Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control
Journal homepage: http://kinetik.umm.ac.id
ISSN: 2503-2267
Vol. 6, No. 2, May 2021, Pp. 161-168

An evaluation of complementary filter method in increasing the performance of motion tracking gloves for virtual reality games

Fairus Zuhair Azizy Atoir*[1], Aji Gautama Putrada[2], Rizka Reza Pahlevi[3]
Telkom University, Indonesia[1,2,3]

Article Info

Keywords:
Virtual Reality, Motion Tracking Glove, Arduino Nano, Bluetooth, MPU6050

Article history:
Received: March 20, 2021
Accepted: April 27, 2021
Published: May 31, 2021

Cite:
Atoir, F. Z. A., Putrada, A. G. ., & Pahlevi, R. R. (2021). An Evaluation of Complementary Filter Method in Increasing the Performance of Motion Tracking Gloves for Virtual Reality Games. Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control, 6(2). https://doi.org/10.22219/kinetik.v6i2.1234

*Corresponding author
Fairus Zuhair Azizy Atoir
E-mail address:
fairus@student.telkomuniversity.ac.id

Abstract

In the use of Virtual Reality-based video games, users need additional devices to interact, one of which is a Motion Tracking Glove. The Motion Tracking Glove is one of the enhancements that users can use to interact with objects in VR video games. To get the angle value, an accelerometer sensor is used in the MPU6050 module. However, the problem that arises is the accuracy of the sensor because VR demands a low error rate. The purpose of this study is to improve the accuracy of the angular value of the accelerometer sensor value with a complementary filter. Complementary filters can increase the accuracy of the accelerometer sensor by combining its value with the gyroscope sensor value. The Motion Tracking Glove is built using the Arduino Nano and the MPU6050 module to capture angles that move according to hand movements, to connect and exchange data to the main VR device, the Motion Tracking Glove using the Bluetooth module. The results are RMSE 0.6 and MAPE 2.5% with a static Motion Tracking Glove position without movement. In sending Motion Tracking Glove data using the Bluetooth module, the resulting delay time when sending ranges from 0.1 second to 0.4 seconds by trying to move the Motion Tracking Glove from 0 degrees to 90 degrees and back to 0 degrees.

1. Introduction

In the last few years, virtual reality (VR) technology has developed very rapidly, one of the developers, Oculus, who made a VR headset that was booming in the market in 2012, the advantage is the full immersion effect of 640 x 800 pixels. The Oculus product sparked another development in VR technology and became a new technological revolution with many companies involved [1]. VR technology uses a device shaped like glasses to immerse the user in a virtual reality environment that is created, to interact with the environment, users need a tool such as a gamepad, joystick or remote controller, motion tracking glove [2][3][4].

One of the VR device products from Oculus is Oculus Go, Oculus go consists of Android-based software and hardware shaped like glasses to display a virtual environment and a remote control. The remote control on the Oculus Go features 3 degrees of freedom (DOF) which can determine the value of rotation that occurs in the inertial value reading controller [5][6]. The way to use it is by holding it. To move the cursor, the controller only needs to be moved in a circle, where the hand movements will be converted into digital data. The data will become input for the VR system to control VR games [7].

One example of the use of VR technology is to play games [8][9][10]. Many types of controllers can be used to run VR games according to user requirements. According to research, the motion tracking glove device to move the cursor while playing games on VR devices supports more immersive feelings than using a device such as a gamepad, joystick, or remote controller [11]. Research on the motion tracking glove was carried out by Seokwon Lee et al. In their research they made a motion tracking glove with the MPU6050 sensor to capture hand movements as input from a VR game controller [12]. Meanwhile, another motion tracking glove study was also carried out by Paul Waber et al. This study used the MPU9150 sensor to obtain hand rotation movements and added a flex sensor to obtain the bending value that occurs in the finger. This sensor is used to input the robot's finger. The communication used to send the input value to the robot is Bluetooth using the HC-05 module [13].

In the development of the motion tracking glove, the measurement of the rotation value uses the IMU device. This device can capture the angular velocity experienced by the glove. The IMU device consists of a 3-axis accelerometer and a 3-axis gyroscope [14][15]. For the microcontroller used, the Arduino Nano can be used as was done by Ricardo Alexander et al. In his research, Ricardo Alexander used Arduino Nano to make a motion tracking glove that can read the angular velocity value from the IMU sensor and convert it to a rotation value and send the rotation value to a VR device using Bluetooth communication [16][17].

The rotation readings made by the IMU device are often inaccurate, so that the objects formed in VR are different from the actual hand position, this is due to the noise that occurs when the IMU sensor reads the angular velocity. To eliminate the noise that appears, a complementary filter method is used that uses the angular velocity reading from the gyroscope and accelerometer [18][19]. For Vu Trieu Minh's research, the rotation angle was obtained from the results of the accelerometer measurement and then added the complementary filter method combined with the gyroscope measurement results to produce a more accurate angle reading.

From the background and benefits of previous research, a motion tracking glove device that can move VR objects in the Oculus go device is proposed. The Glove motion tracking device uses the Arduino Nano as a microcontroller and can be connected to the Oculus go device by Bluetooth communication using the HC-05 module. For rotation readings in the motion tracking glove, use the GY-521 sensor which reads the accelerometer angle and converts it to rotation by combining the gyroscope value in the complementary filter calculation so that the rotation value is more accurate. Table 1 shows a complete comparison of related works with the proposed method in this research.

Table 1. Virtual Reality Research Comparison

Ref	Gaming VR	Gloves Controller	MPU6050	Bluetooth Module	IMU	Arduino Nano	Complementary Filter
[9] [10]	**Yes**	**Yes**	No	No	**Yes**	No	No
[12]	No	**Yes**	No	No	**Yes**	No	No
[13] [21]	No	**Yes**	**Yes**	No	**Yes**	No	No
[14]	No	**Yes**	No	**Yes**	**Yes**	No	No
[15] [16]	**Yes**	No	No	No	**Yes**	No	No
[17]	No	**Yes**	No	No	**Yes**	**Yes**	No
[18]	**Yes**	**Yes**	No	No	**Yes**	**Yes**	No
[19] [20]	No	No	No	No	**Yes**	No	**Yes**
Proposed Method	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

2. Research Method

2.1 The Motion Tracking Glove Design

In the development of a motion tracking glove, a device that can measure the inertia of hand movements is needed, so gloves only use Inertial measurement units (IMUs) in development. The selected device is the IMU MPU6050. The MPU6050 device has an accelerometer sensor and a gyroscope to get the raw value for calculating the rotation of the hand [20][21].

The microcontroller used in the development of the motion tracking glove in this study is the Arduino Nano. The Arduino Nano is a development board that has a small ATmega328P chip, about 18 mm x 45 mm. The input voltage used by the Arduino Nano to work is around 5-7 Volts. The small size of the Arduino nano makes it have only 14 input pins and output pins. In this study SDA and SDL pins (on pins A4 and A5 respectively) were required to obtain values from the sensor [22].

To connect the motion tracking Glove with Oculus go using Bluetooth, the module used is the HC-05. All devices will be assembled like Figure 1 and attached to the glove as shown in Figure 2. The motion tracking device is attached to the center of the hand for rotation.

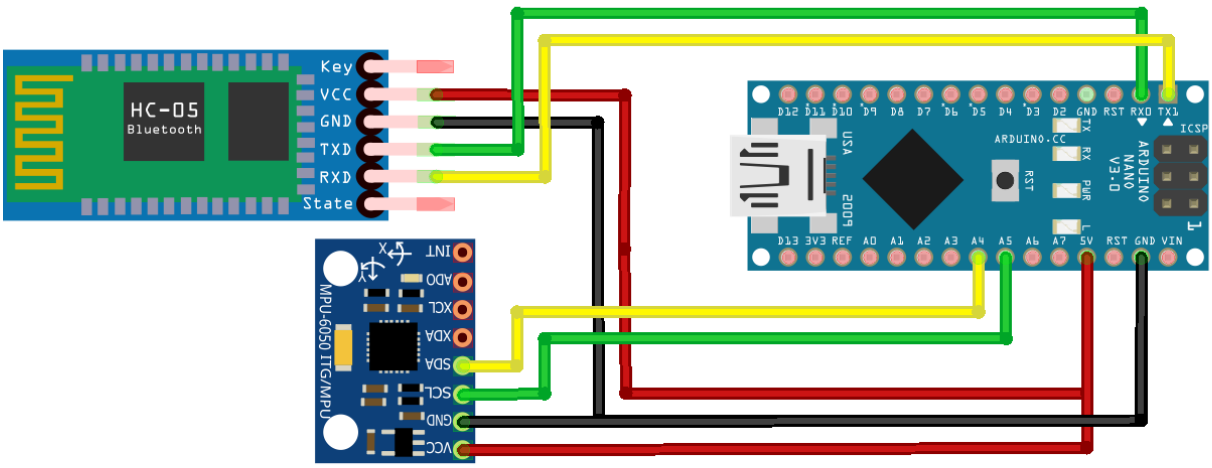

Figure 1. The Motion Tracking Glove Wiring System

Figure 2. The Motion Tracking Glove Design

The system architecture designed in this study can be seen in Figure 3. Hand movement makes the MPU6050 a value that can be used to produce a rotation value that has been integrated with the formula used, the calculation is carried out on the Arduino Nano. After getting the rotation value, the data is sent to Oculus using Bluetooth communication. The result is the movement of the object in VR.

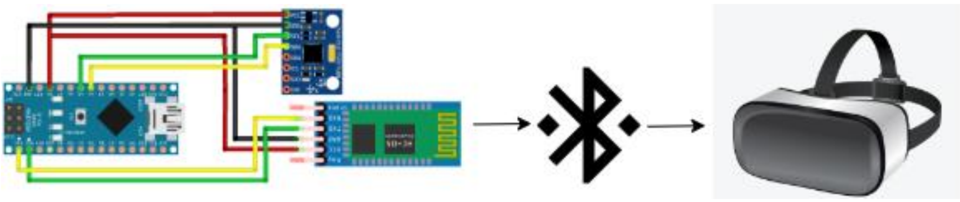

Figure 3. System Architecture

2.2 Data

In the MPU6050 module, there is a gyroscope and accelerometer sensor that can produce a value and from that value 3 parameters can be concluded, namely Yaw, Pitch, and Roll. These three parameters are often used for aircraft navigation. To get data in the form of a rotation from the MPU6050 device with an accelerometer sensor that produces a force in each vector, the formula used are Equation 1, Equation 2, and Equation 3.

$$\alpha = arctan\left(\frac{Ax}{Az}\right) \quad (1)$$

$$\beta = arctan\left(\frac{Ay}{Az}\right) \quad (2)$$

$$\gamma = arctan\left(\frac{Ay}{Ax}\right) \quad (3)$$

where Ax is the force that occurs in vector x, Ay is the force that occurs in vector y, and Az is the force that occurs in vector z.

Rotation can also be obtained from the value of the gyroscope sensor which produces angular velocity. The Equation 4 used is to integrate the initial node and add the output value of the gyroscope sensor multiplied by the time unit.

$$\alpha(t) = \alpha(t-1) + rawdata * dt \quad (4)$$

where $\alpha(t)$ is the rotation obtained, $\alpha(t-1)$ is the previous rotation of the unit of time, raw data is the value that comes out of the calculation of the gyroscope sensor, and dt is the time difference from the present and previous data collection.

The addition of a complementary filter is to get a more accurate rotation value. A complementary filter is a combination of 2 data values. In this study, the 2 data are the rotation value of the accelerometer sensor and the rotation of the gyroscope sensor. The following Equation 5 is used to get a more accurate value by using a complementary filter of 2 data values:

$$\theta_{filtered} = FK * \theta_{accel}(t) + (FK-1) * \theta_{gyro}(t-1) \quad (5)$$

Cite: Atoir, F. Z. A., Putrada, A. G. ., & Pahlevi, R. R. (2021). An Evaluation of Complementary Filter Method in Increasing the Performance of Motion Tracking Gloves for Virtual Reality Games. Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control, 6(2). https://doi.org/10.22219/kinetik.v6i2.1234

where θ_{accel} is the rotation value from the calculation of the raw value of the accelerometer sensor, θ_{gyro} is the rotation value of the gyroscope sensor raw value calculation, and $\theta_{filtered}$ is the result of a complementary filter formula. FK is a coefficient that can be adjusted from a value of 0 - 1.

3. Results and Discussion

In this study, the rotation accuracy and speed of data transmission by Bluetooth communication were tested. In testing the accuracy of rotation, a comparison of the value of Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and Signal to Noise Ratio (SNR) of performance in producing rotation values from accelerometer sensor data and rotation values from accelerometer sensor data combined with complementary filters. Testing is done by placing the motion tracking glove in a flat area without any movement. In measuring the speed of data transmission using Bluetooth communication, the motion tracking glove is moved from 0 degrees to +90 degrees then the time interval from the change in angle in the motion tracking glove to the change in angle in the VR object is observed.

The values compared are obtained from the RMSE, MAPE, and SNR. The calculations for RMSE and MAPE are as the following Equation 6 and Equation 7.

$$RMSE = \sqrt{\frac{\sum_{t=0}^{n}(At - Ft)^2}{n}} \tag{6}$$

$$MAPE = \frac{\sum_{t=0}^{n} \left| \left(\frac{At - Ft}{At}\right) 100 \right|}{n} \tag{7}$$

Where At is the rotation value of the calculation of the raw value of the gyroscope sensor, Ft is the actual rotation value (accelerometer sensor or accelerometer sensor with complementary filters), and *n* is the amount of data. The smaller or closer to the value of 0 the results of the calculation of an algorithm, the better the results of the algorithm [23][24]. The calculations for SNR are as the following Equation 8.

$$SNR = \frac{\mu}{\sigma} \tag{8}$$

Where μ is the mean or average value and σ is the standard deviation value of the sensor and filter values. The larger the value of SNR, the better the results of the algorithm [23][24].

In this study, the VR object that will be observed is a 3D model in the shape of a human arm as shown in Figure 4. The arm model will also move according to the direction of changing the angle of the moving motion tracking glove. The arm model will move in real time by Bluetooth communication.

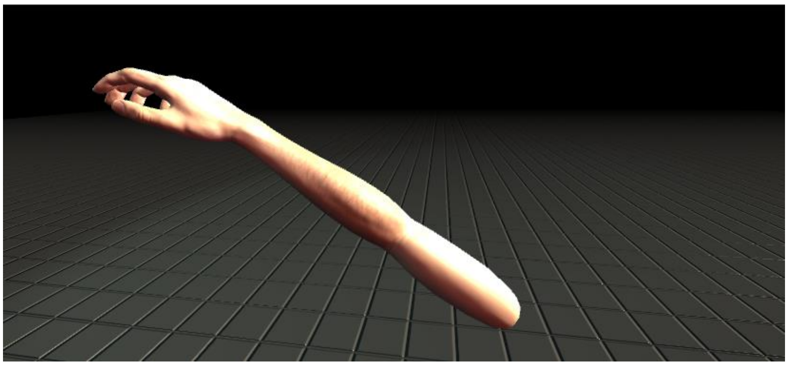

Figure 4. Unity 3D Arm Design

3.1 Complementary filter performance test results

The test is carried out by capturing the rotation value when the motion tracking glove is placed on a flat place with no movement and the motion tracking glove is moved slowly and quickly. The axis captured for this study is the x-axis. The purpose of this test is to determine the best method for obtaining the rotation value derived from the accelerometer sensor.

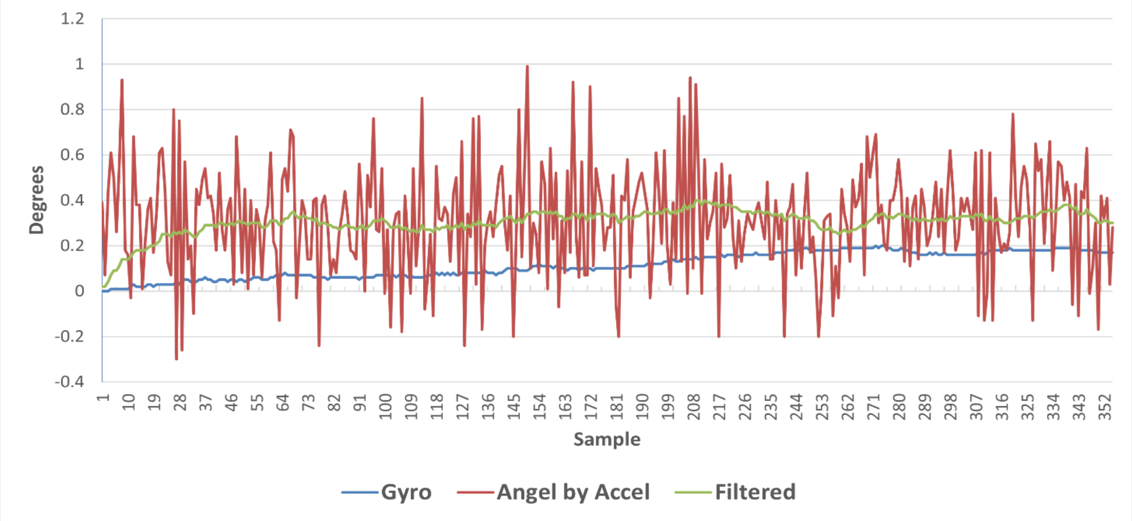

Figure 5. Angel by Gyroscope (blue) vs Angel by Accelerometer (Red) vs Angel by Accelerometer Filtered (Green) Data in a Static Position

Figure 5 shows the results of the experiment from the rotation data of the gyroscope sensor, accelerometer sensor, and accelerometer sensor with complementary filters. There were 356 data collected during the 11 second experiment. The figure shows that the rotation value of the accelerometer sensor (red) has a high variation. After adding a complementary filter (green), the rotation value has a lower variation compared to the rotation data from the accelerometer sensor (red). The RMSE value obtained from this experiment is 0.63 for data from the accelerometer sensor and 0.60 for data from the accelerometer sensor with a complementary filter. This value betters the RMSE value of the research of Malik Kamal Mazhar, which is 0.7 [18]. Meanwhile, the MAPE value obtained is 3.9% for data from the accelerometer sensor and 2.5% for data from the accelerometer sensor with a complementary filter.

Table 2. Accuracy Test Result

Position	Sensor	RMSE	MAPE (%)	SNR
static position	*Accelerometer sensor*	0.63	3.9	6.35
	Accelerometer sensor + complementary filter	**0.60**	**2.5**	**4.18**

The results of the experiments conducted show that the rotation value of the accelerometer sensor calculation combined with a complementary filter has better performance. The comparison is shown in Table 2. In the RMSE column the complementary filter has a lower value which indicates better performance. Although, by the margin it does not show a significant improvement. That is because RMSE does not put standard deviation into consideration of the equation. That is why SNR is also calculated. As seen in Equation 8, the lower the standard deviation, the better the performance of the signal. The value in the SNR column shows more significant difference between accelerometer sensor and accelerometer sensor with complimentary filter.

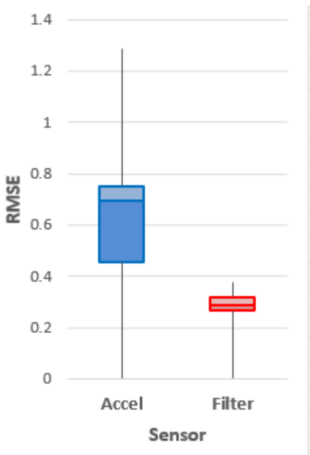

Figure 6. Boxplot of the Static Glove

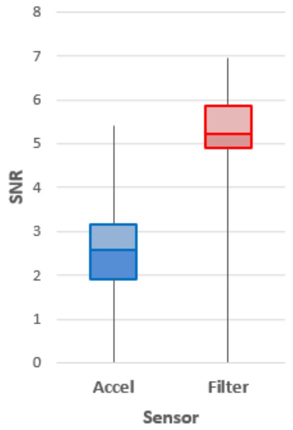

Figure 7. Boxplot of the SNR Static Glove

To show that the filter provides significant improvement, a box plot is created. The box plot is as seen in Figure 6. Filter is the RMSE measurement of the complimentary filter and Accel is the RMSE measurement of the accelerometer sensor. The size comparison shows that the filter, besides having a lower RMSE, also provides smaller standard deviation, which indicates good filter performance. Similar performance are shown in the boxplot of SNR seen in Figure 7.

3.2 Delivery speed test results

Testing in this scenario is done by calculating the delay between the time the motion tracking glove sends data to the time the VR console receives and moves the VR object. The purpose of this test is to determine the time required to send data using Bluetooth for 2 movements from 0 degrees to 90 degrees then back to 0 degrees. Figure 8 and Figure 9 are the results of testing to find out how long the delay is in sending data. The average delay according to the test scheme is 0.18 seconds.

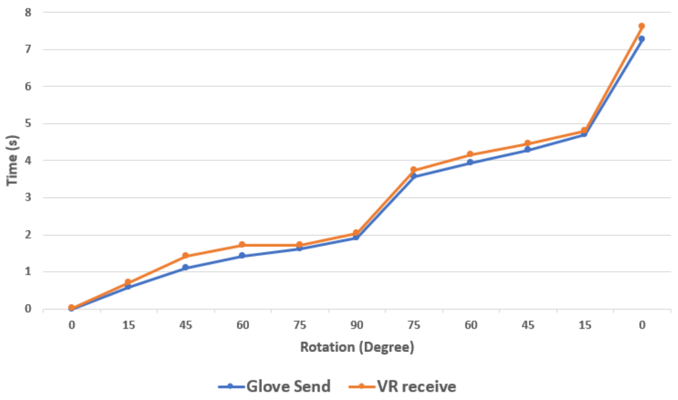

Figure 8. Rotation Timing

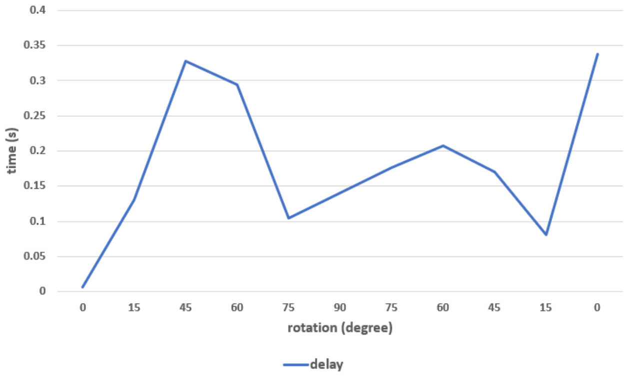

Figure 9. Delay Timing

As shown in Figure 9, the delay is higher at 45 degrees due to changes in hand movements that are less stable towards the time measured when the data was taken.

4. Conclusion

This study succeeded in designing and implementing a motion tracking glove in VR games by utilizing the Arduino Nano, Bluetooth module, and the MPU6050 module which has a gyroscope sensor and an accelerometer sensor. After being tested, the performance of the angle measurement with complementary filter improves the performance of the accelerometer sensor reading. The RMSE and SNR value obtained when the motion tracking glove is static is 0.60 and 4.18 dB respectively for the accelerometer sensor with a complementary filter. That value is better than 0.63 and 6.35 dB respectively for the accelerometer sensor without filter. In addition, the average delay value for the system is 0.18 seconds. For future work, this system can be developed into a better prototype and can be commercialized through the industry.

References

[1] J. L. Rubio-Tamayo, M. Gértrudix and F. García, "Immersive Environments and Virtual Reality: Systematic Review and Advances in Communication, Interaction and Simulation," Multimodal Technologies and Interaction, vol. 1, 2017. https://doi.org/10.3390/mti1040021

[2] V. T. Minh, N. Katushin and J. Pumwa, "Motion tracking glove for augmented reality and virtual reality," Paladyn, Journal of Behavioral Robotics, vol. 10, pp. 160-166, 2019. https://doi.org/10.1515/pjbr-2019-0012

[3] M. J, G. D, B. V, G. O and C. T, "Touchless Haptic Feedback for Supernatural VR Experiences," IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 629-630, 2018. https://doi.org/10.1109/VR.2018.8446522

[4] F. A. D, F. K and C. B. F. N, "First Person Shooter VR based Game on 10 November 1945 With Motion Controller". https://doi.org/10.1109/KCIC.2018.8628484

[5] C. Hillmann, "Comparing the Gear VR, Oculus Go, and Oculus Quest," Unreal for Mobile and Standalone VR, 2019. https://doi.org/10.1007/978-1-4842-4360-2_5

[6] N. Katzakis and M. Hori, "Mobile Phones as 3-DOF Controllers: A Comparative Study," 2009 Eighth IEEE International Conference on Dependable, Autonomic and Secure Computing, pp. 345-349, 2009. https://doi.org/10.1109/DASC.2009.76

[7] H. Youngmo, "Low-Cost Visual Motion Data Glove as an Input Device to Interpret Human Hand Gestures," Consumer Electronics, pp. 501 - 509, 2010. https://doi.org/10.1109/TCE.2010.5505962

[8] M. Hilman, D. K. Basuki and S. Sukaridhoto, "Virtual Hand: VR Hand Controller Using IMU and Flex Sensor," 2018 International Electronics Symposium on Knowledge Creation and Intelligent Computing (IES-KCIC), pp. 310-314, 2018. https://doi.org/10.1109/KCIC.2018.8628594

[9] M. P. Wilk, J. Torres-Sanchez, S. Tedesco and B. O'Flynn, "Wearable Human Computer Interface for Control Within Immersive VAMR Gaming Environments Using Data Glove and Hand Gestures," 2018 IEEE Games, Entertainment, Media Conference (GEM), pp. 1-9, 2018. https://doi.org/10.1109/GEM.2018.8516521

[10] J. Schild, L. Flock, P. Martens, B. Roth, N. Schünemann, E. Heller and S. Misztal, "EPICSAVE Lifesaving Decisions – a Collaborative VR Training Game Sketch for Paramedics," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 1389-1389, 2019. https://doi.org/10.1109/VR.2019.8798365

[11] K.-B. Park and J. Lee, "Comparative Study on the Interface and Interaction for Manipulating 3D Virtual Objects in a Virtual Reality Environment," Transactions of the Society of CAD/CAM Engineers, vol. 21, pp. 20-30, 2016. https://doi.org/10.7315/CADCAM.2016.020

[12] S. Lee, K. Park, J. Lee and K. Kim, "User Study of VR Basic Controller and Data Glove as Hand Gesture Inputs in VR Games," 2017 International Symposium on Ubiquitous Virtual Reality (ISUVR), pp. 1-3, 2017. https://doi.org/10.1109/ISUVR.2017.16

[13] P. Weber, E. Rueckert, R. Calandra, J. Peters and P. Beckerle, "A low-cost sensor glove with vibrotactile feedback and multiple finger joint and hand motion sensing for human-robot interaction," 2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), pp. 99-104, 2016. https://doi.org/10.1109/ROMAN.2016.7745096

[14] S. Tregillus and e. folmer, "R-STEP: Walking-in-Place using Inertial Sensing for Hands Free Navigation in Mobile VR Environments.," in 33rd Annual ACM Conference on Human Factors in Computing Systems, 2016. https://doi.org/10.1145/2858036.2858084

[15] J. Feasel, M. Whitton and J. Wendt, "LCM-WIP: Low-latency, continuous-motion walking-in-place," in 3D User Interfaces, 2008. 3DUI 2008. IEEE Symposium on, 2008.

[16] R. Alexandre and O. Postolache, "Wearable and IoT Technologies Application for Physical Rehabilitation," in 2018 International Symposium in Sensing and Instrumentation in IoT Era (ISSI), Shanghai, 2018. https://doi.org/10.1109/ISSI.2018.8538058

[17] R. Alexandre, O. Postolache and P. S. Girão, "Physical Rehabilitation based on Smart Wearable and Virtual Reality Serious Game," in IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Auckland, 2019. https://doi.org/10.1109/I2MTC.2019.8826947

[18] M. Kamal Mazhar, M. J. Khan, A. I. Bhatti and N. Naseer, "A Novel Roll and Pitch Estimation Approach for a Ground Vehicle Stability Improvement Using a Low Cost IMU," Sensors, vol. 20, pp. 340, 2020. https://doi.org/10.3390/s20020340

[19] R. Tavares and P. J. Sousa, "Virtual environment for instrumented glove," International Conference on Remote Engineering and Virtual Instrumentation (REV), vol. 13, 2016. https://doi.org/10.1109/REV.2016.7444488

[20] Yudhana, J. Rahmawan and C. U. P. Negara, "Flex sensors and MPU6050 sensors responses on smart glove for sign language translation," 2017 1st International Conference on Engineering and Applied Technology (ICEAT), 2017. https://doi.org/10.1088/1757-899X/403/1/012032

[21] J. Alvin, W. N. Wan Zakaria and M. R. B. Md Tomari, "Implementation of IMU sensor for elbow movement measurement of Badminton players," IEEE International Symposium on Robotics and Manufacturing Automation (ROMA), vol. 2, pp. 1-6, 2016. https://doi.org/10.1109/ROMA.2016.7847813

[22] H. Kurniawan and M. Rivai, "Sistem Stabilisasi Nampan Menggunakan IMU Sensor dan Arduino Nano," `Jurnal Teknik ITS, vol. 7, 2018. http://dx.doi.org/10.12962/j23373539.v7i2.31043

[23] J. M, B. E, N. E, E. F, R. L, K. K, M. P, T. M and J. W, "mobile motion analysis system using inertial sensors for analysis of lower limb prosthetics," in Conference: Future of Instrumentation International Workshop (FIIW), 2011. https://doi.org/10.1109/FIIW.2011.6476802

[24] J. B. Ko, J. S. Yoon, C. K. Lee, T. M. Byeon and J. S. Hong, "A Study on the Determining the Optimal Location of IMU Sensors in Dynamic Balance Measurement by Comparing Absolute Percentage Error between the 3D Motion Capture System and IMU Sensor," Computer Science, vol. 38, pp. 419-434, 2019. https://doi.org/10.5143/JESK.2019.38.6.419