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# Internet-of-Things-based Multi-sensor Structure for Geriatric Healthcare

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In the care of the elderly, patients with chronic diseases, Alzheimer's disease, Parkinson's disease, and mobility problems are often encountered, and medical staff will spend more time attending to specific conditions than in the normal case. In this paper, we mainly propose a Healthcare Internet of Things, which is an intelligent monitoring system to assist medical staff in caring for the elderly. We adopt cost-effective sensors for various applications that include the acquisition of location information, the detection of infusion and urine bag weights, and the detection of heartbeat; all patient information can also be transmitted to a cloud server via a wireless network. Thus, medical staff can examine the real-time condition of a patient through an application via a mobile device, and it is more flexible and efficient for medical treatment.

## 1. Introduction

According to the World Health Organization (WHO), in 2020, people over 65 years old accounted for 9.3% of the global total, which is expected to increase to 16% in 2050.(1) Thus, the workload of medical staff will be increased to take care of elderly patients.(2)

The doctor–patient ratio of a hospital is the most used benchmark for hospital manpower allocation. The doctor–patient ratio in Japan or related European countries is about 1:7, and the doctor–patient ratio in Taiwan is 1:13, which is high. It is clear that the workload of medical staff is heavy.(3) However, in recent years, the world has been facing the new coronavirus pandemic. This virus has even impacted the allocation of medical staff, making it even worse. How to reduce the duplication of work for all medical staff and improve the quality of medical care to alleviate the work pressure of medical staff are urgent needs to be met. During hospitalization, the common ward care of medical staff includes intravenous (IV) therapy, urine bag status monitoring, and physiological information monitoring. IV therapy is to inject a drug directly into a vein through a cannula on the bag, which is the nursing staff's daily routine. Because the drip consumption time depends on the patient's condition, monitoring the drip status occupies most medical staff's time. It is difficult to know when to remove the exhausted drip and provide follow-up medical treatment. In another case, daily urine output is related to the health of the

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elderly, and normal urination can reduce bladder infections. Otherwise, it will cause cystitis, and bacteria will continue to spread. Once bacteria of cystitis enter the renal pelvis and even the kidneys along the ureter, it will cause serious upper urinary tract infections. Thus, it is very important to monitor the patient's urine output. In this study, we mainly plan to develop a health care system[4] that can improve medical health care quality, increase medical efficiency, and reduce the overwork of medical staff.

## 2. Materials and Methods

In this study, we used three different sensors, namely, location, load cell, and heartbeat sensors, for four applications to build a geriatric healthcare system. These sensors are highly cost-effective and can assist medical staff to obtain the patient's health information.

There are two methods to detect drip weight;[5] one method is infrared detection. The infrared wavelength is 850 nm, and an infrared module has a transmitter and a receiver, which are placed at relative positions in IV drip chambers.[6] When the drip volume is decreasing,[7] the infrared rays are transmitted from the infrared module to the relative receiver, and once the rays are blocked by the drip, the receiver of the infrared module can no longer detect any signal from the transmitter. The measurement of drip volume depends on whether the receiver of the infrared module can detect any signal from the transmitter. However, infrared detection is also easily affected by light interference and vibration, resulting in inaccurate measurements. The other method is the use of a load cell,[8] which is a special type of force sensor. It is composed of strain gauges ($R1$, $R2$, $R3$, and $R4$), whose properties are similar to those of resistors. The design of load cells is based on the concept of the Wheatstone bridge. Once one of the strain gauges shows small changes in tension and compression (Fig. 1), $Vd$ will appear and follow the formula below:

$$Vd = \left[ \frac{R3}{(R3+R4)} - \frac{R2}{(R1+R2)} \right] \times Vin. \tag{1}$$

As shown in Fig. 2, strain gauges are mounted on steel. When strain gauges exhibit tension or compression, $Vd$ will generate a proportional micro voltage output via the force along a normal line. In this study, the load cell is applied to the volume detection of an infusion bag. When an infusion bag is in use, its weight will gradually decrease, and the load cell can measure the existing weight of the infusion bag. The advantages and disadvantages of the two methods are shown in Table 1. In this study, we chose the load cell because it is used not only for drip weight measurement, but also for urine bag weight measurement.

Electrocardiography (ECG)[9] and photoplethysmography (PPG)[10] are the commonly used heartbeat detection methods. In a hospital, ECG mainly uses electrode pads attached to the body[11] and adopts microelectrode technology to record the potential difference between inside and outside myocardial cells caused by cardiac electrical pulses to calculate the number of heartbeats. PPG is a noncontact detection method for detecting changes in blood volume. It uses a beam with a certain wavelength to irradiate the skin surface at the fingertip. During each heartbeat, the contraction and expansion of blood vessels will affect the transmission or

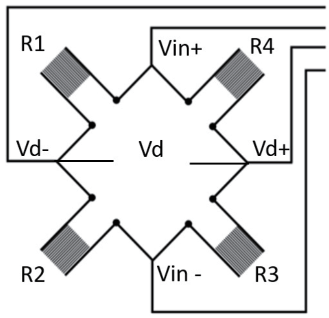


Fig. 1. Full bridge circuit.

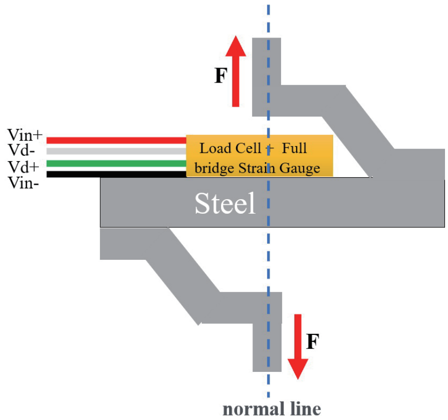


Fig. 2. (Color online) Load cell structure.

Table 1
Comparison of drip detection methods.

| | | Drip detection technology | |
|---|---|---|---|
| | | Infrared detection | Load cell |
| Functional index | Principle | When a droplet passes through the infrared measurement beam area, the droplet will block the infrared rays; then the flow rate and volume of the droplet can be obtained. | It is a special type of force sensor, which is composed of a strain gauge and a bridge circuit. When it is subjected to tension or pressure, it will generate the proportional output of voltage via the force. |
| | Advantages | Has high accuracy. | Regardless of the environment, the weight can be measured realistically. |
| | Disadvantages | Obtain interference by stray light or vibration easily. | It is difficult to detect slight weight changes. |

reflection of light to calculate the number of heartbeats. The advantages and disadvantages of the two methods are shown in Table 2. Considering the convenience and comfort of the user, this system uses PPG to detect heart rate.

The Global Navigation Satellite System (GNSS)[12–14] includes the U.S. Global Positioning System (GPS), Russian Federation GLObal/Navigation Satellite System (GLONASS), European Galileo System, Chinese BeiDou Navigation Satellite System (BDS), Indian Regional Navigation Satellite System (IRNSS), and Japan's Quasi-Zenith Satellite System (QZSS). IRNSS and QZSS are regional satellite systems and cover the Asia-Pacific region, so we only list four main satellite navigation systems in Table 3. GPS is the largest and more popularly used than the other systems. The GNSS receiver system consists of three sections, namely, the ground station, satellites, and GNSS receivers (see Fig. 3). GNSS receivers can operate continuously to receive different satellite signals via a patch antenna with a frequency range of 1561–1603 MHz, GNSS receivers acquire four or more satellites, then it can execute 3D positioning and the Kalman filter algorithm[15–17] to get longitude, latitude and altitude. Besides position information, the GNSS receiver can produce estimates of velocity, and time.

Table 2
Comparison between ECG and PPG.

| | ECG | PPG |
|---|---|---|
| Principle | Measures the electrical ions of the heart by placing electrodes on the skin | Calculates heart rate by using the reflection and transmission of LED to detect blood volume changes in the artery of the index finger |
| Advantages | 1. No noise interference from movement<br>2. Has power saving capability<br>3. The detected waveform can be used to determine the user's heart condition. | 1. Less power supply noise and EMI interference.<br>2. Can be applied to fingers, toes, or ears |
| Disadvantages | 1. It is susceptible to interference from an alternating current power supply.<br>2. The measurement position is limited to the user's chest.<br>3. It is uncomfortable. | 1. It is susceptible to noise caused by movement.<br>2. It is susceptible to background light. |

Table 3
Satellite navigation systems.

| | GPS | GLONASS | Bei Dou | Galileo |
|---|---|---|---|---|
| Country | Unites States | Russia | China | European Union |
| Carrier frequency | 1978 | 1982 | 2000 | 2011 |
| Orbital height (MEO) | 20200 km | 19140 km | 21528 km | 23222 km |
| Carrier frequency (MHz) | L1:1575.42 | G1:1602 + $k$ × 0.5625 | B1I:1561.098 | E1:1575.42 |
| Number of satellites | 27 operational + 4 spares | 24 operational + 3 spares | 27 MEOs + 5 GEOs + 3 IGSOs | 27 operational + 3 spares |
| Modulation | CDMA | FDMA | CDMA | CDMA |

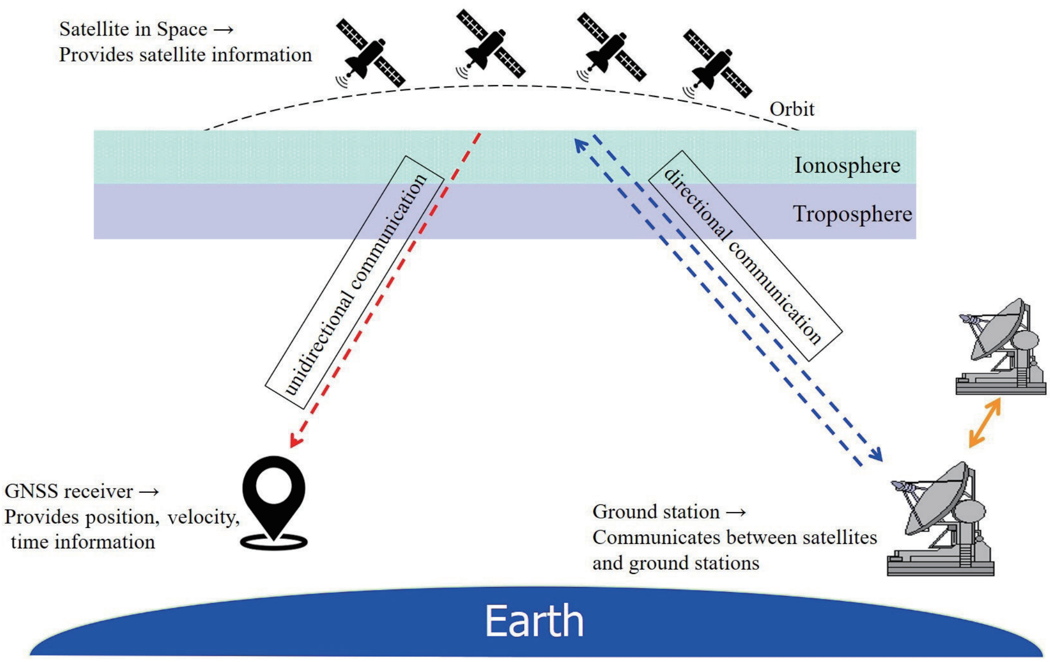


Fig. 3. (Color online) GNSS receiver system.

## 3. System Architecture

The pervasive healthcare system is composed of three parts: the sensor layer, the transmission layer, and the application layer under the IoT architecture.[18] The overall system architecture (see Fig. 4) and each part are explained as follows.

In the sensor layer, different sensors are mainly used to detect the patient's own physiological condition and information related to the surrounding environment, and provide this health information to the medical staff for reference. According to the health care system considered in this study, we apply four scenarios in the sensor layer as shown in Fig. 4. The first scenario is the use of the load cell to detect the drip status, and the second one is the detection of the urine bag status via IV injection. The sensor applies the principle of the Wheatstone bridge circuit,[19] that is, the full bridge strain gauge is closely attached to the steel (see Fig. 2). When the force end is pulled by the weight, the strain gauge will produce a certain amount of deformation, its impedance will change accordingly, and the corresponding voltage can be obtained, then converted into a digital signal to obtain the weight information. Because the deformation of the strain gauge is relative to its weight, it is mandatory to perform the calibration and compensation of the strain gauge before weighing it. Then, we can obtain an accurate weight by regression calculation.

Heartbeat measurement uses a PPG wearable device,[20] which is worn on the finger, and LED light to illuminate the blood vessels under the human skin. When red blood cells flow, the heartbeat signal can be measured owing to the penetration or reflection of light. Although it may be interfered by light, which affects the accuracy of the heartbeat, the PPG equipment is more cost-effective than the ECG equipment, so it is more suitable for long-term monitoring and use in hospital beds.

In the current satellite constellation, the GPS + GLONASS receiver is the most used satellite constellation combination and has a good sky view factor, so its position accuracy can achieve lower than 1 meter resolution.[21]

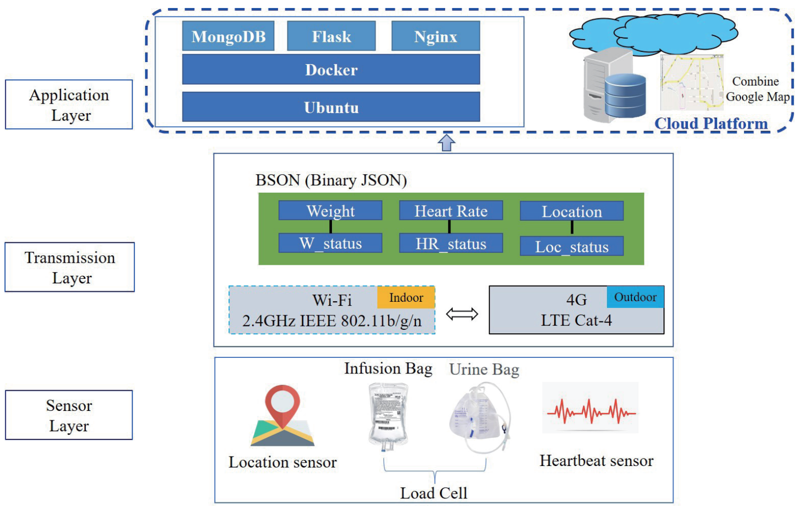


Fig. 4. (Color online) Healthcare system structure.

In the transmission layer, the raw data of healthcare information were fragmented and follow the package format as shown in Fig. 5; then they can be transmitted to the cloud server MongoDB(22) through wired or wireless means of the transport layer. This system adopts Wi-Fi and 4G/LTE. Wi-Fi is used to connect to the hospital network and transmit the data to the remote server through the gateway, which can save power. Outdoors, 4G/LTE can be used to facilitate data transmission.

In Fig. 5, there are four package formats with definitions of healthcare scenarios; the heart rate function has 29 bytes to label the patient's heart beat rate; there are 35 and 32 bytes to label the infusion and urine bag weights, respectively, and 76 bytes to label the location information that includes latitude and longitude. All the data formats also specifically define the patient's status, and once the information of four scenarios exceeds the critical value, the value of status will change from 0 to 1, indicating that the event is an emergency. Moreover, the data transmission order will be adjusted with high priority, and medical staff members can be notified of an urgent case for emergency treatment.

The entire operation process has 13 steps as shown in Fig. 6. When it finishes the raw data fragmentation and transmission, all of the healthcare information will be uploaded to cloud servers.

In the application layer, Ubuntu under a Linux system is used as the host on the server side, Docker is built into the server and the required services are deployed. Through Docker, the required services can be easily deployed, and the required parameters can be set. For the migration of scalability and mobility, in Docker, three services (MongoDB, Flask, and Nginx) are set up at the same time (see Fig. 7). MongoDB is responsible for storing all the information on this system[23] and managing the application's user accounts and passwords. Flask is responsible for reading the internal information of MongoDB and creating application

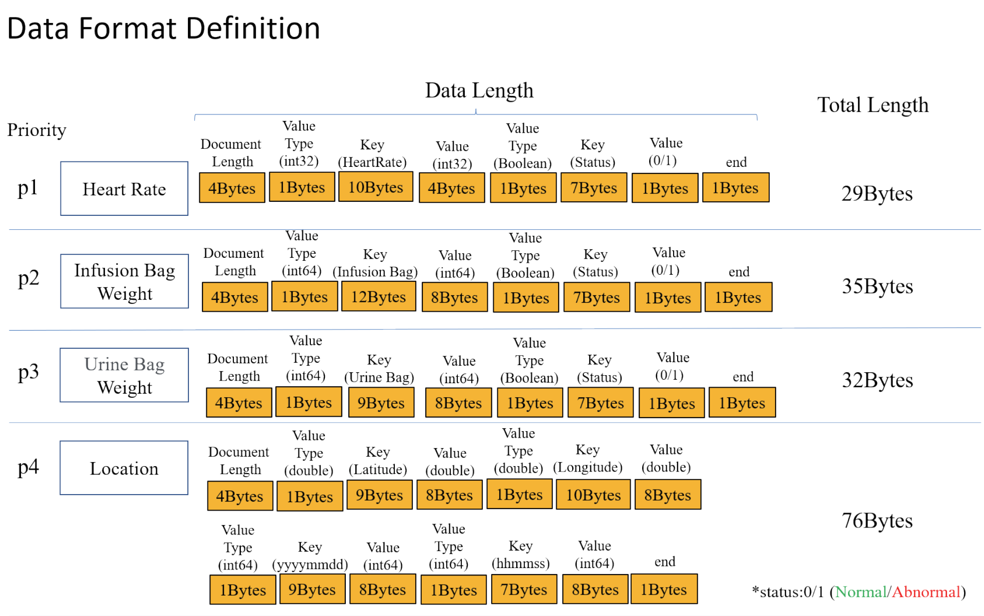


Fig. 5. (Color online) Package formats.

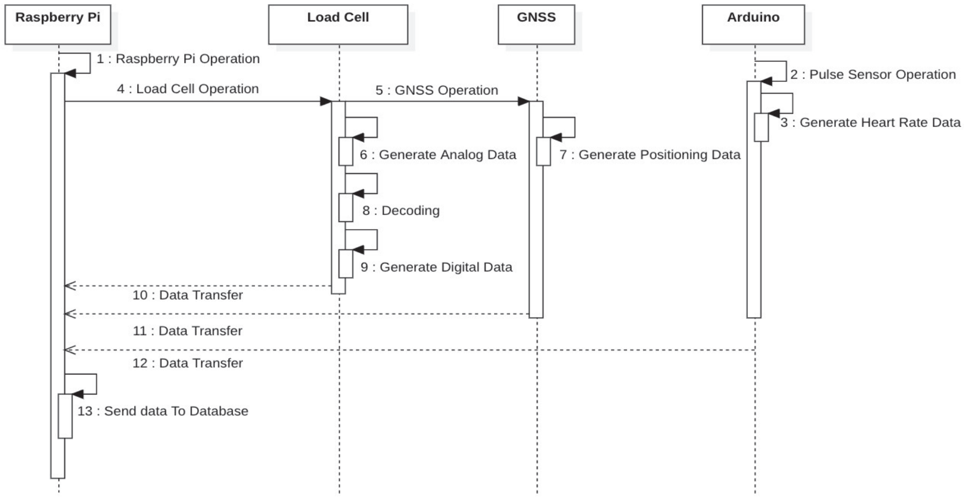


Fig. 6. Raw data flow chart.

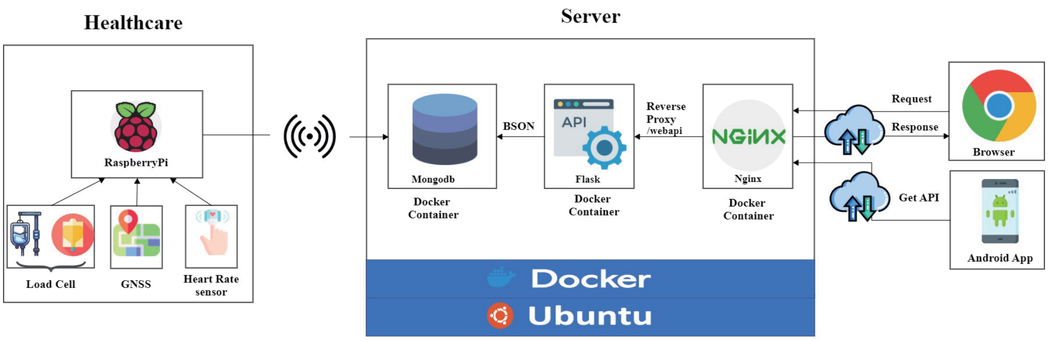


Fig. 7. (Color online) Docker structure.

programming interfaces (APIs) for each piece of information (weight, heart rate, location, and user account). For application or browser access, Flask can provide the function of registering users on the user side and enter account information to MongoDB through Flask, the reverse proxy service (NGINX) is mainly used to forward requests for each API. Through the reverse proxy service, the real IP can be safely hidden, and NGINX will allocate its corresponding forwarding point. For example, the client can send a request to query the weight to the server, and NGINX will forward the corresponding request to the API. After processing the information inside the API, it will be sent back to NGINX, then NGINX will provide the weight information to the client. In addition, the reverse proxy service can effectively control the number of requests and manage the times of accessing servers in a short period of time; otherwise, it will increase the burden on the server.

To ensure that the medical staff can determine the patient's status anytime and anywhere, we developed a system that allows the medical staff to log into it via an application in their mobile devices as shown in Fig. 8, which can examine the patient's IV information, urine bag capacity warning settings, patient location, heart rate, and real-time master patient information. Thus, the benefits of mobile medical services are achieved and a smart medical care system is realized.

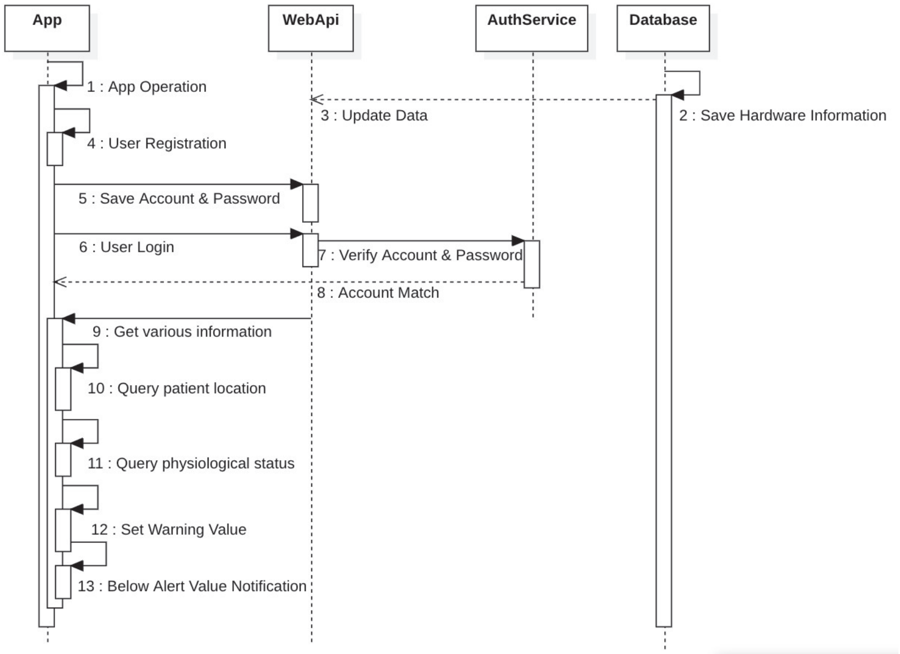


Fig. 8. Application data flow.

## 4. Experimental Results

In Fig. 9, the weight range of measurement is from 0 to 500 g, there are seven measured points, and each condition's difference between the load cell and the scale of standard weight is shown. The maximum weight gap is about 37 g between the load cell and the scale of standard weight, and the error rate is about 7.87% under the 470 g condition. It shows that the attribute of weight gap is nonlinear, that is, when the object is heavier than 100 g, the error of the load cell will increase gradually. In this study, we refer to the property of the strain gauge to figure out a second-order regression function $F(x)$ as follows:

$$F\left(x\right)=\left(0.000026\times x^{2}+0.064338\times x-1.700877\right), \tag{2}$$

where $x$ is the measured weight of the load cell and $F(x)$ is the weight that has been compensated.

After obtaining the regression function for load cell weight compensation, we measured different load cell weights, then obtained Fig. 10. The green line indicates the gap between the load cell and the scale of standard weight before load cell calibration. Likewise, the yellow line indicates the gap between the load cell and the scale of standard weight after obtaining the function for load cell calibration by $F(x)$. In Fig. 10, after the calibration, the measured accuracy of the load cell is increased from 92.64 to 98.13%. It is very clear that the correction compensation of the load cell is mandatory.

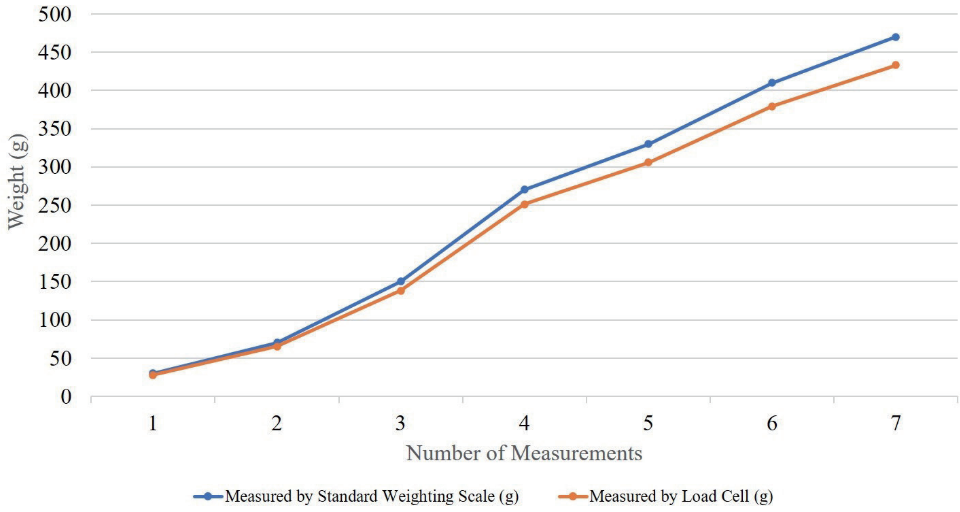


Fig. 9. (Color online) Comparison of measured weights.

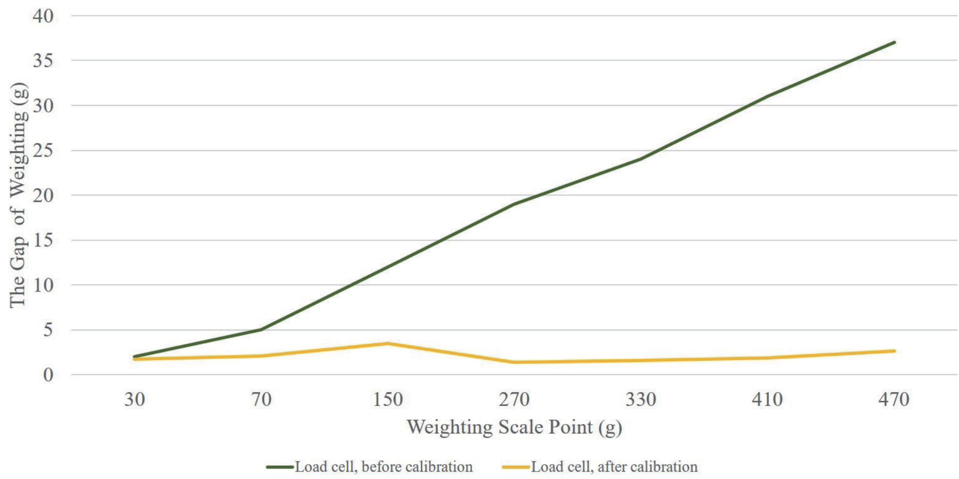


Fig. 10. (Color online) Calibration performance.

## 5. Discussion

In this study, there are two applications to share the load cell technology. The load cell is very cost-effective and can be applied to measure the weights of an infusion bag and a urine bag. It saves a lot of medical staff's time for examining the patient's health information regularly. In the experimental result, it is very clear that, after the load cell executes a compensation process, the weight accuracy can be increased from 92.64 to 98.13%.

## 6. Conclusions

The elderly population is increasing every year; however, medical staff resources cannot catch up with this change, especially with COVID-19. This study is based on the completion of a health care system for the elderly and emphasizes the importance of load cell calibration. The goal of the system architecture is to reduce the workload of the nursing staff and save more flexible time to take care of more elderly. In the future, we will focus on the combination of different sensors for healthcare and the sensor fusion algorithm to improve the intelligence of the sensor and its excellent sensing function.

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