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Evaluation of inertial Sensors and optical measurement methods for head and shoulder angle motion analysis

Abstract: This paper describes the advantages and disadvantages of inertial sensors and stationary camera-based measuring methods for the application of detecting head and shoulder angles. For this purpose three inertial sensor modules from Shimmer Sensing and a Kinect 2 camera system are used. The recorded data of both systems are converted into a comparable form. Based on an evaluation of the recorded measurement data, the inertial sensor and the camera-based methods are compared with regard to their suitability for detecting movements in the head and shoulder area.

Keywords: Inertial sensors, Kinect 2 camera system, head and shoulder angle measurement, improvement of stationary motion detection

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1 Introduction

Often a lack of exercise or wrong movements are the reasons for pain. The real-time data acquisition, processing and analysis of such movements can help to identify the reasons for this pain. Therefore inertial sensors or stationary camera-based systems are used. For real-life data recording, inertial sensor-based methods have significant advantages, e.g. small size, light weight or low power requirements. They are suitable for mobile, portable and non-stationary systems. i.e. for mobile long-term monitoring of human body movement under everyday conditions. But inertial sensor-based methods also have some limitations. A camera based measuring method is not limited in monitoring body movement, but it is also

compared to the inertial sensor not suitable for a mobile long-term monitoring of a human body.

In this paper the ExG inertial sensor modules from Shimmer Sensing and a Kinect 2 camera system from Microsoft are used. The ExG inertial sensor module is a 9 degree of freedom (9DOF) sensor board. It consists of three digital three-axis sensors in the form of an acceleration sensor, a gyroscope and a magnetometer [1]. Through a combination of these sensors using a gradient descent algorithm (Madgwick Algorithm), the sensor orientation in space can be calculated [2]. Body parts like for example shoulders consist of a radial and translational joint movement. Due to the high sensitivity of the acceleration sensor to errors when calculating the distance covered, the inertial sensor is limited in the recording of translational movements. [3]. The Microsoft Kinect 2 camera system works with an infrared camera and an infrared projector that allows in combination a depth measurement of the space in front of it. As a result, the calculation of the position of persons in the cameras field of view is possible [4].

Both systems are compared for the application of detection of head and shoulder angles to show the advantages and disadvantages of inertial sensors and stationary camera-based measuring methods. No reference system is used to verify the accuracy of the measured angles. The values of both systems are only be evaluated for plausibility in order to verify the suitability of the individual systems.

2 Angle Measurement Methods

2.1 Head Angle Measurement

The measurement of the head angle is organized in three head movement types. Each movement type describes a rotation around one of three movement axis. This consists a jaw-, pitch- and roll rotation of the head.

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For the measurement of the head angle one Shimmer 3 ExG inertial sensor is mounted at the head with a strap. The strap allows a sensor measurement location at the back of the head. The orientation data of the inertial sensor needs to be calibrated first to measure proper head rotation angles. Therefore the quaternion data of the inertial sensor is multiplied with the unit quaternion. The result of this multiplication can be used to calculate the rotation value on all three axis [2]. In a final step the quaternion rotation values will be converted into Euler angles. Figure 1 illustrates the

Figure 1: Head location of the inertial sensor

mounting with the strap and the location of all three axis of the inertial sensor. The red axis represents the roll axis, the blue axis the yaw axis and the green axis the pitch axis.

The measurement of the head angle with the Kinect 2 camera is based on the Joint system of the Microsoft Kinect Framework [5]. This system allows to track the three-dimensional locations of specific points on the body of a person in front of the camera. For the measurement of the head angle movement the head- and neck joint is used. The connection of the joints with vectors allows to calculate the angle between them.

For a complete evaluation of the deviation between the results of the two sensor systems, a test run should include a movement of the head around all head axis. The following enumeration contains the complete procedure.

1. forward tilt
2. backward tilt
3. roll to the left
4. roll to the right
5. left side yaw
6. right side yaw
7. chin forward
8. chin backward

2.2 Shoulder Angle Measurement

Because of the complexity of shoulder measurements, its angle is split up in a horizontal and a vertical motion. This allows a more precise comparison between inertial sensor and stationary camera-based measuring methods.

For the measurement of the vertical and horizontal shoulder angle three Shimmer 3 ExG inertial sensors are mounted with straps on the body. Figure 2 illustrates the locations of the sensors.

Figure 2: Shoulder location of the inertial sensors

Two inertial sensors are mounted at the shoulders and one inertial sensor is mounted on the back. A multiplication between the resulting quaternion of sensor 2 and 1 and sensor 2 and 3 allows to calculate the precise rotations between the sensors. In a final step the quaternion rotations are converted into Euler angles [6].

The shoulder angle measurement with a Kinect 2 camera works with a system similar to the head angle measurement. For the shoulder angle calculation the shoulder center-, shoulder right- and shoulder left joints are used.

The test run for the shoulder angles is performed in three parts. The movement of the shoulders forwards, upwards and backwards. All movements are performed twice. The following list contains the complete process for the shoulder angle test run.

1. left shoulder forward
2. right shoulder forward
3. shoulders up
4. left shoulder backward
5. right shoulder backward

Figure 3: A) Pitch angle measurement B) Roll angle measurement C) Yaw angle measurement D) Translational head movement

3 Results

3.1 Head Angle

The results of the head angle measurements are divided into pitch-, jaw and roll angles. The calculated angles of the inertial sensor- and the camera system of all series of measurement are compared.

The recording of the pitch angle of the head in Figure 3A, shows great deviations between the Kinect 2 Camera and the Shimmer 3 ExG sensors when tilting the head forward. When considering a tilt of the head to the back, the calculated angles of the two sensor systems are much closer together. The Shimmer 3 ExG sensors have recorded higher angles than the Kinect 2 camera.

Figure 3B illustrates the roll of the head. The calculated angles in the area of the roll of the head to the left show a significant difference between the two sensor systems. The roll of the head to the right does not show these large differences.

Figure 3C illustrates the measurement of the yaw angle. The measurements of the Shimmer 3 ExG is more stable compared to the recorded pitch and roll angles. The calculated angle has for both directions almost the same value. Only measured series 3 includes a significant deviation between both yaw axis rotation directions.

Figure 3D illustrates the measurement of the translational head movement. After moving the head around each rotation axis, the forward and back movements of the chin can be clearly observed. The distance between the torso and the head increases and drops twice. During the return movement to the starting position, it can be seen that the chin position has been moved back further than the starting position. Only after completion of the test chin movements, the approximate starting position is reached again.

3.2 Shoulder Angle

Figure 4A illustrates the recorded horizontal left shoulder angle data of the Shimmer 3 ExG- and Kinect 2 camera system. The movement of the shoulder to the front and back is highlighted. The angle values of both systems have a negative angle in the starting position. This is due to a malposition of the subject, leading to a pulling forward of the shoulder. There are large differences between the calculated angles of the two sensor systems. Particularly noteworthy is the increasing angle when the left shoulder compensate the right shoulder movement. The Kinect 2 camera also has a time delay compared to the inertial sensor system. While moving the shoulders up in the middle of the test measurement, the inertial sensor system angles record a horizontal movement. Figure 4B illustrates the recorded vertical shoulder angles while moving the shoulders up. The values of the Shimmer 3 ExG sensors indicate a continuous noise. Due to the natural position of the shoulders both sensor systems record a negative angle

Figure 4: A) Shoulder angles horizontal
B) Shoulder angles vertical

at the beginning. There are large differences between the recorded vertical angles of both systems. The Kinect 2 has compared with the inertial sensor system a time delay in the recording of the vertical shoulder movement.

3.3 Summary

Overall, the Shimmer 3 ExG sensor has delivered a better result for the application of detecting head angles than the Kinect 2 camera. Both systems can impress with great stability, but with the Kinect 2 there are implausible pitch- and roll angles of the head. In addition, only the Shimmer 3 ExG sensor allows a recording of the head rotation in around the yaw angle, while only the Kinect 2 camera allows to record the translational position changes of the head.

In the application of detecting horizontal and vertical shoulder movement the Shimmer 3 ExG sensor also shows better results than the Kinect 2 camera. The measurement of the shoulder angle can be observed in both directions. The Kinect 2, however, has a time delay in the recording of the vertical and horizontal movement of the shoulder. In addition, the measured series indicate, that in a recording of the shoulder without fixation of the upper body, the compensation movement will also be recorded.

4 Conclusion

In this paper an inertial sensor and a stationary camera-based measuring method were compared for the application of detecting head and shoulder angles. This comparison allows to indicate the advantages and disadvantages of both systems. The inertial system allows to detect movements around every axis of the head, but can't be used to measure the translational movement of a body part. Furthermore the inertial measuring method allows to record complex movements of the shoulder. The Kinect 2 is not able to detect movements around all axis of the head. The camera system also have time delays in the recognition of complex shoulder movements. But compared to an inertial sensor system the Kinect 2 camera is able to detect translational position recording. All these advantages and disadvantages allow the conclusion that for an optimal result in the recording of head and shoulder movements a combination of both systems must be used.

Author Statement

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