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Development of a Hybrid Motion Capture Method Using MYO Armband with Application to Teleoperation

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***Abstract*— In this paper, we have developed a motion capture method based on data collected by MYO armband. The method can be applied on any healthy operator wearing two MYO armbands on both upper and lower arms, respectively. The first MYO armband is worn near the centre of the operator's upper arm, the other is worn near the centre of the forearm. MYO armband has built-in eight bioelectrical sensors as well as a 9-axis IMU. The IMU sensors of the MYO are used to detect and reconstruct physical motion of shoulder and elbow joints, while the bioelectrical sensors are used to collect electromyography (EMG) signals associated with wrist motion. This hybrid method enable us to fully capture the motion of the 6-DOF (degree of freedom) of the arm. To test the proposed method, hardware-in-loop simulations studies are performed, with both physiological and physical signals received and processed in MATLAB/Simulink via a low-power bluetooth interface. Results demonstrate the validness and effectiveness of the proposed method.**

I. INTRODUCTION

Nowadays, robots technology is used in a large number of fields, e.g., industrial assembly, medical operation and space exploration. Despite robotics technology now is developing rapidly, there are still lots of problem for human to deal with, such as made a decision in uncertain environment by robot itself. The current technology of artificial intelligence (AI) is still unable to reach such level to enable robots to completely replace our humans. Thus, the human guidance of robot operation is desired for in many scenarios.

Teleoperation is the method that a human operator can remote accurately control a slave robot , and it is important and useful in lots of fields, e.g., working environment is dangerous and not suitable for human, and some tasks that require. Various of teleoperation methods have been proposed in resent years [1], [2], [3]. A system of teleoperating a slave robot to write using EMG signals is proposed. A robot arm is tele-controlled to imitate operator to write through using the EMG signals in [1]. A teleoperation system including haptic feedback is proposed and its effective and validness are demonstrated by a Baxter robot in [2]. In [4] [5], the motion capture system is solved by inertial measurement units (IMUs) and a robot arm is controlled remotely by measuring human joint angles. In [3], a Baxter robot imitates human movement and the Kinetic sensor is used to capture operator's motion, but once the operator is out of the scope of the Kinetic sensor, this approach is no longer applicable. The other important approach of teleoperation robot is using of electromyographic (EMG) signals [6], [7], [8], [9], which are able to get from the skin surface without non-invasive electrodes. Lots of important information enable to get from EMG signals, such as the operator's intended motion, muscle force. The method that using a position tracking system and EMG signals tele-operated a robot arm was introduced in [6]. In [7], EMG signals are used to measure human joint angles and the force from the operator's moving lower arm.

In this paper, we employ a wearable MYO armband to teleoperate a virtual robot arm remotely. Wearable MYO armband is built with 8 channels sEMG and 9-axis IMU sensor (3-axis geomagnetism, 3-axis angular velocity and 3-axis acceleration). Due to these features, MYO armband can be used to measure the orientations of human upper arm and forearm by 9-axis sensors, as well as the wrist joint is calculated by data from 8 bioelectrical sensors

II. PRELIMINARIES

A. MYO Armband

MYO armband is a wireless wearable device that can recognize hand gesture worn on forearm and manufactured by Thalmic Labs. A MYO armband is built-in 8 EMG sensors and along with 9-axis IMU sensor. MYO armband is able to sense a slight electrical impulses from arm muscles. The data measured by MYO armband can be transferred to the computer via bluetooth.

B. The Human Arm Joints Kinematics Model

A human arm includes three joints and consists of seven DOF: shoulder joint including three DOF, elbow including two DOF and the wrist joint including two DOF. Using the method of standard D-H parameters, we can establish a kinematic model that represents human arm as shown Fig2. Here we assume human arm is a 7-DOF serial robot arm,

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Fig. 1. MYO armband is wireless device [10]

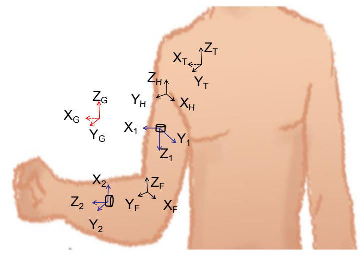

Fig. 3. The global frame, local frame and MYO armbands frames (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2). Modified from [13]

and TabI showed the relevant D-H parameters [11] [12]. The Z-axes present the rotation axis. L_1 represents the length of the operator's upper arm. L_2 represents the length of the operator's forearm. L_3 is the length of hand. The unit of L_1, L_2 and L_3 is meter. There we assume the wrist yaw angle is zero.

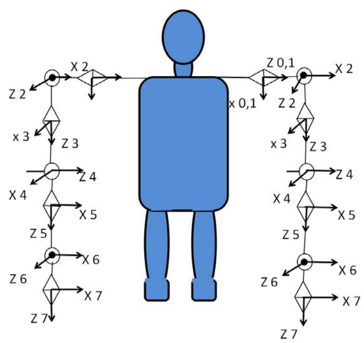

Fig. 2. Kinematics model of human arms

TABLE I
STANDARD D-H PARAMENTS OF KINEMATICS MODEL FOR HUMAN ARM.

i	θ_1	d_i	a_i	α_i
1	q_1	0	0	-90°
2	q_2+90°	0	0	90°
3	q_3	L_1	0	-90°
4	q_4	0	0	90°
5	q_5	L_2	0	-90°
6	q_6	0	0	90°
7	q_7	L_3	0	0

III. METHODOLOGY

A. Shoulder and Elbow Motion Capture Method I

The global coordinate frame (x_G, y_G, z_G) (refer to Fig.3) is defined as: x-axis points to the side; y-axis points forwards, and z-axis points upwards. We assume that initially the humerus frame (x_H, y_H, z_H) and forearm frame (x_F, y_F, z_F) coincides with the global frame, such that we have identity matrices for $R^i_{GF} = [X^i_{GF}, Y^i_{GF}, Z^i_{GF}]$ and $R^i_{GH} = [X^i_{GH}, Y^i_{GH}, Z^i_{GH}]$, where R represents the rotation matrix; the superscript "i" denotes the initial position; the subscripts "G", "H" and "F" represent the global, the humerus and the forearm frames, respectively. The rotation matrix R_{YX} denotes the orientation of the frame "N" with respect to frame "M". The column vectors X_{MN}, Y_{MN} and Z_{MN} denote unit vectors describing the principal directions of the frame "N" in terms of frame "M", and X_{MN}, Y_{MN}, $Z_{MN} \in \Re^{3\times 1}$.

The orientations of humerus coordinate frame with respect to the first MYO coordinate frame and the lower arm coordinate frame with respect to the second MYO coordinate frame can be expressed as follows:

$$R^i_{UH} = (R^i_{GU})^T R^i_{GH}, \quad R^i_{LF} = (R^i_{GL})^T R^i_{GF} \tag{1}$$

where the subscripts "U" represents the first MYO armband frame which is worn on the upper arm, and the subscripts "L" represents the second MYO armband frame worn on the lower arm.

When the operator moves arm to a new pose, the orientations of the humerus and forearm in the global frame can be describe by the following rotation matrices:

$$R^f_{GH} = R^f_{GU} R^i_{UH}, \quad R^f_{GF} = R^f_{GL} R^i_{LF} \tag{2}$$

where the superscript "f" denotes a new posture of the operator's arm.

From the first MYO's gyroscope, we obtain a quaternion q=[x,y,z,w]^T, where the (x,y,z) is a vector and w is a scalar quantity.

$$q = xi + yj + zk + w$$

From the quaternion, the orientations of the humerus in the global is represented as follows

$$R^f_{GH} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \tag{3}$$

$$= \begin{bmatrix} 1-2(y^2+z^2) & 2(xy-wz) & 2(wy+xz) \\ 2(xy+wz) & 1-2(x^2+z^2) & 2(yz-wx) \\ 2(xz-wy) & 2(wx+yz) & 1-2(x^2+y^2) \end{bmatrix}$$

Consider the the three Euler angles between a frame $\{B\}$ and a frame $\{A\}$, namely γ, β, α, which are the roll, pitch and yaw angles respectively. Firstly, the frame $\{B\}$ coincide with frame $\{A\}$, and then frame $\{B\}$ rotates about x-axis by γ radians, next about y-axis by β radians, and finally, about z-axis by α radians [14]. Therefore, R^f_{GH} can be written as below:

$$R^f_{GH} = R_Z(\alpha)R_Y(\beta)R_X(\gamma) \tag{4}$$

$$= \begin{bmatrix} c\alpha c\beta & c\alpha s\beta s\gamma - s\alpha c\gamma & c\alpha s\beta c\gamma + s\alpha s\gamma \\ s\alpha c\beta & s\alpha s\beta s\gamma + c\alpha c\gamma & s\alpha s\beta c\gamma - c\alpha s\gamma \\ -s\beta & c\beta s\gamma & c\beta c\gamma \end{bmatrix}$$

where $c\beta$ is the shorthand of $cos\beta$ and $s\beta$ is shorthand of $sin\beta$, and so on.

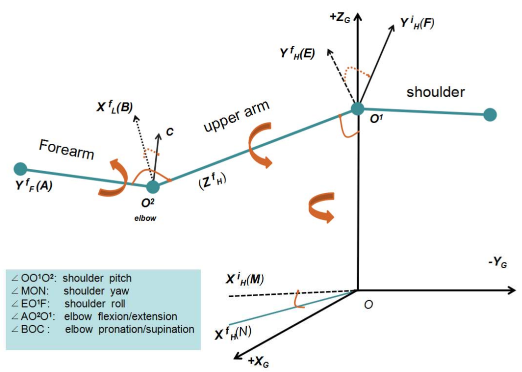

Fig. 4. Illustration of the joint angles in human arm frame

From the readings of the two MYO armbands, the first five joint angles can be calculated for the operator's arm. From (3) and (4), The three shoulder joint angles (shoulder flexion/extension, abduction/adduction and internal/external rotation) can be calculated.

$$\beta = Atan2(\sqrt{r_{31}^2 + r_{32}^2}, r_{33}) \tag{5}$$

$$\alpha = Atan2(r_{23}/s\beta, r_{13}/s\beta) \tag{6}$$

$$\gamma = Atan2(r_{32}/s\beta, -r_{31}/s\beta) \tag{7}$$

where the γ, α and β represent the joint angles of shoulder roll, shoulder yaw and shoulder pitch, respectively.

Through the data collected from the two MYO armband, we can also calculate the two elbow joint angles (elbow flexion/extension and pronation/supination) as follows. Let us denote

$$R^f_{GL} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{8}$$

Then, we have

$$\begin{aligned} A_{fe} &= arccos(a_{12}r_{13} + a_{22}r_{23} + a_{32}r_{33}) \\ A_{ps} &= arccos(r_{11}a_{11} + r_{21}a_{21} + r_{31}a_{31}) \end{aligned} \tag{9}$$

where the A_{fe} and A_{ps} represent the joint angles of elbow flex and elbow roll, respectively.

B. Shoulder and Elbow Motion Capture Method II

In order to estimate the rotation angles of the upper arm, the first step is to find three rotation matrices about rotation axis of operator's upper arm. We denote W_{FE} as rotation matrix to represent flexion-extension, W_{AA} to represent abduction-adduction, and W_{IE} to present internal-external with respect to thorax frame.

To find W_{FE}, let the human operator stand in an upright manner and the arm wearing two MYOs put down naturally on one side. First, let the operator flexes the upper arm completely at a suitable speed. Second, let the operator extend the arm back to the initial position. To find W_{AA}, let the human operator completely abducts the upper arm with a suitable speed. After that let the operator adduct the arm back to the initial position. By the same procedure, we find W_{IE} in the following manner. Let the human operator's arm spun inward fully with a suitable speed, and then rotate back to the initial position. The operator performs each motion five times. To find the rotation axis of the upper arm flexion-extension in the thorax frame, we assume the orientation of the thorax is stationary, and the frame of the thorax coincides with the global frame. The orientation of the final position of the first MYO armband frame in the initial frame is the rotation matrix

$$R^{if}_U = (R^i_{GU})R^f_{GU} \tag{10}$$

The rotation axis of R^{if}_U can be denoted by a skew-symmetric matrix W^{FE}_U [15] as below:

$$W^{FE}_U = R^{if}_U - (R^{if}_U)^T = \begin{bmatrix} 0 & -w_z & w_y \\ w_z & 0 & -w_x \\ -w_y & w_x & 0 \end{bmatrix} \tag{11}$$

The rotation matrix about the above rotation axis is

$$W = W^{FE}_U / \sqrt{w_x^2 + w_y^2 + w_z^2} \tag{12}$$

Because the thorax frame coincides with the global frame, the rotation matrix of the rotation axis in the thorax frame can be written as

$$W_{FE} = R^i_{GU} W \tag{13}$$

Similarly, we can introduce the antisymmetric matrices W_{AA} and W_{EI} corresponding to the axes of abduction-adduction and the axis of internal-external respectively [16].

From (5), the orientation of the humerus coordinate in the thorax can be calculated as

$$R^n_{TH} = (R^n_{GT})^T (R^n_{GH}) \tag{14}$$

where the subscript "T" denotes the thorax frame. The rotation matrix that denotes the humerus frame at time-step n with respect to the initial pose can be calculated as

$$R^{i,n}_T = (R^i_{TH})^T R^n_{HR} \tag{15}$$

The rigid body rotates about a fixed axis in a exponential form that is $R = e^{\widehat{W}q}$, where $q \in \Re$ is the rotation angle about the rotation axis. In a more explicit form [17]

$$R = e^{\hat{W}q} = I + \hat{W} sinq + \hat{W}^2(1 - cosq) \tag{16}$$

where w=$(w_x, w_y, w_z)^T \in \Re^{3\times1}$, and $\hat{W}$ represents the rotation axis of a rigid body. There are three DOF in the shoulder joint, so that the movement of the upper arm can be decomposed into three consecutive rotations, one about the axis of flexion-extension, one about the axis of abduction-adduction, and the last one about the axis of internal-external:

$$R_{shoulder} = e^{W^{FE}q_{FE}} e^{W^{AA}q_{AA}} e^{W^{EI}q_{EI}} \tag{17}$$

where the rotation matrix $R_{shoulder}$ and $R_T^{i,n}$ represent the same motion at upper arm. q_{FE}, q_{AA} and q_{EI} are the rotation angles relative to the the axis of flexion-extension, the axis of abduction-adduction and the axis of internal-external respectively.

The orientation of forearm's final position with respect to initial position in the second MYO armband coordinate is

$$R_L^{if} = (R_{GL}^i)^T R_{GL}^f \tag{18}$$

The rotation axis of R_L^{if} is represented by the skew-symmetric matrix W_L^{EF}

$$W_L^{EF} = R_L^{if} - (R_L^{if})^T \tag{19}$$

The rotation matrix of the rotation axis in the second MYO frame is:

$$W_2 = W_L^{FE} / \sqrt{w_{2x}^2 + w_{2y}^2 + w_{2z}^2} \tag{20}$$

where w_{2x}, w_{2y} and w_{2z} are the components of W_L^{FE}.

The rotation matrix of the rotation axis in the first MYO frame is:

$$W_1 = R_{UL}^i W_2 \tag{21}$$

And the rotation matrix of the rotation axis in the humerus frame is:

$$W_{EF} = (R_{GH}^i)^T R_{GU}^i W_1 \tag{22}$$

Similarly, the rotation matrix of the rotation axis pronation-supination W_{PS} can be obtained. From (3) (4) (5) (6), the orientation of forearm frame in the humerus frame is calculated as

$$R_{HF}^n = (R_{GH}^n)^T R_{GF}^0 \tag{23}$$

The forearm coordinate frame with respect to the initial pose in the humerus coordinate frame is represented by:

$$R_H^{i,n} = (R_{HF}^i)^T R_{HF}^n \tag{24}$$

Consider that there are two DOF for the elbow. The movement of the elbow can be composed of two consecutive rotations: one is about the axis flexion-extension, and the other is about the axis pronation-supination:

$$R_{elbow} = e^{W^{FE}q_{FE}} e^{W^{PS}q_{PS}} \tag{25}$$

where R_{elbow} and $R_H^{i,n}$ are the same rotation matrix that describes the motion of operator's elbow, q_{EF} and q_{PS} are the rotation angles with respect to the axis of flexion-extension and pronation-supination, respectively.

C. Wrist Joint Angle Estimation

When the MYO armband is worn on the subject's forearm, it is able to recognize the subject's hand poses through EMG signals, such as wave-in and wave-out. Through the determined gesture, the joint angle model is established based on EMG signals. Let us focus on the wrist yaw angle. Let θ_i represent wrist joint angle with $i = 1, 2$ represent different directions of rotation. Integral EMG (IEMG) [18] is a introduced variable which is got by applying full-ware rectification and smoothing. The magnitude of EMG signals is expressed by AIEMG features that is the mean value of the IEMG signals

$$AIEMG_l(m) = \frac{1}{t}\int_0^t IEMG_l dt \tag{26}$$

where $IEMG_l(n)$ $(l = 1, ...8)$ is the value that the lth EMG sensors measures IEMG signals in the nth frame. The mean value of L AIEMG features in the nth frame is calculated as follows:

$$E(n) = \frac{1}{L}\sum_{l=1}^{8} AIEMG_l(n) \tag{27}$$

We assume that the relationship between the magnitude of wrist joint angles and the ENG signals is approximately linear. The wrist joint angle is calculated as

$$\hat{\theta}_i = \frac{E(n) - E_i^{min}}{E_i^{max} - E_i^{min}} \theta_i^{max} \tag{28}$$

where θ_i^{max} is the maximum value in the range of the gesture i, $i = 1$ stands for the wrist joint angle of wave-in, $i = 2$ for the angle of wave-out. E_i^{max} and E_i^{min} are the maximum value and minimum value of $E(n)$, respectively.

IV. EXPERIMENTAL RESULTS

One subject participates the experiment. The subject operator stands up right with two MYO armbands on the same arm. The first MYO armband is worn near the centre of the upper arm. The second MYO armband is worn near the centre of the forearm. The virtual robot arm is established by the Robotic Toolbox [19] built under MATLAB and it's initial pose is showed in Fig.5. Before the operator controls the virtual robot arm, the MYO armband must be calibrated and the EMG sensors must be warm up, so that the MYO armband can discern different hand poses. The operator must not move

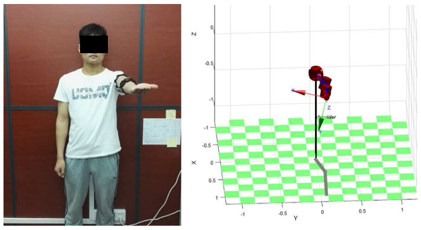

Fig. 5. The operator's arm initial pose (pose 1)

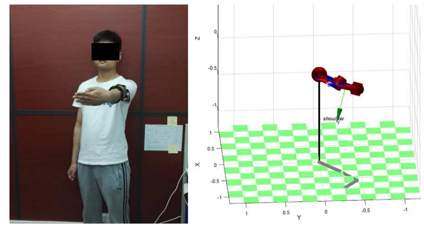

Fig. 6. The operator's hand wave-in (pose 2)

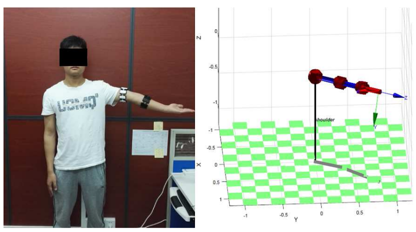

Fig. 7. The operator's shoulder adduction (pose 3)

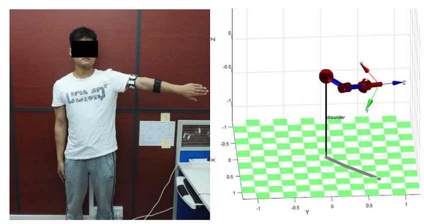

Fig. 8. The operator's shoulder internal rotation(pose 4)

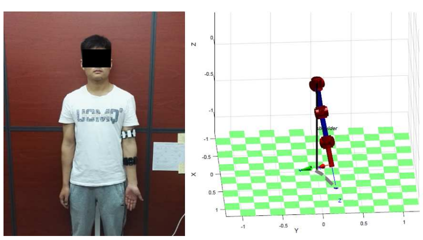

Fig. 9. The operator's arm put down (pose 5)

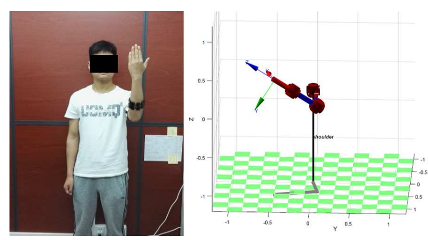

Fig. 10. The operator's elbow extension (pose 6)

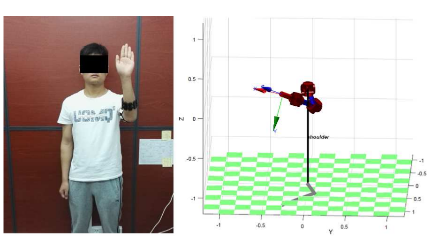

Fig. 11. The operator's elbow supination (pose 7)

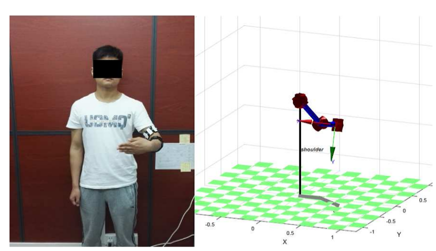

Fig. 12. A complex pose of the operator (pose 8)

position so that only both arms can freely, and the arm must not at a fast speed through the course of the experiment.

From Figs.5 to 12, we can see that when the operator moves arm with a proper speed, the virtual robot arm follows the operator's arm movement well. The orientation of the operator's arm in different poses are shown in Tabs. II and III. The values of the first three lines are for shoulder angles of pitch, yaw and roll, respectively. The values of the fourth and five row are elbow joint angles of flex and roll, the sixth row for wrist joint angle. The unit of all the values in Tabs. II and III is degree. From the Tabs. II and III, we see that both methods are able to capture human arm posture. Further investigation shows that the first method is able to close follow the physical motion, while the calculation of the second method may produce notable disparities for complicated motions, as can be see by comparison between Tab III and Figs. 5 to 12.

TABLE II

THE JOINT ANGLES OF OPERATOR'S ARM IN DIFFERENT POSES CALCULATION BY THE FIRST METHOD.

pose	pitch	roll	yaw	flex	roll	wrist roll
1	12.58	-17.44	-12.36	18.72	5.70	0
2	4.41	-31.54	-11.78	12.85	19.31	42.85
3	-15.42	-28.08	62.70	18.59	12.34	0
4	-15.61	-79.54	53.28	6.5	47.69	0
5	-64.96	-18.30	20.04	16.63	47.69	0
6	-6.63	-21.30	-8.79	89.58	17.54	0
7	0.07	-22.65	-10.28	73.02	27.49	0
8	-34.87	-58.39	22.93	65.68	30.05	75.08

TABLE III

THE JOINT ANGLES OF OPERATOR'S ARM IN DIFFERENT POSES CALCULATION BY THE FIRST METHOD.

pose	pitch	roll	yaw	flex	roll	wrist roll
1	18.00	-8.02	-4.67	16.33	0.78	0
2	12.18	-24.52	-6.23	7.92	21.34 42.85	
3	-21.34	-40.41	47.55	8.63	13.51	0
4	-4.92	-86.27	41.59	36.6	12.60	0
5	-77.18	-21.12	-31.01	14.28	5.56	0
6	-4.19	-21.52	-12.36	81.25	21.84	0
7	5.17	-19.51	-8.61	71.00	4.16	0
8	-42.61	-66.68	-59.90	60.19	27.81	75.08

V. CONCLUSION

In this paper, a hybrid motion capture approach is developed based on a pair of MYO armbands worn on the operator's arm. Two methods are compared to extract the 5 DOF motion of shoulder and elbow. Because different subjects have different range of arm movement, the second method needs to calculate the rotation matrices of the rotation axis of different joints for different operators before teleoperating the robot. So the first method is much easier to be implemented. The wrist roll angle is calculated by the EMG signals. The 6 DOF motion of human operator's arm is detected and reconstructed by using both physiological EMG signals and physical IMU signals in a hybrid manner.

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