolet sterilization of the seat for user hygiene.

This newly-designed toilet showed an increase in energy production efficiency, which means that the previously wasted resources were reclaimed through the research of developing an improved toilet. However, the produced amount of renewable energy and the economic value were not attractive enough to convince other people to participate in this research. Therefore, we began this study with the aim to analyze collected urine to obtain personal health information, which would be collected and used as big data on an urban and national level to build new value for that as well [11]–[14].

To entice people using this toilet, we introduced a system to give value to their feces by returning a compensation. This compensation was given in the form of ''honey coins,'' which had the same economic value as traditional money within the Science Walden's platform [14], [16]. The number of awarded honey coins was determined by combining all of Science Walden's economic factors that affect society, such as the amount of renewable energy produced [15]. So, to give a user a number of honey coins based on their activity with our toilet, it is crucial to detect the user's environmental impact accurately, including the difference between the amount of feces contributed or thrown away food.

II. USER SCENARIOS WITH THE SMART TOILET SYSTEM

As mentioned before, it is very important to analyze the user's toilet environment accurately to give users the appropriate number of honey coins. For this, various user scenarios and technical requirements need to be taking into account.

A. USER SCENARIOS

There are three main toilet environment scenarios that users can follow. First, the user only urinates, and the toilet only collects urine. For this case, the toilet has inside a urine and feces separation wall that can divide them effectively. For this to function, the user must sit on the toilet—at the current development state—regardless of gender. Second, the user excretes both urine and feces, and the toilet collects both into each storage part simultaneously using the separation wall. This also functions regardless of gender since the emitted location of the urine and feces is different; after emission, both excrements are divided and collected into their respective container. And lastly, the user does not excrete any urine or feces, but the user throws away food waste instead. Then, the user must throw the food waste into the feces storage part of the toilet as it is treated the same.

B. SENSOR-BASED SMART TOILET SYSTEM

Various features were considered in order to select the sensors required to distinguish between the three scenarios clearly. First, the method of measuring relevant values had to be done with a simple sensor [17]. This approach was taken to reduce errors that might occur when using complex sensors. So, the measurements from the selected sensors will be simple and clear, taking up less data capacity as well [18], [19]. Second, the sensor must be compact so that it can be installed in the toilet. It must be possible to install it in such a way so that the space of various parts, such as urine component analyzers and communication devices, is fully available and not intruded by other key functions [20]. Finally, because this sensor will be used frequently—creating a higher chance that problems will occur during its use—the maintenance of it should be easy and inexpensive in the event of a problem. Given these conditions, an infrared distance sensor was chosen, which was inexpensive but accurate and did not take up much space.

A total of two infrared distance sensors were used to determine the user's behavior with the toilet. Infrared distance sensor 1 was attached to the top of the toilet seat and had a relatively long measurement distance (Figure 2, Table 1), which will determine whether the user is seated on the toilet or not. Then, infrared distance sensor 2 was attached to the underside of the toilet seat and had a shorter measurement distance than sensor 1, where it can read values more accurately to detect the passage of foreign matter through the feces storage part (Figure 3, Table 2).

The two infrared distance sensors made it easy to identify a user's scenario. However, the use of an additional variety of sensors may still be considered to increase the reliability regarding scenario determination. For example, installing a sound sensor (Figure 4) or capacitive contact sensor on the toilet seat's surface would further supplement the validity of the information from the two distance sensors. Finally, the sensor data was interlinked with the applications of Science Walden to provide users with honey coins that can be used or shared with others through Science Walden's platform [21]–[24]. Algorithms to classify the behavior of users must, therefore, connect with the Internet to provide honey coins and health diagnosis information to the user [25].

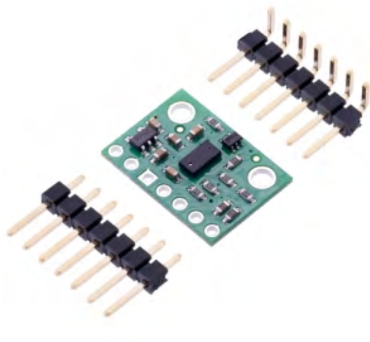
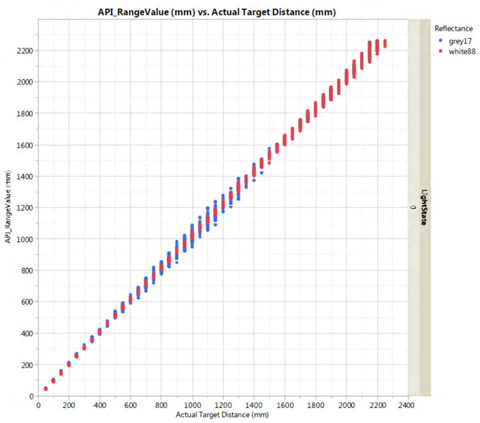


FIGURE 2. Sensor 1_VL53L0X infrared distance sensor (∼2000 mm).

TABLE 1. Sensor 1_VL53L0X infrared distance sensor (∼2000 mm) sensing capabilities and precision table.



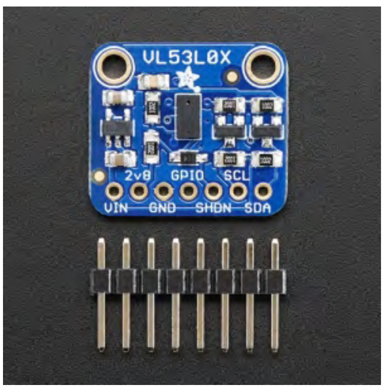


FIGURE 3. Sensor 2_VL53L0X infrared distance sensor (∼1000 mm).

Hence, data transfer technology was essential to meet this requirement.

Smart toilets will process the abovementioned amount of data, which will converge on a server from numerous toilets scattered around the building [26]. For this reason, the smart toilet requires both short- and long-distance communication to send the measured data through the urine analysis sensor to the server through gateway and to transfer honey coins to the user from the server.

TABLE 2. Sensor2_VL53L0X infrared distance sensor (∼1000 mm) sensing capabilities and precision table.

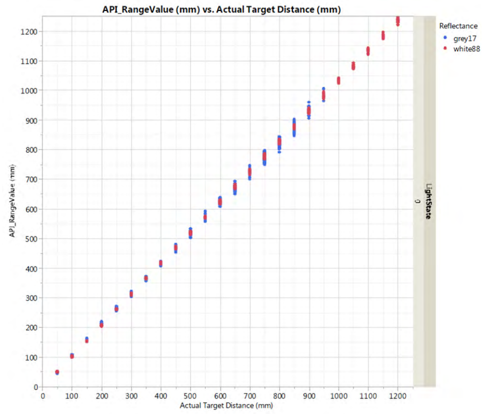


FIGURE 4. The added sound sensor to increase the accuracy of measurement.

There are various studies that have described the communication technology required for IoT healthcare services [27], [28]. In this context, Bluetooth Low Energy (BLE) is extremely well-suited for healthcare applications in regard to short-range communication standards [29]. It is secure and features a good range, low latency, low power consumption, and robustness to interference [33]–[38]. Therefore, BLE is a suitable option as a short-range communication standard for healthcare service compared to other communication standards [25], [30]–[32]. Then, the toilet also requires long-range communication standards. Some of these include SigFox, LoRa, and NB-IoT. Here, NB-IoT is very suitable as a long-range communication standard compared to others because of several advantages such as its security features, data rate, range, network capacity, communication directions, and band of operation [39]–[45], [48], [70]. Nevertheless, we used the LoRa standard instead because it is a non-licensed band, easy to access, and also less expensive while still fulfilling our requirements for a smart toilet's data communication system [52], [53]. The LoRa standard provides a secure bidirectional connection and offers the options of locating as well. As shown in Figure 5, the LoRa-capable devices connect via LoRa through the gateway [47]. The gateway then transmits the data via a standard IP connection to the cloud server. By using LoRa, transmission of a small

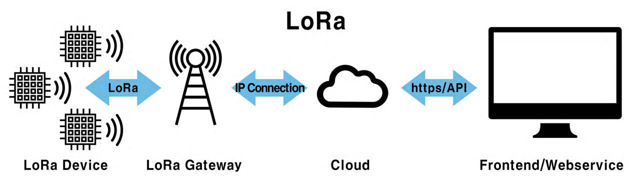


FIGURE 5. How LoRa functions.

amount of information is possible over a long distance using relatively little power [62]–[69].

For the toilet, BLE technology is used to receive more data from a short distance than LoRa reliably. After the user finishes in the bathroom, the user receives a reward of 10 honey coins when he or she uses BLE to connect a smartphone to the tagging device installed in the toilet [49]–[51]. Figure 6 shows the application interface, including an activated "Take 10 Ggool." To get Ggool from the app, a user must share some with their peers first. This process involves the user and the toilet to be first connected with the sensor. Then, the data generated is transmitted through LoRa from the toilet to the cloud server [55]. As a result, the server pays honey coins to the user through BLE by connecting the toilet and smartphone. Finally, it connects people for honey coin transfers [57]–[61].

III. HEALTH MONITORING SYSTEM BY URINE COMPONENT ANALYSIS

Illustrated in Figure 7, conventional techniques to diagnose a patient's health by urine require collected urine directly of which the analyses must be performed. Because of this, the process of taking urine samples can feel quite cumbersome and unhygienic for people who are not familiar with it. The discomfort that can result from the manual collection and analysis of the urine and the problems that can arise from this process have been resolved by the feces and urine separating toilet and can monitor a user's health condition instantly.

Science Walden's feces and urine separating toilet has an installed urine analyzing sensor (located in the separate urine storage section). This way, the urine is collected and analyzed immediately inside the toilet without the user having to come into contact. The results are then sent to the user in real time. This is an important aspect for urine analysis as sugar levels can be analyzed immediately, which is one of the most direct indicators of a person's health status, especially in regard to diabetics. Therefore, an algorithm was proposed that can process information about a user's health condition stochastically.

After determining the user scenario for the specific usage of the toilet, regarding urine or feces (or food), users can analyze their health information thank to the urine component analyzer. At this time, the urinal component analyzer is a method for analyzing urine components based on a urine reagent strip test that is marketed in the existing medical device market. After separating the urine from the feces, the analyzer exposes a urine reagent strip to the collected urine, which is then analyzed by the spectrophotometric sensor of the component analyzer.

A. URINE STRIP TEST

A urine strip test is a basic diagnostic tool used to determine pathological changes in a patient's urine using standard urinalysis [71]–[75]. A standard urine test strip may comprise up to 10 different chemical pads or reagents that react (change color) when dipped into the urine. The test can often be read in as little as 60 to 120 seconds after exposure. Routine testing of the urine with multiparameter strips is the

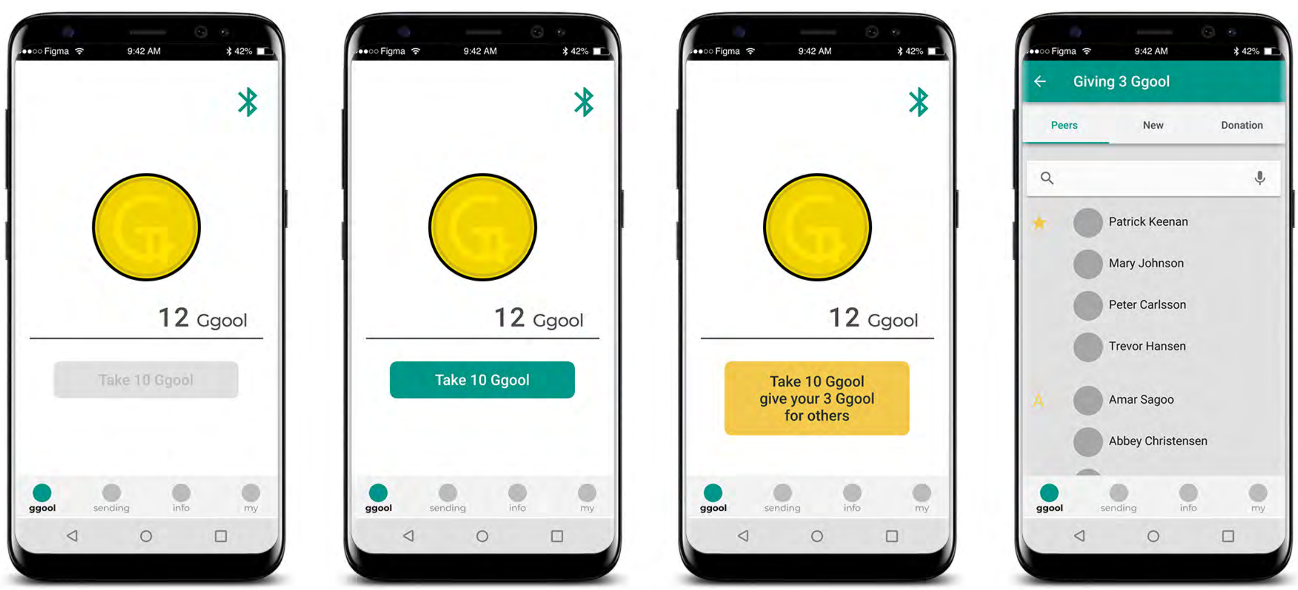


FIGURE 6. The science Walden application for android.

FIGURE 7. Traditionally, the analysis of urine requires users to collect their urine themselves, which is then sent to a laboratory where an analyst analyzes the sample and forwards the information to the user by mail.

first step for the diagnosis of a wide range of diseases. The analysis includes testing for the presence of proteins, glucose, ketones, hemoglobin, bilirubin, urobilinogen, acetone, nitrite, and leucocytes, as well as the testing of pH, specific gravity, and infection by analyzing for various pathogens. The test method consists of immersing the test strip completely in a well-mixed sample of urine for a short period of time, followed by its extraction from the container while supporting the edge of the strip over the mouth of the container to remove excess urine. The strip is then incubated for the reactions to occur (usually 1 to 2 minutes). The color changes are then compared against the chromatic scale provided by the manufacturer. Here, it must be noted that an improper technique could produce false results. For example, leukocytes and erythrocytes precipitate at the bottom of the container and may not be detected if the sample is not properly mixed. Similarly, if an excess of urine remains on the strip after it has been removed from the test sample, it may cause the reagents to leak from the pads onto adjacent pads, causing mixing and distortion of the colors. For this reason, the edges of the strip are dried on absorbent paper [77].

The urine test can evaluate multiple parameters to make a diagnosis, including suspected diseases, see Table 3. The majority of urine tests rely on oxidation and reduction reactions. For these tests, false negative or false positive results can occur quite easily due to interference from various antioxidants or reductants. The test results can also be affected by the user's diet, water intake, medication, vitamin C status, and underlying illness [76]. Therefore, it should be emphasized that a urine strip test is a quick test, and it only presents probabilities. The detection limit of a test is the concentration at which the test starts to turn from negative to positive. Although the detection limit may vary between urine samples, the detection limit is defined as the concentration of the analyte that results in a positive reaction in 90% of the examined urine samples.

TABLE 3. Reference and problem range of the urine test with suspected diseases.

Parameter	Reference Range	Problem Range	Suspected Disease
Blood	-	> 1	Inflammation or tumors of the kidneys
Bilirubin	-	> 1	Gallstone disease, acute hepatitis, chronic liver disease
Urobilinogen	-	> 2E.U.dl	Liver disorder, hemolytic jaundice and pulmonary jaundice
Ketones	-	> 1	Severe diabetes
Glucose	-	> 1	Diabetes, pancreas disease, liver trouble, brain tumor
Protein	-	> 1	Kidney infection, diabetes, Wilson's disease
Nitrite	-	+	Cystitis, urethritis
Leukocytes	-	> 1	Kidney and urinary tract abnormalities, tumors
PH Value	4.5 ~ 8.5	< 4 or > 9	Diabetes, gout, hunger, dehydration, urinary tract infections
Specific Gravity	-	> 1	Cystitis, urethritis

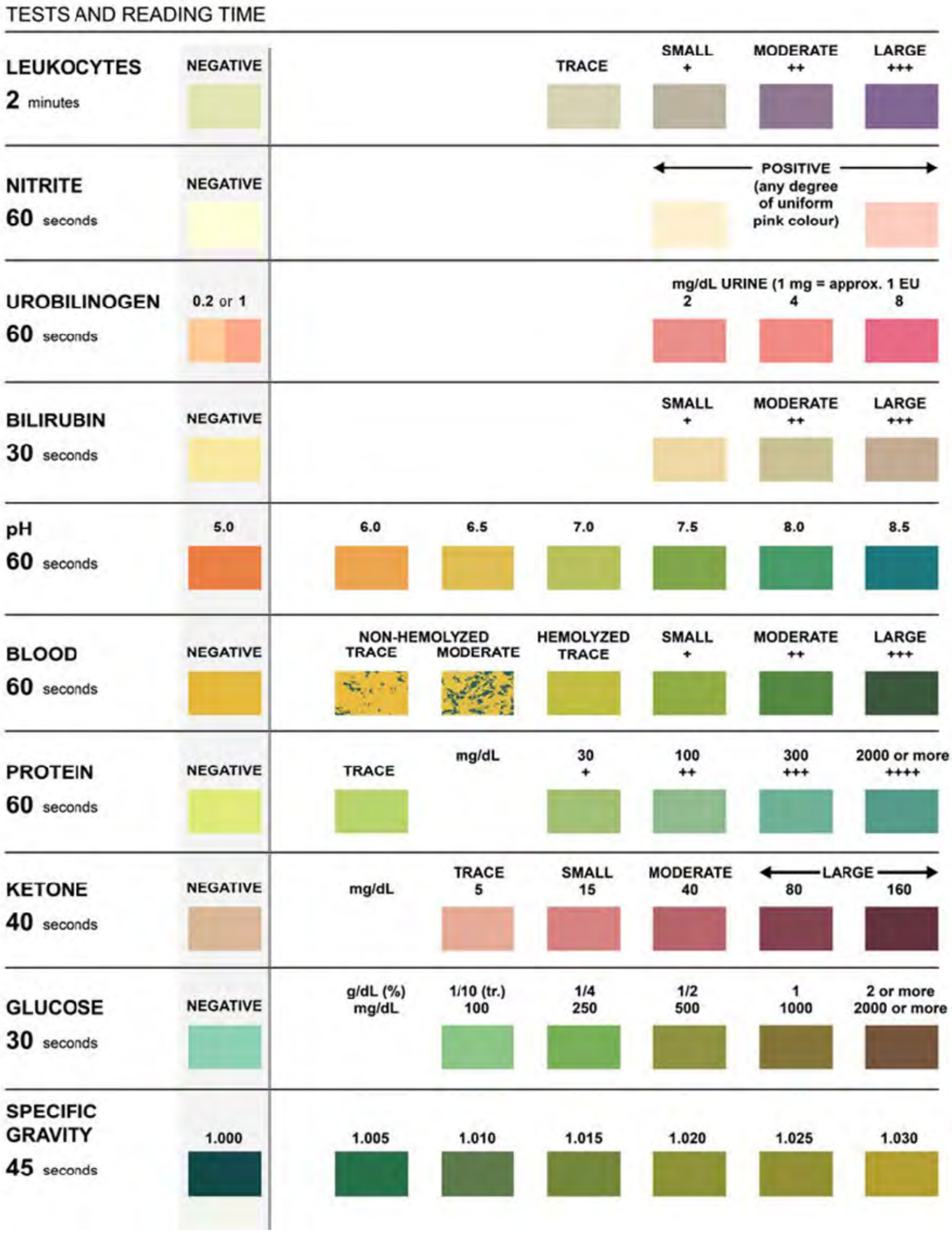


FIGURE 8. The colors of the urine test strip after reacting.

The urine strip test provides information about 10 parameters (as shown in Table 3 above), see Figure 8 for the color change meanings on a used urine stick.

On this strip, the glucose test is based on a double sequential enzyme reaction. One enzyme (glucose oxidase) catalyzes the formation of gluconic acid and hydrogen peroxide

TABLE 4. Truth table based on two different infrared distance sensors.

	Sensor 1	Sensor 2
Empty	F	F
Urine	T	F
Feces	T	T
Food Waste	F	T

from the oxidation of glucose. A second enzyme (peroxidase) catalyzes the reaction of hydrogen peroxide with potassium iodide chromogen to oxidize the chromogen causing different colors ranging from blue-green to greenish-brown to brown and dark brown.

The bilirubin test is based on the coupling of bilirubin with a diazotized dichloroaniline in an acid medium. The colors range from light tan to reddish-brown.

The ketone test is based on the reaction of acetoacetic acid with sodium nitroprusside in a basic medium. The colors range from beige or buff-pink color for a ''negative'' reading to pink and pink-purple for a ''positive'' reading.

The specific gravity test is based on the apparent pKa change of certain pretreated polyelectrolytes in relation to the ionic concentration. In the presence of an indicator, the colors range from dark blue or blue-green in urine with a low ionic concentration to green and yellow-green in urine with a higher ionic concentration.

Then, the blood test is based on the pseudo-peroxidase action of hemoglobin and erythrocytes, which catalyzes the reaction of 3,3',5,5'-tetramethylbenzidine and buffered organic peroxide. The resulting colors range from orange to yellow-green and dark green. A very high blood concentration may cause the color to become dark blue.

The pH test is based on the well-known double pH indicator method, where bromothymol blue and methyl red give distinguishable colors indicating a pH range of 5–9. The colors range from red-orange to yellow and yellow-green to blue-green.

The protein test is based on the protein error-of-indicator principle. At a constant pH, the development of any green color is due to the presence of protein. The colors range from yellow for a ''negative'' reaction and the yellow-green and green to blue-green for a ''positive'' one.

Next, the urobilinogen test is based on a modified Ehrlich reaction, in which p-diethylamino benzaldehyde reacts with urobilinogen in an acid medium. The colors range from light pink to bright magenta.

The nitrite test depends on the conversion of nitrate to nitrite by the action of Gram-negative bacteria in the urine. The nitrite reacts with p-arsanilic acid to form a diazonium compound in an acid medium. In turn, the diazonium compound couples with the 1,2,3,4-tetrahydrobenzo[h] quinoline to produce a pink color.

TABLE 5. The concordance rate between the user and sensor package #1.

	Male #1	Male #2	Male #3	Male #4	Female #1	Female #2	Female #3	Female #4
Test #1	T	T	F	T	F	F	T	F
Test #2	T	T	T	F	F	T	T	T
Test #3	F	T	T	T	F	F	F	F
Test #4	T	T	T	T	F	F	T	F
Test #5	T	F	F	T	T	T	T	T
Test #6	F	T	F	T	T	F	F	T
Test #7	T	T	T	F	F	F	F	F
Test #8	T	T	T	F	F	T	F	F
Test #9	F	T	F	T	F	F	T	F
Test #10	T	T	T	T	T	F	F	T
%	0.7	0.9	0.6	0.7	0.3	0.3	0.5	0.4

TABLE 6. The concordance rate between the user and sensor package #2.

	Male #1	Male #2	Male #3	Male #4	Female #1	Female #2	Female #3	Female #4
Test #1	T	T	T	T	T	T	T	F
Test #2	T	F	T	T	F	T	F	T
Test #3	T	T	T	T	T	T	T	T
Test #4	F	T	T	T	F	F	T	T
Test #5	T	T	T	F	T	F	F	T
Test #6	F	T	T	F	T	T	T	F
Test #7	T	T	T	T	F	T	F	F
Test #8	T	T	T	T	T	F	T	T
Test #9	T	T	F	T	T	F	T	F
Test #10	T	F	T	T	F	T	T	T
%	0.8	0.8	0.9	0.8	0.6	0.6	0.7	0.6

The leukocytes test is based on the action of esterase present in leukocytes, which catalyzes the hydrolysis of an indoxyl ester derivative. The liberated indoxyl ester reacts with a diazonium salt to produce a beige-pink to purple color.

Finally, the ascorbic acid test is based on the action of a complex chelating agent with a polyvalent metal ion in its higher state, which is an indicator dye that can react with the metal ion in its lower state to produce a color change from blue-green to yellow.

Together, on the top of the urine test stick, there are colored papers placed of which each corresponds to one of the ten

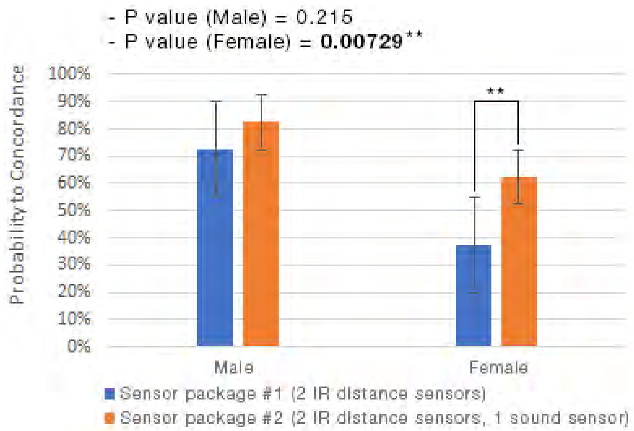


CHART 1. Concordance probability between the real environment and sensor-detected environment with the P value showing significance.

FIGURE 9. Distance preference of the urine and feces separating wall, based on the urine angle of user experiences (men = yellow, women = green).

parameters discussed. When this part is exposed to urine, the colors change according to the chemical processes taking place. For the chemical reactions, the most crucial factor in determining the results involves not the reaction itself but the determination of the c olor change of each test. Some of the 10 items are extremely reactive to color-changing when responding to urine, while others are not. Therefore, in order to analyze this accurately, it is necessary to detect the subtle color changes by applying various wavelengths to the urine test stick. For example, in the case of leukocytes, there is a clear color difference between negative and positive outcomes, depending on the amount of material in the urine. However, in the case of the specific gravity or protein tests, there are only subtle differences between a negative and a positive outcome. So, to compare the components of urine that are abnormal to human eyes with those of abnormal urine through the urine test strip, it will take longer to identify the outcome with more subtle color changes. However, this is not an issue when using spectrophotometric, where the accuracy of the data can simply be improved by increasing the number of lights that emit a certain wavelength. To simplify the experiment, we had chosen and utilized wavelengths commonly used in other commercial urine analyzers, including 450 nm, 530 nm, 610 nm, and white light. These four different areas of wavelengths are mostly within the range of visible light because the colors of the paper used for component analysis are mostly between blue and red. For example, if you place red cellophane in front of your eyes, you may not see red colored letters. Based on this principle, when four lights are turned on and off sequentially, otherwise the color of the urine component analysis strip cannot be correctly read by the RGB sensor located on the opposite side.

B. SPECTROPHOTOMETRIC ANALYSIS AND RGB SENSOR

Inside the toilet, there is an RGB sensor that can read the color of the urine test paper using spectrophotometric analysis. Spectrophotometric analysis is a method of determining materials in a substance or mixture by measuring the amount of light absorbed in the infrared, visible, or ultraviolet region of the electromagnetic radiation (light) spectrum. So, when the user is using the toilet to check their personal health information, the urine test paper is sent from the installed cartridge to react with the urine. This results in 10 color test indicators changing into various colors depending on the urine's components, which are then converted into a data format via the RGB sensor. Additionally, it is necessary to repeat the analysis using the illumination of the various wavelengths to reduce the error of the values read through the RGB sensors of the urinal component analyzer. The used wavelengths of light depended on the algorithms; the accuracy of the urine component analyzer increases when using various wavelengths.

IV. RESULTS

A. INFRARED SENSORS IN THE SMART TOILET

Through the two different infrared distance sensors, a truth table showing each scenario that might occur in the bathroom (Table 4) can be obtained, in which T represents a detected scenario. First, if no one is sitting on the toilet without any detection on sensor 2, the status is F/F (Sensor 1/Sensor 2), representing that there is no person on the toilet and no waste in the feces or urine storage parts. Second, if someone is sitting on the toilet, but without detection of sensor 2, the status is T/F, which means that a person who is using the toilet only urinates. Third, if someone is sitting on the toilet

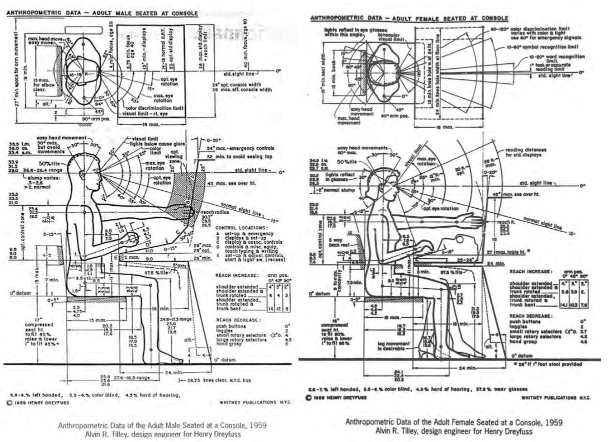


FIGURE 10. Adult male and female seated anthropometric data.

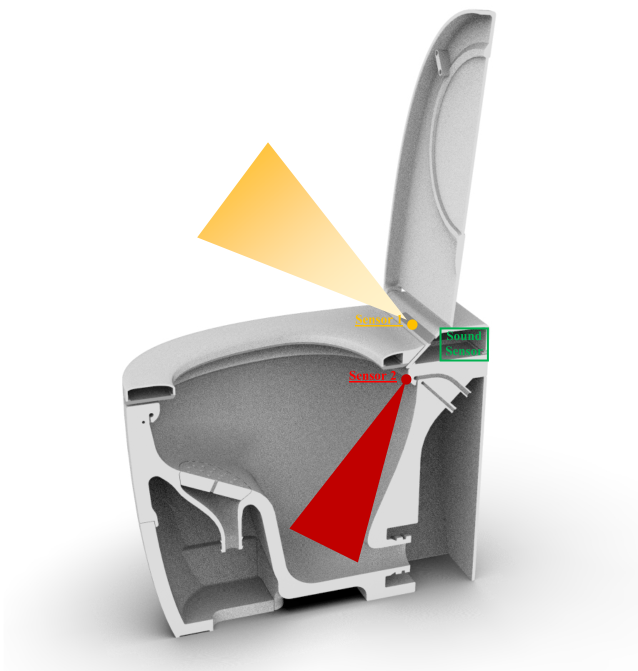


FIGURE 11. Detection area of three different toilet sensors.

and sensor 2 detects waste, the status is T/T, which means that a person who is using the toilet urinates and excretes feces. In the second and third scenarios, the application can offer the user a health monitoring function using the urine test. Lastly, if no one is sitting on the toilet, but sensor 2 reports a detection, the status is F/T, which means that the toilet has detected waste.

The truth table status based on sensor 1 and 2 was tested in the Science Walden Living Lab by subjects consisting of four men and four women. The experiment was designed to determine the concordance rate in a real environment by the sensor package, which only consisted of the two infrared distance sensors. Therefore, the subjects were asked to freely use the bathrooms in the laboratories over several days but record

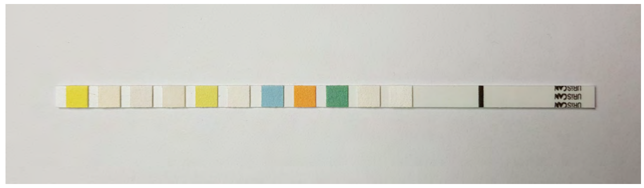


FIGURE 12. The urine test strip without additional light exposure.

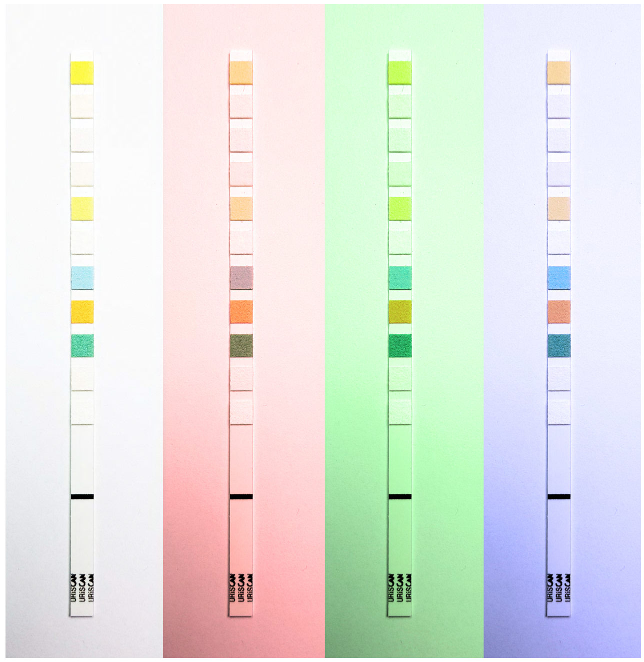


FIGURE 13. The urine test strip exposed using each LED light with different wavelengths (white, 610 nm, 530 nm, 450 nm).

the matching ratio between sensors and the real environment for a total of 10 recordings. In this setup, the users tested the toilet by urinating only.

In Table 5, T means that the sensor value matched with the actual value and F that it did not. Based on the results, the average level of concordance rate between the sensor package and the actual environment was only 55%. However, if only male experimenters were taking into account, the concordance rate rose to 72.5%. In other words, the sensor package was not very suitable for analyzing the female experimenters' toilet environment.

To improve these results, an additional sensor had to be added to the sensor package. Here, it was important that the added sensor was also inexpensive, small in size, and took a small amount of data. Most importantly, unlike the infrared sensors previously mentioned, it had to be able to detect a new type of information, such as the sound in the toilet environment. So, we chose the sound sensor as the third sensor in the sensor package (Figure 4). Table 6 shows the concordance rate table of sensor package #2.

Shown in Table 6, the overall average level of concordance rate between the sensor package and the actual environment

TABLE 7. Character map for each type of wireless communication technology.

	Short-Range Communication		Long-Range Communication		
Type of Communication Standard	**Bluetooth Low Energy**	**ZigBee (XBee Module)**	**SigFox**	**LoRaWAN**	**NB-IoT**
Band of Operation	2.4 GHz	2.4 GHz	868 MHz (Eu) 915 MHz (US)	868 MHz (Eu) 915 MHz (US)	Various
Range	150 m	30 m	9 km	12 km	15 km
Data Rate	**1 Mbps**	250 kbps	100 bps	0.5–5.5 kbps	250 kbps
Security Features	- Secure pairing prior to key exchange - Two keys used to provide authentication and identity protection - 128-AES encryption	- Optional 128-AES encryption - Network key shared across the network - Optional link key to secure application-layer communications	- Messages signed with a private key - Limit of 140 messages per day - Encryption and scrambling methods supported	- Unique key assigned to each node on the network, known only to the node and base station - Data encrypted using the unique key	- 3 GPP S3 security scheme includes entity authentication, device identification, user identity confidentiality and data integrity as mandatory security features

had noticeably risen to 72.5%. Especially, the female experimenters' concordance rate rose sharply from 37.5% to 62.5%.

Based on Chart 1, the P value (significance factor) for adding the sound sensor shows that the link between the added sound sensor and increased concordance of male data was uncertain (insignificant); however, the concordance of female users was significantly affected by the added sound sensor. This difference can be inferred because of the physical differences between men and women.

In Figure 9, women preferred the urine and feces separating wall to be positioned closer to the back. This is most likely due to the difference in the urine angle between men and women. To verify this difference, we compared anthropometric data of men and women (Figure 10). When men and women sat on the toilet, assuming that the back of the knee contacted the front of the toilet, the length from the front of the toilet to the back was longer for men (men: 17.6–20.2 inch vs. women: 16.5–19.7 inch). As such, based on this data, males should prefer the position of the urinal separation wall to be further back than women. However, the results of the survey showed the exact opposite. Although it is difficult to relate women's preference to the backward location of the urine separation walls to the anthropometric data, results from surveys further confirmed this. By interviewing the male and female subjects, we concluded that the difference in men's and women's urine excretion angles

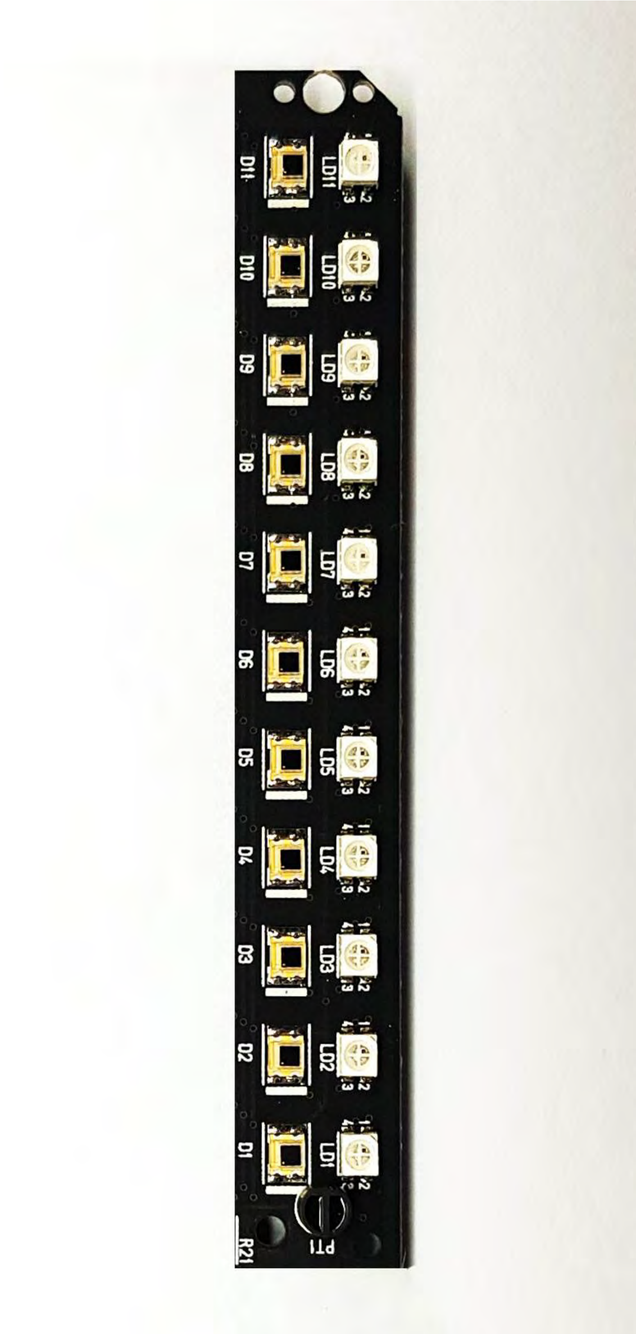


FIGURE 14. **The RGB sensor used for the urine test strip.**

may have been a significant factor. In the same context, it could be determined that the cause of error in the sensor 2 is interference caused by excretion angle.

This caused an error in the data regarding the toilet environment detection sensors. Therefore, to distinguish between urine or feces more precisely, a sound sensor was added (sensor package #2). Here, the sound sensor only reacts to a feces-related environment as it is located on the back of toilet seat in Figure 11.

FIGURE 15. **Campus map of UNIST.**

FIGURE 16. **Science Cabin located in UNIST.**

B. URINE TEST STRIP

Figure 12 shows an image of the original urine test strip without any additional light exposure, and Figure 13 shows a urine test strip using each LED light with different wavelengths.

Figure 14 shows the RGB sensor used to analyze the LED-exposed urine test strip and sends the obtained color information. Therefore, to make the RGB sensor read color information accurately, four different patterns of light were used. For example, the 1st, 5th, 7th, 8th, and 9th color block on the urine test strip were so vivid that it could be read without additional LED exposure. However, other color blocks on the urine test strip were too blurry and pale requiring the additional exposure of the LED lights.

Overall, the urine test paper analysis technology, using specific wavelengths, is used in various previous studies [71]–[77]. Thus, our study actively accommodated these published methods associated with urine analyzers using the wavelengths and selected appropriate wavelength areas.

FIGURE 17. The smart toilet and BLE communication device.

In addition, we attempted to combine its obtained data to utilize information together with IoT technology. Furthermore, we aim to combine related research cases to the toilet (to analyze the urine) to create IoT healthcare equipment that can be used by individuals at home [1]. To this end, we have selected the appropriate long-range communication technology by comparing and analyzing the long-range wireless technologies used in preceding research.

C. WIRELESS COMMUNICATION TECHNOLOGY

Communications related to IoT for healthcare can be classified into two main categories: short- and long-range communications. In this study, the two main types of wireless communication technology were BLE and LoRa. Nevertheless, there are many other short- or long-range communication standards. To compare the advantages and disadvantages of these different types of wireless communication standards, please refer to Table 7. There are five major different wireless communication technologies, but for the smart toilet system, BLE was chosen as a short-range communication standard as it can transmit large amounts of data better than ZigBee. Also, with BLE, the user can connect with the smart toilet system using their smartphone. For the long-range communication, the smart toilet system uses LoRa rather than SigFox and NB-IoT. This because LoRa is operated in a free license band range making it more flexible and easier than NB-IoT to enter the market for the first time. Additionally, LoRa has a larger communication range than SigFox.

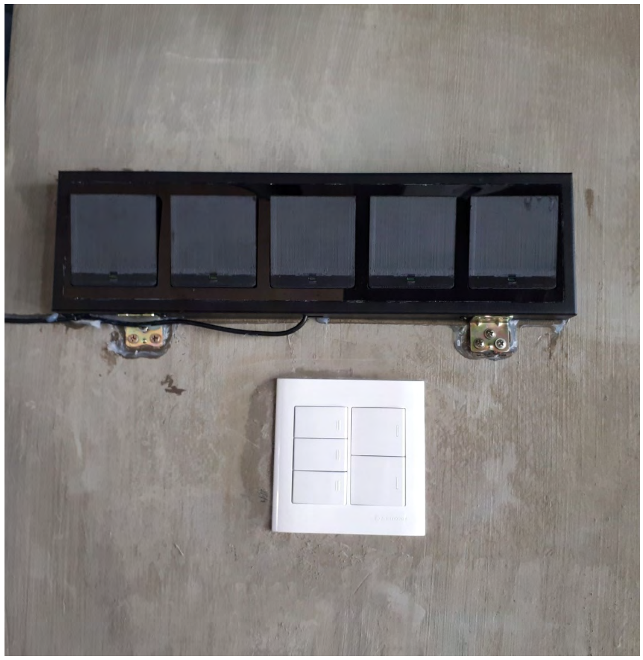


FIGURE 18. Gateway for connecting the toilet with the cloud server by LoRa.

Technically, LoRa can transmit the data gathered from the sensor packages to the main server and cloud over a distance of 10 km (Table 7). Therefore, data can be sent and received through LoRa at any location depicted in Figure 15. This means that inside the UNIST (Ulsan National Institute of Science and Technology) site—with the server (Science Cabin) located in the indicated red circle—can be covered. Moreover, using the frequency band of LoRa reduces costs as it can be freely used.

In Figure 16, the Science Cabin is shown where the study took place. There were three different toilets in total, and each one had a transmission device using BLE (Figure 17). Figure 18 shows the gateway for connecting the toilet with the cloud server by LoRa.

Overall, LoRa seemed to be superior to other wireless technologies in all respects; however, it has a disadvantage as well: LoRa can only send a small amount of information. Therefore, to compensate for this shortcoming, we used BLE when a large amount of data needed to be shared between the smartphone and toilet after the user had used it and also when data had to be shared. This, so that the user can receive honey coins from the server by communication devices which located in Science Walden.

V. CONCLUSION

Many researchers have been struggling for a long time to develop successful technology to recycle excrements on a commercial level. Unfortunately, most efforts have failed, and no widely available or commercially used product exists. However, while important, the reason for failure is not only due to technological or economic issues. When we (Science Walden) reviewed those problems with a brand-new perspective, there were several potential solutions found. First, we have added the additional value of a medical checkup. This approach removes the traditional frame or prejudice—with views of defecation as nothing but a cost—and enhances the process with technology and economic feasibility. By using RGB sensors and spectrophotometric analysis, it was possible to design a special toilet equipped with a new sensor system. Furthermore, we speculate that if this new toilet design would be installed in public bathrooms, it will increase the awareness among citizens who were not aware of the importance of health and hygiene. This will be another added value in terms of social welfare. Second, we construct a small rotating business system with honey coin platform using LoRa and BLE technology. LoRa consumes a minimum of energy and can send electrical signals up to 10–30 km away. Together, it becomes possible to obtain and archive numerous data related to bowel movement into the data cloud system. It is expected that this data brings undiscovered research topics. Additionally, this project incorporates the process of excrement disposure into the matter of economy and opens it up to the circulation of resource and business. Furthermore, it becomes an example of utilizing business as a tool to solve social problems. That is, Science Walden has raised the economic feasibility and application one more step by reevaluating the problem with an original perspective.

Science Walden's philosophy empathizes with the new economic movement called the ''Sharing Economy,'' which pursues sustainability based on voluntarily participation from users. In our study, there was a clear accordance between this cultural change and the vision of Science Walden. First, there was a process of redefining the concept of excretion disposal, which has been regarded as only ''costs.'' This project changes this view toward a ''hidden resource.'' Second, it adds special value to a toilet. Smart toilet not only helps to circulate natural metabolism but also to construct a feedback system about users' health, forming a meaningful service value chain together. Third, it motivates users to participate in this responsible movement toward the improvement of the environment without imposing additional pressure. As such, the users' daily lives become part of a desirable campaign or movement. Together, this casual participation will bring a positive change to society. As long as human beings are alive, Science Walden will be moving.

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