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An Internet-of-Things (IoT) system development and implementation for bathroom safety enhancement

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Abstract

Statistics show that a bathroom is one of the most hazardous places especially for older people. Older people typically have greater difficulties with mobility and balance, making them more vulnerable to fall and slip injuries in a bathroom and causing serious health issues related to short and long-term well-being. Various components in a bathroom including shower, tub, floor, and toilet have been re-designed, and independently upgraded their ergonomics and safety aspects; however, the number of bathroom injuries remains consistently high in general. Internet-of-Things (IoT) is a new concept applicable to almost everywhere and man-made objects. Wireless sensors detect abnormalities and send data through the network. A large amount of data can be collected from multiple IoT systems and it can be utilized for a big data analysis. The big data may reveal a hidden positive outcome beyond the initially intended purposes. A few commercial IoT applications such as wearable health monitoring and intelligent transportation systems are available. Nevertheless, An IoT application for a bathroom is not currently known. Unlike other applications, bathrooms have some unique aspects such as privacy and wet environment. This paper presents a holistic conceptual approach of an Internet-of-Things (IoT) system development and implementation to enhance bathroom safety. The concept focuses on the application in a large nursing care facility as a pilot testing bed. Authors propose 1) sensor selection and application, 2) integration of a wireless sensor local network system, 3) design concept for IoT implementation, and 4) a big data analysis system model in this paper.

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Keywords: Internet-of-Things; Bathroom Safety; Wireless Sensor Network; Big Data

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1. Introduction

Injuries associated with bathroom activities cannot be ignored. According to the Center for Disease Control and Prevention [1], About 235,000 people visit emergency room per year because of injuries caused in bathrooms. Injuries increase with age; especially people over 85 suffer more than half of their injuries near toilets. The bathroom injury rate for women was 72 percent higher than that for men. Three most hazardous activities for all ages are bathing, showering, and getting out of a tub. People who have degenerative joint disease and joint or other senile disease suffer disability while using a toilet. Similarly, according to New York Times, over 30 percent of total injuries associated with activities in bathrooms are head and neck parts. Main activities are bathing, using a toilet, and leaving and entering a tub. The injury rate is significantly increasing as people become older over 60 years [2].

IoT development in healthcare industry has focused on wearable and in-body sensor devices such as digital pill, smart bed, smart food, and smart band-aid. Wearable devices are typically attached in various body parts including head, neck, wrist, waist, and leg to get specific metabolic data [3]. However, wearable devices are not suitable to be used in bathroom environment and private activities because of wetting and undressing clothes. In addition, wearable devices need constant re-charging of power and maintenance to maintain functionality and network connectivity. Therefore, sensors shall be installed in objects in a bathroom such as toilet, bath tub, floor, ceiling, light fixtures. These unique aspects of bathroom environments differentiate from other IoT applications.

IoT is an emerging IT technology. A main function of IoT is to collect data measured by sensors integrated with short range wireless networks such as Bluetooth, ZigBee, or Wi-Fi, which again transmit data to larger networks such as Internet network gateways. IoT sensors provide low cost, scalable, efficient, low power, and integrated data through all sub-networks. As more sensors are incorporated and data collection period increases, the data becomes significantly large and hence the name “Big Data”. Big data was introduced by Gartner Report in 2001 [8] and had a threefold definition encompassing 3Vs: Volume, Velocity, and Variety. This definition has been reiterated by others to include a fourth V: Veracity [9]. In summary, IoT provides means of data collection, detection of monitoring events, algorithms to act on the events, and big data storage and analysis.

The main objective of this research is to provide a conceivable IoT system and to develop a big data model. This paper presents a holistic conceptual approach of an Internet-of-Things (IoT) system development and implementation to enhance bathroom safety. Authors propose 1) sensor selection and installation, 2) integration of a wireless sensor local network system, 3) design concept for IoT implementation, and 4) a big data analysis system model in this paper.

2. Sensors for Bathroom Applications

Most electronic sensors measure electric resistance or energy occurred by physical and chemical changes. Electronic signals can be digitally processed in an on-board microcontroller or directly transmitted to other devices through short-range wireless networks. Many sensors are commercially available, but require signal calibration, hardware modification to fit to existing bathroom objects, and configuration to connect to sensor communication networks. Below is a list of commercially available sensors.

- Leak Detection Sensor: It measures electronic resistance between two nodes. It can be installed on a bathroom floor to detect water leakage and flooding especially when an injured person is unable to move.
- Digital Light / Lux Sensor: It measures intensity of light radiation. Light sensors detect most spectrum ranges including infrared ray, visible ray, and ultra-violet ray. The sensor can be used to detect human-presence and movement, total time spent in a bathroom, and identification and frequency of a person in a bathroom.
- Voice Detection Sensor: It detects acoustic and noise signals. It is very useful as it can translate pre-programed messages (e.g., Help!) through a microcontroller in the case of medical emergency.
- Pressure Sensor: It detects magnitude of contact-pressure. A simple pressure sensor is able to detect a person’s status of using toilet and bath tub. A digital load cell sensor is same kind but provides more precise pressure readings that can be used for weight pattern analysis.

- Positional Sensor (Gyro/Accelerometer/Magnometers): It detects tilt, pitch, and inclination. These sensors can be used to detect falling, tilting, and locational changes for installed objects such as bath tub, shower room, and bathroom floor.
- Motion Sensor: It detects movement of people in a bathroom. Mobility in a bathroom can provide pattern of bathroom usage and alarm for emergency situation.
- Water Flow Sensor: Water leakage detection and measurement of water usage are important data for saving water and monitoring health conditions. Unusual water usage may indicate an emergency situation such as unconsciousness before finishing a shower or unnoticed internal plumbing leakage.
- Energy Harvesting Sensor: One of key requirements for IoT sensors is low power consumption to minimize maintenance of those sensors. Energy harvesting sensors generate small amount of electronic energy enough for their operation from the sensor device or adjacent energy harvesting medium such as sunlight, pressure, and hydraulic flow.

Although the aforementioned sensors are at the lowest hierarchy of an IoT system, their functions/capabilities can be used in various ways for this study, which are summarized as follows:

- Water consumption and flushing sequence in a toilet
- Pressure distribution on a toilet cover
- Deriving medical conditions of human from feces and urine
- Water consumption, water temperature, event sequence in shower and bath tub
- Falling or slipping detection from impact and pressure sensors

Our preliminary sensor study demonstrates suitability of the off-the-shelf sensors in bathroom environment conditions including, but not limited to, high humidity, wet and submerged in water, and confined and private space. However, those sensors are designed for normal operational conditions that may not be suitable for specific bathroom environmental conditions. Thus, appropriate modification is required.

A typical sensor module consists of four main components/functions including power supply, sensor part, actuator, and communication port. Figure 1 shows layout example for sensors that can be installed in a toilet and a bath tub.

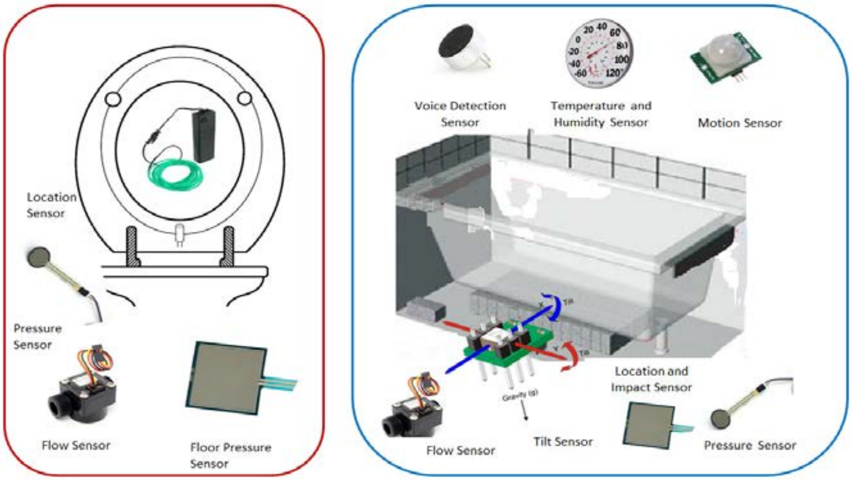

Figure 1. Layout Example for Toilet and Tub Sensors

3. Sensor Network and IoT Application

3.1 Sensor Network and Bathroom Design for IoT Implementation

Figure 2 illustrates a sensor network integrating multiple and heterogeneous (digital and analogue) sensor data through a short-range network within a bathroom. The short-range network transmits data to a larger network through a gateway or hub. Short-range networks are then integrated through multiple gateways and connected to a virtual cloud serving as a database server.

Such an IoT and big data system can be implemented in a pilot test bed. Basic functions and installations of a bathroom are similar regardless of difference in architectural design. Sensors shall be embedded in the fixtures and bodies of objects such as inside of floor, ceiling, and wall. Interior design of a bathroom pilot test bed focuses on alleviating black spots of network communication, improving convenience of sensor operation and maintenance, meeting design requirements, and enhancing well-being of older people. The proposed design for the pilot test bed is shown in Figure 3.

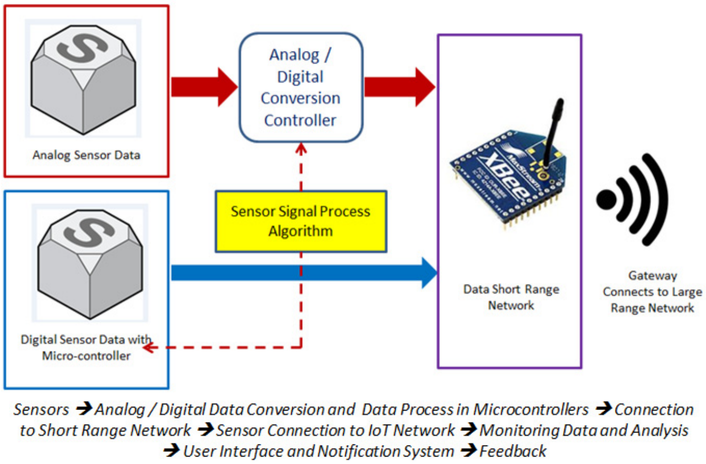

Figure 2. Sensor Controller, Algorithm, and IoT Network Flow Diagram.

3.2 Design of a Pilot Test Bed

Our pilot test bed consists of multiple groups of sensors, IoT networks, and big data components. Data analysis algorithms and user services shall be tested to ensure functionality and feasibility of the system. Utilities including electric power, water supply, and wastewater drainage will be connected to sink, toilet, and shower booth to be fully functional. All sensors and networks will be installed in several levels from short-range sensor networks to long-range networks via gateways. A virtual cloud server will be connected and completes a full circle of data transmission and storage. As shown in Figure 3, the pilot test bed plans to utilize Temboo, IFTTT, Arduino IDE, XCTU [4], Microsoft Azure and Power BI. Temboo is used to automatically compose sensor as well as gateway code/programs from function libraries. Arduino IDE is used to fine-tune the code. XCTU is used to test and build short-range networks. Azure and Power BI are used to store and visualize sensor data. The programs are installed on sensors and gateways. When integrated, IFTTT can be used to interface clouds services for data logging and notifications. The pilot test bed provides a baseline of research outcome implementation to a business case. Testing results and lessons from building a pilot test bed can be used to improve design and construction process of an IoT bathroom.

3.3 Big Data System Development

One of main objectives of this study is to develop a big data concept for the data collection, analysis, and implementation. Figure 4 illustrates the configuration of our big data analysis prototype system. It consists of four parts: a sensor unit, a hub unit, a base station, and a main server.

The sensor unit is composed of various sensors and actuators, but is grouped for easier management and geographical distance and connected to a hub in the region. The sensor unit and information gathering hub has similar structure to that described in detail in Figure 2. The difference here is that we aim to have a more standardized and bigger scale, but in terms of functionality, we plan to shrink a little because in this sub-task, data processing will be done more on the primary server and the base station.

A hub is responsible for connecting between a group of sensors/actuators and the base station, and supports both wired and wireless Machine-to-Machine (M2M) communication. In addition, hubs are used for setting sensor configurations and the development and improvement of sensor program and management algorithms.

A building base station serves to connect the information acquisition target buildings and the main server, and serves to provide a real-time analysis service for administrators, care recipients, and their guardians. The user information module stores encrypted personal information of care recipients, and security management module provides a user login and logout service and secure connection, and generates a session ID to maintain security [7]. The service broker receives queries from users and is responsible for transmitting sensed values/information and processed information to the users. The building base station includes a router and gateway that supports short-distance wired or wireless communication. Main mission is to process real-time analysis commands of an administrator and user's service queries. The human resource information module stores information of allowed users, and the security management module manages and controls their secure connection. The service broker module obtains data and information from both sensors and the main server to fulfil user queries, and additionally sends periodic notifications (for example, automatic safety check function is invoked when bath time is prolonged abnormally) or recommendations. The real-time analysis module senses an accident (for example, falls) or event that requires immediate action and sends a warning or processing feedback to the necessary components and recipients, and provides alert to the administrator.

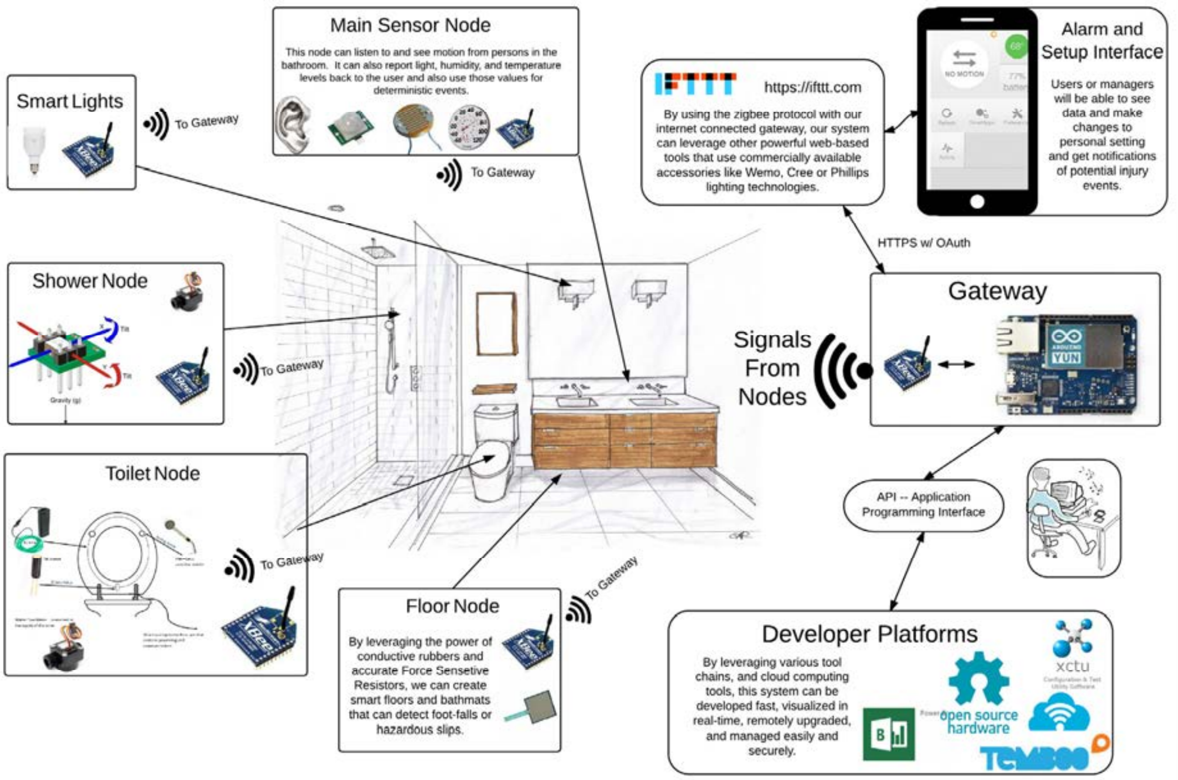

Figure 3. Pilot test bed design and installation layout.

The main server is a core intelligent computer used to efficiently process and analyze large sensor data, and store the results for research and technology development of comprehensive and intelligent processing, management, display, and empirical evidence. Here we develop methods and algorithms that comprehensively handle a variety of sensor events, knowledge database construction, implement a decision-support expert system, and support the work of the administrator through the administrator interface. To effectively classify, store, and handle diverse and continuous stream of sensor data, this study will use an open source Oliot EPCIS [5] event-based sensor data processing middleware that shows excellent scalability and flexibility. If we are unable to intelligently and smartly process, display, and manage the stream data that are collected from a variety of sensors, it will only add confusion. Therefore, the technology research, development, and demonstration for a structural abnormality monitoring and management are also important. The main server provides storage service for the sensor data coming from all managed bathrooms, and provides data analysis and its results to the administrator group. Administrators can develop and run a wide variety of algorithms for analyzing and processing data through the administrator interface. A knowledge storage, an expert system, and a decision support system serve to aid in the various operations of administrators. If needed, the system takes immediate action by sending messages or leaving voicemails to care recipients' guardians, physicians, and emergency crew. For this purpose, we plan to use a fault-tolerant, scalable, open-source Apache Cassandra that supports column-oriented storage, and is best for schema flexibility and efficient big data storage and management.

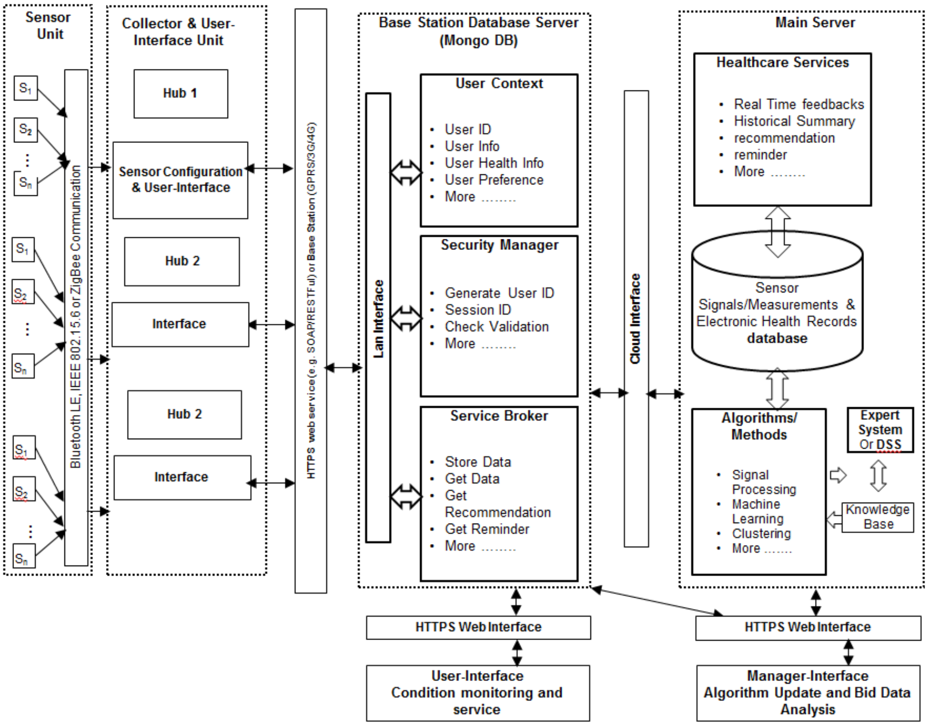

Figure 4. Big data system data and control flow diagram, modified from Ahmed et al. [6]

3.4 Big Data Acquisition, Analysis, and Application

Big data analysis and application focus on the utilization of collected data from bathrooms. The data we collect form bathrooms are water consumption in toilets, the frequency of toilet usage, pressure distribution on toilet covers, toilet usage and time, toilet flushing interval and sequence, water consumption in shower and bath tubs, temperature and humidity for shower and bath tubs, shower and tub usage and time, impact and pressure sensors for falling or slipping, as well as motion and scream voices.

The big data collected via a bathroom IoT system can be used for various purposes. One of the most important purposes is to analyze data in order to develop an algorithm used to derive individual personalized data patterns. In a variety of modern living lives, life patterns for individuals differ significantly from others, and thus, it is not appropriate to issue a warning based on criteria that are established with uniform standards. Rather, first set personalized criteria by observing the lifestyle of each individual over time, and then, in case a situation differs from the individually set criteria, an emergency or appropriate warning should be sent. As many participants need to be observed and various sensor data exist, the study is to derive complex logic by analyzing and processing individually tailored data patterns. Figure 5 illustrates an example of a complex logic flow chart. For example, from the flow chart, falling possibility could be raised when several conditions are met such as screaming and large area of pressure on the floor detected while no pressure detected both on toilet and shower tub for a specified period.

An early-warning capability is another big data application example. Once individual criteria are established, by using big data predictive technology, when anticipated events do not occur or unanticipated events occur, alarm can be raised and thus important action can take place. The following four steps are proposed as development guidelines for individually tailored data pattern analysis and utilization.

1) Development of algorithm for personalized criteria generation, storage, management, and abnormality detection.
2) Development of customized warning system algorithms with respect to alarming stage and magnitude of injury
3) Development and application of algorithms for the efficient management and use of big sensor data obtained from IoT network.
4) Customized service and rule creation for system administrators and customers

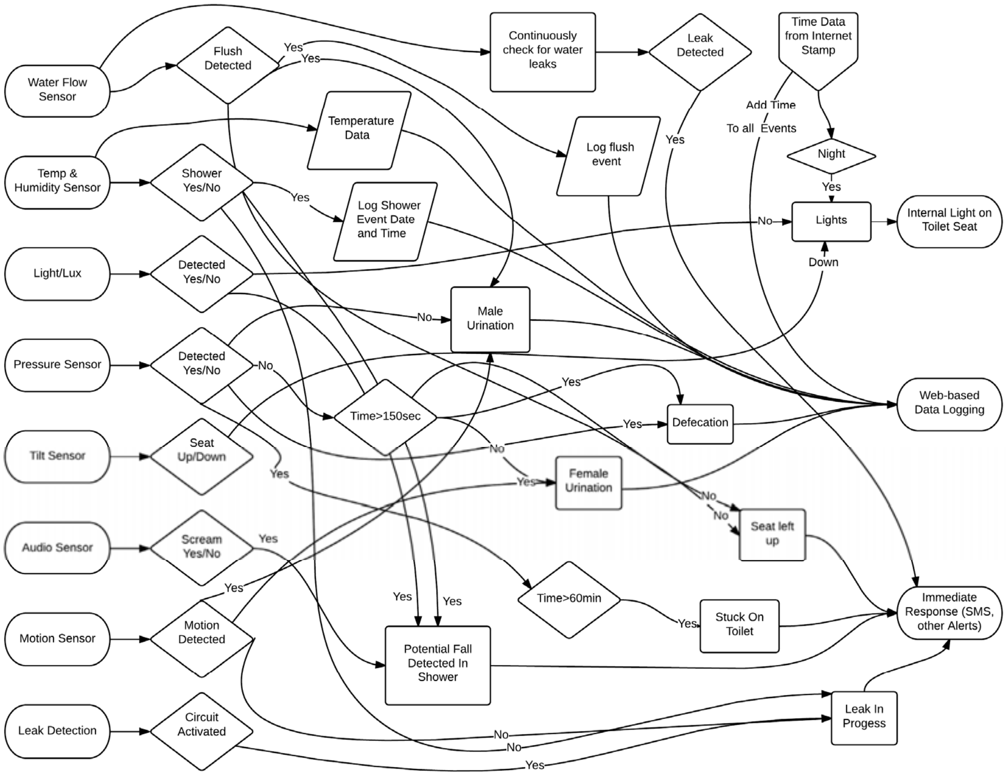

Figure 5. The flowchart of bathroom IoT system operation.

4. IoT Toilet Test

A small-scale IoT application has been tested using two round Force Sensitive Resistor (FSR) pressure sensors and one CdS photocell sensor. A set of electroluminescent (EL) wire was placed under a toilet cover to provide light in dark night. The hardware components of this system include an open-sourced development board and other open hardware sensor breakout boards.

Data are collected from the analog sensors by a Wi-Fi-enabled microcontroller (Arduino Yun) and algorithms were devised to act on appropriate events. For example, if a “lights on” event is triggered from a low light level in the bathroom, the toilet interior lighting is powered on. The real-time data obtained from sensors are sent via Wi-Fi to a service called Temboo, which will pass them to Microsoft Azure’s SQL database as Yun cannot communicate directly with Azure. Azure functions as a data storehouse for the big data created by many nodes. For data visualization, Microsoft Power Bi polls the SQL database and graphically displays the sensor data in real-time as shown in Figure 6. Power Bi visualizes user-designated parameters, weather graphs, spreadsheets, or pie charts, with any set of manipulation that could normally be performed in Microsoft Excel. In Figure 6, the display is showing a brief segment of the recorded time and specified sensor data. The green line represents light levels and the black line represents pressure on the toilet seat. The large spikes in the waveforms are corollary to the discrete events of force applied to the toilet seat and lights being turned on (when no force detected) or off (when force detected).

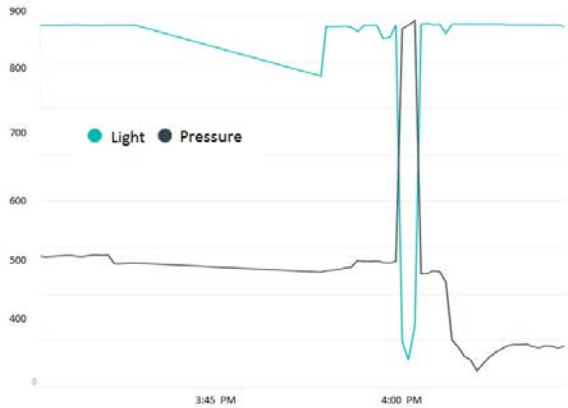

Figure 6. The outputs of the sensors visualized using Power Bi (provided by Microsoft).

5. Conclusion

Information technology advances in the development of IoT and big data toward various aspects of human activities. Bathrooms are one of the most dangerous places especially for older people. The IoT and big data concept introduced in this paper proposes four objectives: 1) sensor selection and application, 2) integration of a wireless sensor local area network system, 3) design concept for IoT implementation, and 4) a big data analysis system model. Sensor study reveals that off-the-shelf sensors are available for IoT applications, but many of them require hardware modification and software configuration to integrate into small range network systems. Several small range wireless sensor network protocols are available and are able to connect to larger network systems such as Internet through various levels and types of hubs/gateways. The study proposes a design concept for a pilot test and big data system. Various software applications and open source platforms are reviewed and will be tested to consist of large-scale big data, which is based on the data acquired from sensors detecting bathroom activities. As an example, a test was conducted using an IoT application in a toilet. Several sensors including pressure sensors are tested to verify the concept in a small-scale example. Potential impact of this study is not only to timely inform special events but also to reduce hazardous conditions in bathroom environment and probability of severe implication from bathroom injuries especially for older people. Moreover, this study demonstrates tremendous potential of IoT and big data applications for improving user sustainability in various aspects.

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