Simulation of human arms by detecting IMU data of Myos

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1 Introduction

The motion of huamn arms are mainly decided by joints and muscles. In order to simulate human arms, the movements of each joint angle, including euler angles for shoulder and joint angle for elbow , are necessary. Therefore, we try using Myo, an IMG sensor which can detect accelerometer, gyroscope and orientation data, to obtain the motion of upper arm and forearm. By computing the IMU data from two Myos on upper arm and forearm, we hope to perfectly achieve our goal.
The coordinate system and the direction of rotation angle we used are shown as the fiqure below.

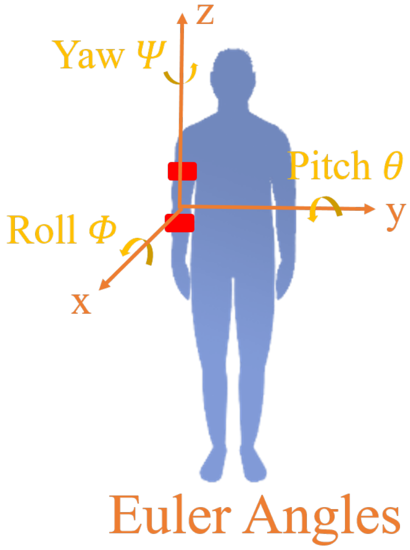

Figure 1: ϕ represents roll angle, θ for pitch angle, and ψ for yaw angle

2 Euler angle estimation

2.1 Using accelerometer and gyroscope

Before analyzing the motion of arms, computing the IMG data and transform it into rotation angles is important. First, we try using accelerometers to derive a function for rotation angles. The accelrometer data given by Myos is seperated in x, y, z three dimensions, in units of g, which represents the effect of gravitational field. The normalized accelerometer data equals to a matrix multiplying a vector $(0, 0, 1)$, where the matrix consists of three rotation matrices corresponding to angle ϕ, θ, ψ with x, y, and z axis respectively, and the vector represents the gravitational force.

$$\frac{1}{\sqrt[2]{A_x^2 + A_y^2 + A_z^2}} \begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} \cos\psi & \sin\psi & 0 \\ -sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \cos\psi\sin\theta\sin\phi - \cos\phi\sin\psi & \cos\phi\cos\psi + \sin\theta\sin\phi\sin\psi & \cos\theta\sin\phi \\ \cos\theta\cos\psi\sin\theta + \sin\phi\sin\psi & \cos\phi\sin\theta\sin\psi - \cos\psi\sin\phi & \cos\theta\cos\phi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$= \begin{pmatrix} -\sin\theta \\ \cos\theta\sin\phi \\ \cos\theta\cos\phi \end{pmatrix}$$

Then, we can derive:

$$\tan\phi = \frac{A_y}{A_z}$$

$$\tan\theta = \frac{-A_x}{A_y\sin\phi + A_z\cos\phi} = \frac{-A_x}{\sqrt{A_y^2 + A_z^2}}$$

Now, we get roll and pitch angle. However, accelerometer output has only two degrees of freedom, since accelerometers are insensitive about gravitational field vector, thus unable to determine rotation about z axis. Therefore, we come up with the solution mentioned in section 2.2. to measure yaw angle.

2.1.1 Gyroscope

Computing rotation angle from a gyroscope is different, since gyroscope sensors measure angular velocity, which is in units of degree/second. We have to integrate the rate of change in rotation angles with time, adding up every time interval's computed result around x, y, and z axis respectively.

$$gyroAng_{x,y,z} = gyroAng_{x,y,z} + gyroData \times \delta t$$

However, while integrating the computed results, this approach will simultaneously accumulating every systematic errors, which may cause drifting over long time scales.

2.1.2 Complementary Filter

In order to solve the gyroscopic drift, we fuse the accelerometer and gyroscope data, since accelerometer has no drifting problem. On the other hand, gyroscope data is very precise and robust enough against external forces, which implements the disadvantage of accelerometer that is too sensitive to disturbances. Taking both advantages, we combine both outputs with complimentary filter.

$angle = \alpha \times gyroAng + (1 - \alpha) \times accAng$

where $\alpha = \frac{\tau}{\tau + \delta t}$

δ t: sample rate, τ: time constant, chosen 1 second

We simply test the motion of lifting the right arm above the head and lowering it only by accelerometer(orange line) or gyroscope(blue line), and also the result with the application of complementary filter(gray line). The figures below show the differences. Apparently, accelerometer is very sensitive but has a better performance in long term, while gyroscope provide accurate data in short term. Combining two data through the filter contain both advantages.

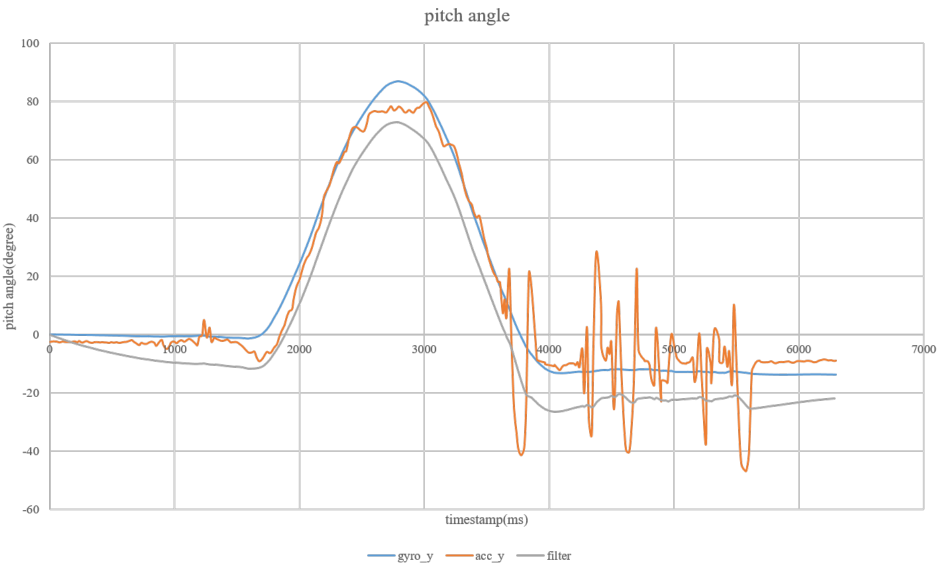

Figure 2: rotating the arm 90 degrees by y axis

2.2 Using quaternion

Unit quaternions provide a convenient mathematical notation for representing rotations of objects in three dimensions, which can get the yaw angle that accelerometer is unable to measure. Consider an ordinary vector $\mathbf{p} = (p_x, p_y, p_z) = p_x\mathbf{i}+p_y\mathbf{j}+p_z\mathbf{k}$ in 3-dimensional space. After rotation, the new position vector is denoted by $\mathbf{p'} = (p'_x, p'_y, p'_z)$, and it can be shown that desired rotation can be applied to it by evaluating the conjugation of p by q:

$$\mathbf{p'} = \mathbf{qpq^{-1}}$$

where $\mathbf{p'}$ is the new position vector of p after rotation by unit quaternion $\mathbf{q}$. The equation can be manipulated into a matrix rotation $\mathbf{p'} = \mathbf{Rp}$, where $\mathbf{R}$ is given by:

$$\mathbf{R} = \begin{pmatrix} 1-2(q_2^2+q_3^2) & 2(q_1q_2-q_0q_3) & 2(q_0q_2+q_1q_3) \\ 2(q_1q_2+q_0q_3) & 1-2(q_1^2+q_3^2) & 2(q_2q_3-q_0q_1) \\ 2(q_1q_3-q_0q_2) & 2(q_0q_1+q_2q_3) & 1-2(q_1^2+q_2^2) \end{pmatrix}$$

Furthermore, the direction matrix from the rotated Body XYZ coordinates to the original xyz coordinates corresponding with Euler angles (ϕ, θ, ψ) is given by:

$$\begin{pmatrix} x & y & z \end{pmatrix}$$

$$= \begin{pmatrix} X & Y & Z \end{pmatrix} R_z(\psi)R_y(\theta)R_x(\phi)$$

$$= \begin{pmatrix} X & Y & Z \end{pmatrix} \begin{pmatrix} \cos\psi & \sin\psi & 0 \\ -sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{pmatrix}$$

$$= \begin{pmatrix} X & Y & Z \end{pmatrix} \begin{pmatrix} \cos\theta\cos\psi & -\cos\phi\sin\psi+\sin\phi\sin\theta\cos\psi & \sin\phi\sin\psi+\cos\phi\sin\theta\cos\psi \\ \cos\theta\sin\psi & \cos\phi\cos\psi+\sin\phi\sin\theta\sin\psi & -\sin\phi\cos\psi+\cos\phi\sin\theta\sin\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{pmatrix}$$

Comparing two rotation matrices, we can get the relationship:

$$\tan\psi = \frac{\sin\psi}{\cos\psi} = \frac{2(q_0q_3+q_1q_3)}{1-2(q_2^2+q_3^2)}$$

$$\to \psi = \arctan\frac{2(q_0q_3+q_1q_3)}{1-2(q_2^2+q_3^2)}$$

Now, we can get roll, pitch, yaw angles of human arms. All we need to do is to handle IMG data from upper arm and forearm, and then calculate the angle of the elbow.

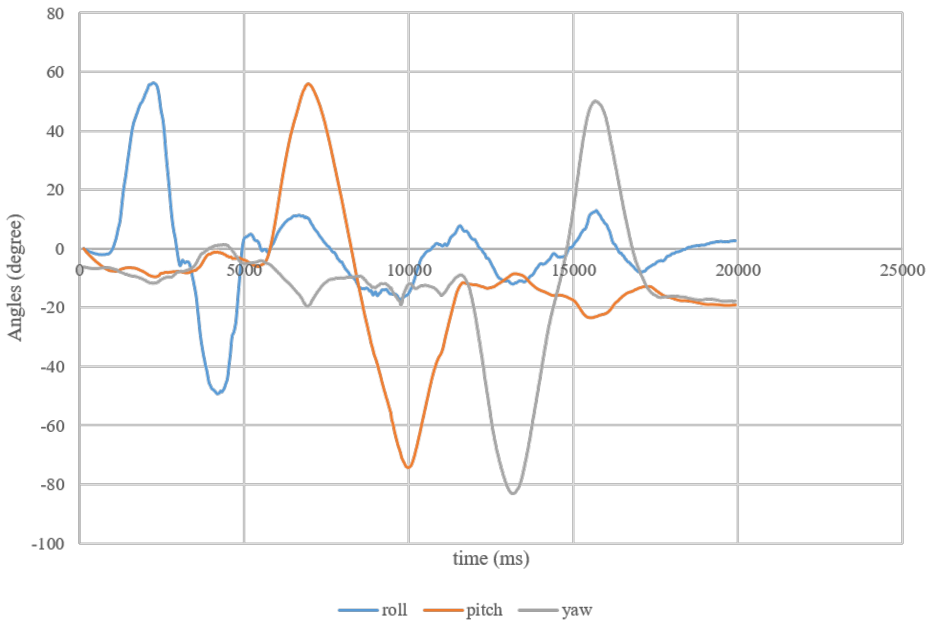

Figure 3: rotating the arm 90 and -90 degrees by x, y, and z axis sequentially, that is, each euler angle growing in turn from 0 to 90, and then -90, finally back to 0

3 Arm vector construction

With the help of euler angles, we can quantify the rotation of arm. Assume the initial position of arm vector being $(1, 0, 0)$ for both upper arm and forearm, which indicates hand pointing to the front. Applying the rotation matrices to the initial vector, in order to rotate the arm by an angle $\phi, \theta, or \psi$ about the axis x, y, or z respectively, results in the current arm vector of both upper arm and forearm. By computing the inner product of the two vectors, we can get the joint angle.

$$\mathbf{UpperArmVector} = R_x(\phi_u)R_y(\theta_u)R_z(\psi_u)\begin{pmatrix}1\\0\\0\end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta_u \cos\psi_u & \cos\theta_u \sin\psi_u & -\sin\theta_u \\ \cos\psi_u \sin\theta_u \sin\phi_u - \cos\phi_u \sin\psi_u & \cos\phi_u \cos\psi_u + \sin\theta_u \sin\phi_u \sin\psi_u & \cos\theta_u \sin\phi_u \\ \cos\theta_u \cos\psi_u \sin\theta_u + \sin\phi_u \sin\psi_u & \cos\phi_u \sin\theta_u \sin\psi_u - \cos\psi_u \sin\phi_u & \cos\theta_u \cos\phi_u \end{pmatrix}\begin{pmatrix}1\\0\\0\end{pmatrix}$$

$$\mathbf{ForearmVector} = R_x(\phi_f)R_y(\theta_f)R_z(\psi_f)\begin{pmatrix}1\\0\\0\end{pmatrix}$$

$$\mathbf{JointAng} = \mathbf{UpperArmVector} \cdot \mathbf{ForearmVector}$$

4 Conclusion

Now, both upper arm and forearm's euler angles and the elbow joint angle are knowned. Thus, the movement of arms can be analyzed easily. Outputing the roll, pitch, yaw angle of upper arm and the joint angle to the module in LabVIEW, then we can see the simulation of human arm. Despiste some singularity that causes the measurement unable to work exceeding 90 degrees, other movements perform well. By the way, the IMG data updating frequency is 50Hz, which enable the arm module moves quite smoothly. Through the method above, we accurately simulate human arms motion. Moreover, it can be applied to several fields that stongly needed wearable devices, such as VR games or medical appliance.

5 Reference

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