Interactive Performance Using Wearable Devices: Technology and Innovative Applications

Tzu-Chieh Tsai, Gon-Jong Su and Chung-Yu Cheng

Abstract This paper presents wearable computing in the Art and interactive performance. With AR/VR technology, human can play with virtual characters. However, people might feel bored to type keyboard or joysticks to play with computer and video game characters. We develop our motion sensors to capture user's motion. In this way, it becomes more interesting and fresh to swing your hands or shake your hips to interact with virtual characters. In the future, the wearable computing will be more and more popular, so we try to merge these sensors to let everyone can wear these tiny and cute sensors to experience. We believe this will be a new bright spot of the world.

1 Introduction

In recently years, wearable items grow more and more popular, such as iWatch, google glass, and so on. With these wearable items, many interesting things can be fulfilled. For example, there are many art performances using virtual characters and various lights to create amazing performance [1]. To perform this amazing show, the performers need a lot of time to practice. It is innovative to let performers wear sensors to make the effect on acousto-optic interaction. This inspires us to decide to combine wearable sensors with art. In this paper, we present our idea about how to use wearable sensors to combine with art performance. We surveyed many wearable sensors in the market to ensure whether the sensors can work or not, and implemented a platform to deliver sensing data in real time. We named the platform as Wearable Item Service runtimE (WISE) which coordinates all messages. As long

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as wearing our wearable sensors, the skeleton (posture) information from the user will be delivered to WISE in real-time to render animation. Our other team members use the AR/VR to present the virtual characters which was designed by professionals. However, the wearable sensors still have some problems about its appearance and instability. To this end, we tried step by step to miniature our sensors and overcome the problems. These problems will be introduced and solved in following sections.

2 Related Work

A successful design of interactive performance is not only the stability of wearable sensors but also the interactive experiment from users. For interactive story, the users' feeling is very important for overall benefit assessing. In 2000, Csikszentmihalyi [2] proposed the flow theory, the immersive moment when a person is completely involved in an activity for its own sake. Therefore we design wearable sensors to hope to let user in the "flow"—a state of heightened focus and immersion in activities such as art, play and work. Also, we try to let audiences wear our sensors to participate and perform in digital live. This concept is based on Sheridan [3] who proposed the ideals to make audiences participate in the performance.

MIThril (2003) is the wearable computing research platform [4] from MIT. The design core of the architecture is "Enchantment Whiteboard" which is used to integrate and coordinate the wearable sensors from users. Our team designed the platform, Wearable Item Service runtimE (WISE), to integrate wearable sensors and coordinate to work in the performance.

What the performance needs is the posture of the performances. Therefore, we decide to survey sensors with gyro and accelerate to get skeleton (postures) information. Then, we find the 6-axis accelerometer and gyroscope sensors, named MPU6050, with the library of the scholar Rowberg [5], to be used in our performance, and the arduino nano with BLE [6] to transmit signals. Besides, the location of the user is another issue in the performance. Based on Erin-Ee-Lin Lau‘s [7] experiment, the Received Signal Strength Indicator (RSSI) can track user's location in real-time for indoor and outdoor environments. Finally, we decide to use the RSSI from Bluetooth low energy and raspberry pi to serve as the coordinator in our platform.

3 Proposed Approach

With the wearable computing, many interactive performances can be fulfilled. By using our platform to connect sensors, the performance will be more interesting and exciting. However, there are still some limitations, we try step by step to overcome.

The research is divided into three parts: (A) system architecture, (B) wearable sensors, and (C) interactive storytelling. Details are as follows:

3.1 System Architecture

In the beginning, human wear many small sensors, named WISE Items, as $a_1 \ldots a_2$ and $b_1 \ldots b_2$ in Fig. 1. In addition, these WISE Items can be used for various applications to meet the needs of the performance. Besides, there is a WISE Coordinator used to integrate all the sensors. Due to these wearable sensors must be tiny and light, so we use low energy BLE to transmit messages.

From the implementation-level, the difference between WISE item and coordinator is its computation. These tiny WISE items are limited on the resource and size such as Arduino. On the contrary, the coordinator with more ability to compute can operate in the IP layer such as Raspberry pi. In live digital script, there are many issues need to be solved even in the easy interactive scenes. Therefore, we implemented the WISE to integrate message and finish the most important things to deliver data as soon as possible. As shown in Fig. 2, the WISE platform consists of wearable mo-cap sensors called WISE Items (see Fig. 2), a set of protocol gateway devices called the WISE Coordinators, and a message bus called the WISE Broker. The wearable mo-cap sensors detect dancer's motion and deliver the message to the WISE Coordinator by BLE, then send motion messages to the Unity from WISE Broker.

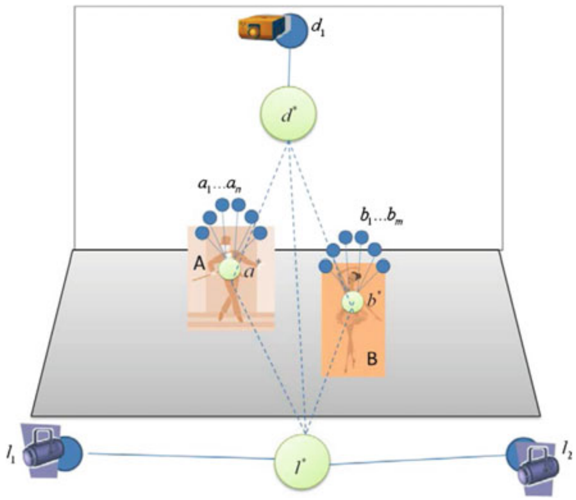


Fig. 1 The architecture of wearable performance

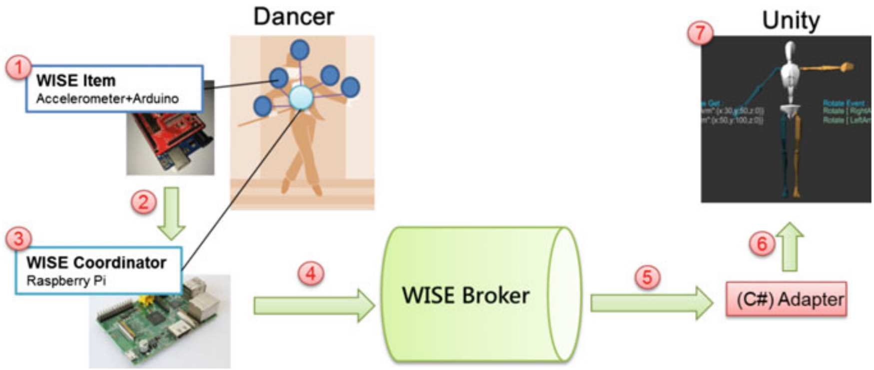


Fig. 2 The integration of wearable sensors

Followings are some items used in the platform:

1. WISE Broker
   Broker is the core of the message delivery in the WISE for connecting WISE items to other computers. The message queue is designed to receive and send data as soon as possible to meet the needs of the performance in real-time. Currently, a WISE Item is able to transfer mo-cap data up to 55 messages per second. In live performance, we set the data rate of 33 messages per seconds.
2. WISE API, Adapter
   To offer the connection of many different soft and hardware, the WISE must develop relative APIs and Adapters. For example, our team creates animation in Unity, so the WISE have to implement relative Adapter to deliver message between Unity and WISE Broker.
3. WISE platform
   In the test, we encountered many difficulties in whether messages are sent to the Unity from WISE or not. In this way, the WISE offers a platform to monitor and simulate the delivery of messages. The platform implements three functions.
   First, the MQTT Simulator, which provides graph interface, lets users transmit messages to WISE and receive messages in some topics you are interested as Fig. 3.
   Second, the virtual data player, which can replay the real messages from the pre-recorded model, lets users test the efficiency of WISE as Fig. 4.
   Finally, the skeleton poster simulator can monitor the effect of the animation under some conditions as Fig. 5.
4. WISE message protocol
   The protocol formulates some message formats to deliver well and filters unnecessary data to ensure messages delivery in real-time.

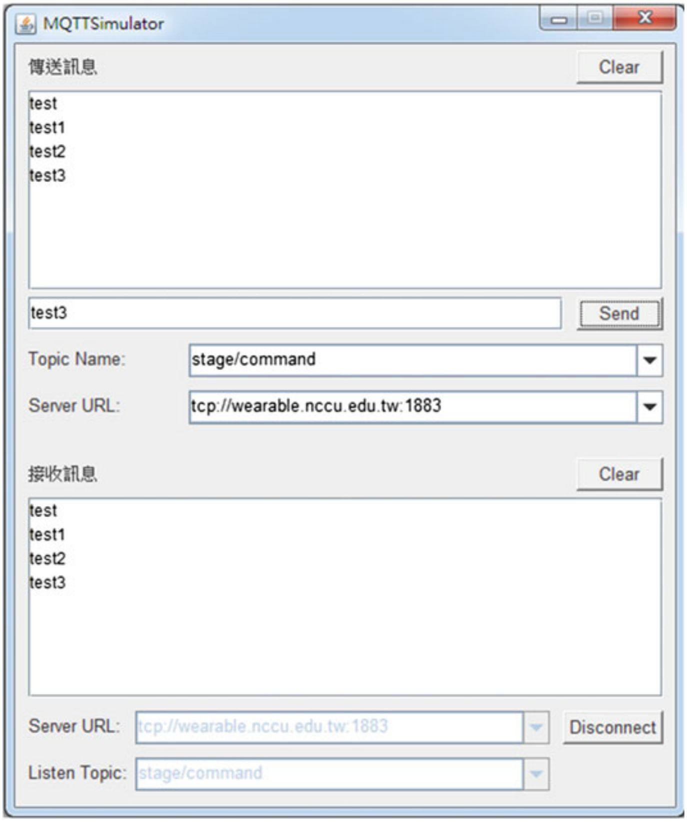


Fig. 3 MQTT simulator

3.2 *Motion Capture*

At the beginning, we try to get accelerate and gyro signals from the IMU (Inertial Measurement Unit). The raw data of IMU is unstable and has accumulative errors apparently, so we must filter the signals to reduce these errors. Fortunately, Rowberg [5] offers the library of digital motion processor (DMP) to filter noise and provide some useful APIs. In this way, we get the pitch, roll and yaw from IMU to detect the rotation from users.

Second, we chose the raspberry pi (RPi) to serve as our WISE coordinator, which can integrate signals of the IMU. The RPi is tiny, only 85.60 × 53.98 mm, and high efficient, CPU up to 900 MHz. But how can the IMU connect to RPi? According to the Internet Data Center (IDC) report "Worldwide Bluetooth Semiconductor 2008–2012 Forecast," [8] Bluetooth low energy (BLE), will link wireless sensors up to the 70 % of cell phones and computers likely to be fitted with the Bluetooth wireless technology. Because of low energy, we use the 3.7 V lithium cell for its power as Fig. 6.

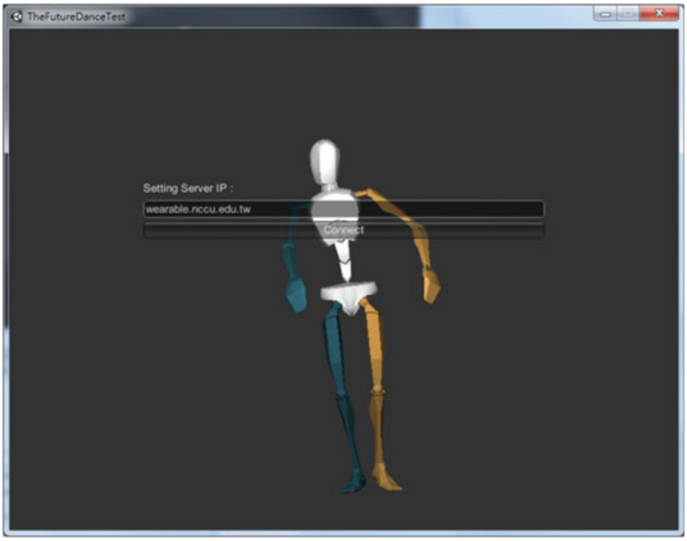


Fig. 4 The virtual data player

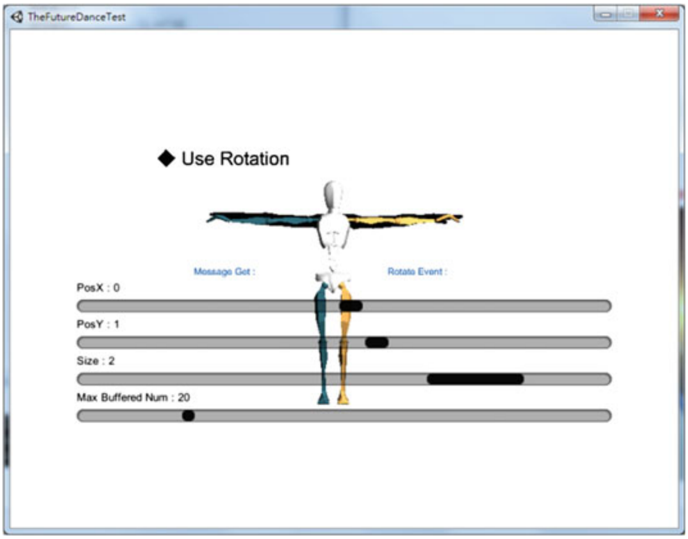


Fig. 5 Skeleton poster simulator

Third, we take the Arduino Uno, BLE and MPU6050 sensors in the market. However, the Arduino Uno is so large that we replace Arduino Uno of Arduino Nano, and use printing circuits board (PCB) layout to merge Arduino Nano and BLE together as the Fig. 7. Besides, it is important to protect the electronic equipment from wet skin, so we design its 3D modeling to create its home by 3D printer.

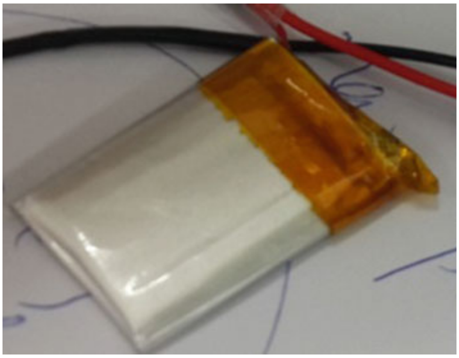


Fig. 6 3.7 V lithium cell

Fig. 7 The motion sensors: MPU6050, BLE, Arduino Nano, 3.7 V lithium

Finally, there are still some problems from wearable sensors, such as the cumulative errors from MPU6050. These errors are as following values.

The gyroscope signal can be modeled as:

$$Gyro_{total} = G_v + G_b + G_n.$$

where G_v, G_b and G_n are the angular velocity vector, the related angular velocity vector bias, and a white noise.

The acceleration signal can be modeled as:

$$Acc_{total} = A_v + A_b + A_n.$$

where A_v, A_b and A_n are the angular velocity vector, the related angular velocity vector bias, and a white noise.

The DMP from Jeff Rowberg uses the value of the acceleration to get the rotation and merges with the gyroscope to reduce the noise from the bias and white noise. However, it still suffers from cumulative errors even using the library of DMP. To solve these problems, we implemented the calibrated system to map sensors signals to the user's posture as the following: $Y = A \times X + B$

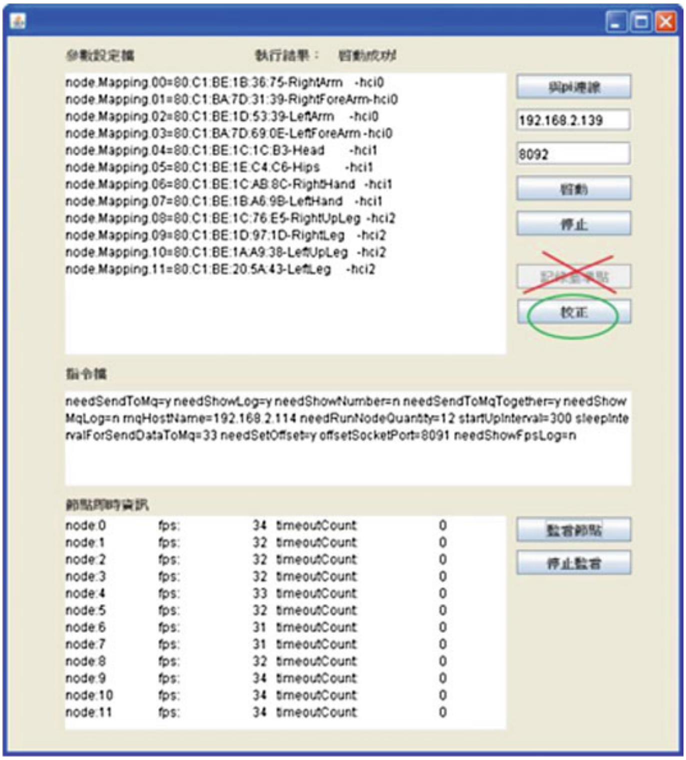


Fig. 8 Graph user interface of Motion monitor

$$\begin{bmatrix} Y_w \\ Y_p \\ Y_r \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \times \begin{bmatrix} X_w \\ X_p \\ X_r \end{bmatrix} + \begin{bmatrix} B_w \\ B_p \\ B_r \end{bmatrix},$$ which w, p, and r represent yaw, pitch, and roll.

X is the value from our DMP and Y is the value from user's rotation. In addition, we implement a graph user interface to monitor the sensors as Fig. 8.

However, there are still some limitations of hardware that we can't solve, such as some angles can't be detected. Therefore, we put our sensors sticky to users and calibrate sensors after few minutes to reduce the noise from sensors as the Fig. 9.

After getting the user's posture, we still have another issue about how to get user's location.

To avoid the cumulative errors, we use the feature of the RSSI from BLEs, and propose our algorithm to detect the location of users. Due to the RSSI is more precise in 30 cm, we deploy 21 BLEs in 6 m $*$ 2 m stage as in the Fig. 10. Owing to the frame rate of BLE is just only 5–20 fps, the gyro sensors are used to improve its frame rates and offer the credibility of RSSI.

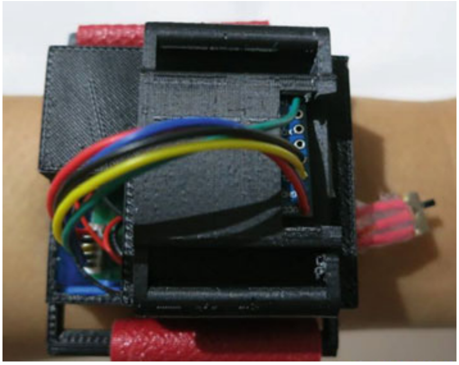


Fig. 9 IMU sensor put sticky on the arm

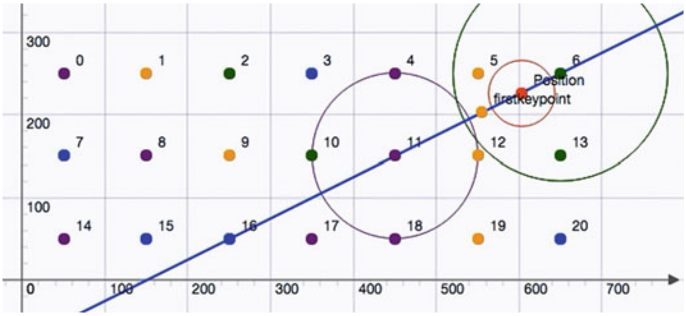


Fig. 10 The 21 BLEs illustration

With the RSSI, our algorithm gives the weight of each BLE from sorted node to get the user position as follows.

First, we sort all beacons by RSSI and get three closest beacons, named BLE_1, BLE_2, BLE_3. Then, we get the reference node (RN) by using weighting on BLE_2 and BLE_3 as following.

$RN = BLE_2 + Weighting \times Vector_{2,3}$, where $Vector_{2,3}$ is from BLE_2 to BLE_2

$$Weighting = \frac{(BLE_2)}{(BLE_2 + BLE_3)}.$$

Finally, the nearest BLE is most precise, so we combine its RSSI with RN to ensure user's position. As Fig. 11 and Table 1, using following functions to calculate the intersection of them.

Circle: $(x - x_0)^2 + (y - y_0)^2 = RSSI^2$, which RSSI is from BLE_1

Line: $y - y_1 = m(x - x_1)$, which Line is from RN to BLE_1

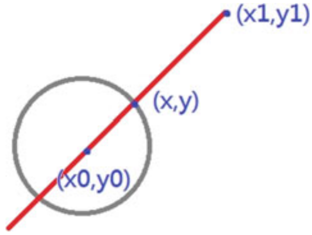
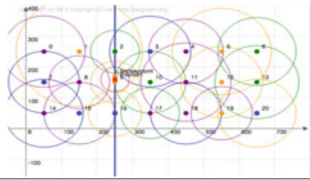


Fig. 11 Localize user's position

Table 1 The results of the 21 BLEs

Number of BLE	21		
Distance from BLE (cm)	50	30	15
Real position	(100, 250)	(80, 250)	(65, 250)
Calculate value	(85.1, 203.8)	(81, 196.8)	(61.4, 222)
Error (cm)	48.54	53.20	28.23
Graph			

Intersection: $X = x_0 + \frac{rssi(x_0 - x_1)}{\sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2}}$, $Y = \left(\frac{y_0 - y_1}{x_0 - x_1}\right)(X - x_1) + y_1$.

Besides, the value of the variation from gyro can ensure the user's movement as follows.

$Position_{final} = credibility \ * \ Position_{RSSI} + (1 - credibility) \ * \ Position_{final-1}$, where credibility = $Gyro_t - Gyro_{t-1}$/(Max_movement) as the Fig. 12.

Fig. 12 Human really move indoor and show its results

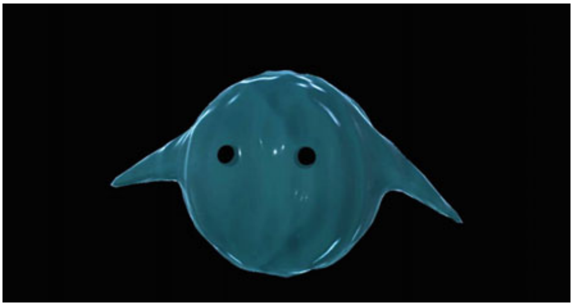
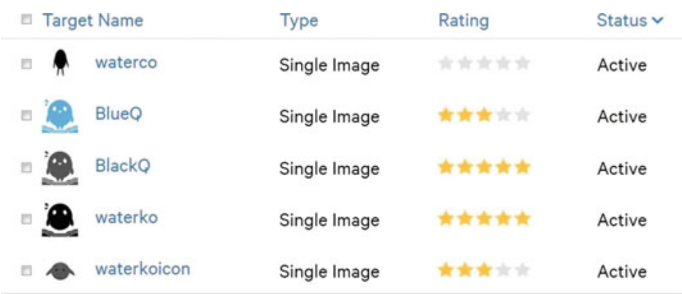


Fig. 13 3D model virtual character—water



Target Name	Type	Rating	Status
waterco	Single Image	☆☆☆☆☆	Active
BlueQ	Single Image	★★★☆☆	Active
BlackQ	Single Image	★★★★★	Active
waterko	Single Image	★★★★★	Active
waterkoicon	Single Image	★★★☆☆	Active

Fig. 14 Design our target figure to improve the recognition

3.3 Interactive Storytelling

To interact with virtual characters, there needs three steps to finish this storytelling. First, our team used 3D model to design a cute virtual role, named Water, in Fig. 13, which presents fresh start and hope from water.

Second, using Vuforia and Unity 3D to make animations and let the user interact via smartphones, 3D smart glasses and our wearable sensors. To improve the recognition from AR, our team have tried many different ways and found that it is hard to recognize from symmetric figures. Therefore, adding the water decoration on one side and water ripple on the bottom can get high recognition. As in Fig. 14, more starts means better.

Third, our team designed following patterns to let user interact with Water and create short films to introduce the story in Table 2.

Table 2 Patterns and reaction of the AR

Step	Action	Water react	Describe
1	Hand push down	Water is pushed in the water	By doing this to trigger the animation
2	Hands push left and right	Water spreads	Use the ripple from unity to create animation (flat and spread)
3	Hand push toward	Water moves back	Interact with users by user's action (this action means water wants to play with user)
4	Hand push up	Water swept up (such as tornado)	Let water rise to the surface
5	Body wag from side to side	Water swings around	Water follows users curiously

4 Simulation Results

We use the Raspberry pi 2 Model B with OS of the Raspbian as our central controller, and Arduino Nano with MPU6050 and BLEs as wearable sensors. The raspberry pi 2 with two BLE dongles to receive the RSSI from beacons and we use 21 beacons to locate user's position. In addition, the frame rate of MPU6050 is 33 fps, and our wise server can serve up to 55 messages per second. Our team use MQTT (MQ Telemetry Transport) as the protocol in the WISE platform and test WISE Broker to ensure it can transmit message efficiently. We simulate to send 50 messages per second last 20 min, so the wise transmit 60,000 messages. This test proves that average delay time is 0.39 ms and the worst case is just 61 ms via WISE Broker. These delay time is acceptable and the WISE transmits messages high efficiently.

As mentioned before, our WISE can connect to different hardware and programs including, Unity, Arduino, Java, and C#, coordinate to make our performance work successfully. SensorDataRetriever is the API of Java, and it can be used to transmit data from BLE. The JAVA Adapter and the Unity Adapter(C#) can connect from JAVA to WISE and from Unity to WISE. With these adapters, we can send data to WISE, so Unity can receive data from WISE as in Fig. 15.

Finally, we use our wearable sensors to interact with the virtual character. Audiences can use tablets or smart glasses to see the reaction of the virtual character in real time. We perform on campus and invite audiences to wear our sensors to experience in Fig. 16.

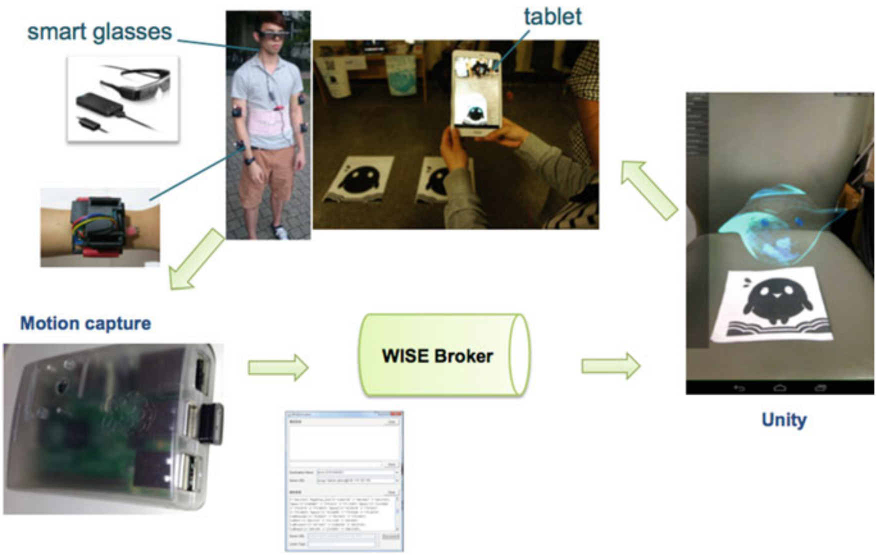


Fig. 15 System architecture: interactive performance is realized by our wearable sensors and the WISE, a platform for interacting our virtual character developed by our research team

Fig. 16 Audiences use our wearable sensor to interact

5 Conclusions and Future Work

We combine many wearable items and implement the WISE server to perform our interactive performance in campus successfully. Besides, we encountered some problems such as error cumulative from sensors, so we develop the calibration to solve. In the future, many users can wear our sensors and interact with not only AR/VR but also other people. We hope that for one day, users can play together by our sensors in different places. Finally, special thanks to our team members.

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