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Transhumeral Sensory System to Control Robotic Arm

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***Abstract*— Humanoid behavior of robots has resulted in significant development in many fields, including medical science and automation. Understanding Human motions and movements plays a crucial role in designing such humanoid robots. Technological research development can apply human actions in significant fields like humanoid robots, medical analysis and assistance systems, and sports analytics. This paper presents a sensory system that interacts and reads the movement and orientation of individual arms and is used to control robotic arms. The proposed system is a 7 Degrees of Freedom (DoF) sensory system with a 7 DoF robotic arm miming the human transhumeral arm. A wearable sensor plays a vital role as the data collected can be used in numerous ways, from training robots and other modules, to analyzing the performance of sports personnel. The sensory band collects data to provide each joint's rotation angle. The sensory system was built using IMU sensors, flex sensors, and a potentiometer with Arduino Uno as the primary controller. The acquired sensory data was communicated to a robotic arm using an RF transceiver setup. This system can be inexpensive and easily used in various fields, including sports analytics in rural areas. The experimental results are promising, providing a linear connection between the sensory system and the robotic arm with average error for the joints below 2%. Incorporating higher-range sensors can improve the performance of the proposed model.**

Keywords*— *Sensory band, robotic arm, wearable sensors, co-bot, arm movement recognition, human-machine interaction, flex sensor, robot

I. INTRODUCTION

All around the world, robotics is increasingly becoming a part of regular human life as humanoid robots. Co-bots can be used as medical or sports aids, which require human control to train and human motion data to understand movements. More affordable solutions like inertial measurement units (IMU) and other wearable sensor systems replace laboratory-based motion capture systems. The use of IMU sensors provides an effective movement assessment. Pelvic Movement Detection, Finger Joint movements detection, Upper Limb Motion Assessment, Upper Body Pose estimation, and Walking Speed estimation are superior results obtained through the effective IMU sensor systems [1]–[6]. Camera-based systems have also played a prominent role in human-robot interaction [7], [8]. Other sensors that have a significant use include flex sensors to detect the joint angles in fingers or other joints with one degree of freedom[9], [10].

Yi et al. present an IMU-based Joint angle estimation system using wearable sensors. They have considered a lightweight design where the IMU data is collected, and the influence of the IMU data in the joint angle estimation is investigated [3]. Unlike popular multi-sensor systems, Su et al. present a single-sensor system using an EMG sensor. This system shows potential for developing-bot control systems[11]. The use of EEG signals to detect gait phases is also available[12]. Some materials, like triboelectric nanogenerators, are explored to understand how much they can be used as tactile sensors [13]. These tactile sensors can improve reception, and the efficiency of human-machine interaction can be increased. Nizamis et al. discussed using Human-machine interfaces to transfer human movement data to bionic arms to treat impairments and diseases better [14]. Tognetti et al. proposed an implementation that blends the non-inertial angular measurement through a textile goniometer with the inertial information derived from the two accelerometers to assess knee joint flexion extension through a hybrid system [15].

Motion sensor systems have great potential in medical aids. A practical sensory human activity recognition (HAR) system for older people that uses a wearable ambient sensory system was implemented [16]. The wearable sensory system uses multiple sensor modules, including magnetometers, gyroscopes, and barometers. A system that tracks a surgeon's hand movements during a simulated open surgery task to evaluate their manual expertise uses sensory gloves with 15 flex sensors to record the hand movements. The system uses flex sensors to detect the flexion/extension in ang finger joints and the IMU sensor to detect a deviation in the wrist [17]. A wearable sensor combines a plantar pressure measurement unit and IMU integrated with the LSTM model to detect human gait abnormalities prone to the risk of falls [18]. The Amrita progressive training assistance uses a haptic simulator to train various hand-held powered tools [19]. An Arduino-

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based mobile robot controlled using a Myo band was proposed [20]. An artificial human hand model that precisely follows the natural movements of the human hand employing image processing, thus avoiding sensor noise [21].

Gomez-Arrunategui et al. exhibited a rehabilitation-aiding sensory system that will collect Arm movements. This IMU sensor-based model uses Convoluted Neural and Random Forest networks to classify the movement signals [22]. Though Sensor-based systems are computationally light to use, hybrid setups with visions-based and sensor-based systems provide more elaborate data. Fiorini et al. presented a model that fuses data from two RGB cameras and the sensors worn by the users. The fused data provided significant accuracy in movement detection [7].

These research studies provide a base for the proposed model in this work and its application in various fields for data collection and as co-bot assistance. This paper presents a transhumeral sensory system that patients, athletes, and employees can wear to understand the movements and motions to control and train co-bots and for personal analysis. The electronic and mechanical design of the sensory system is proposed and concluded with the robot's variance and repeatability. Table 1 shows the state-of-the-art comparison. The various models proposed by different scholars and the advantages and disadvantages are clearly lineated in the table.

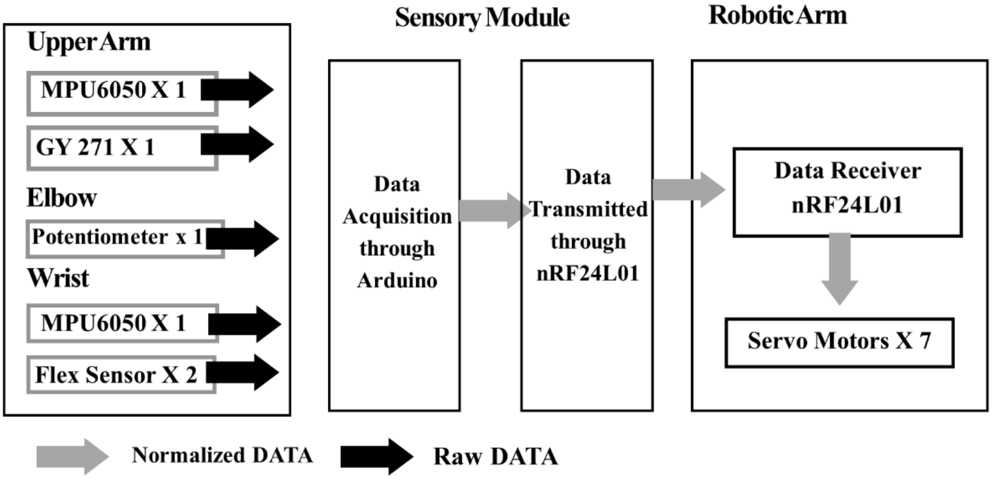

Fig. 1. Schematic Representation of the proposed system

The proposed system is a simple robot controlled by a sensory band. The role of sensory devices to mimic robotic applications is fast-growing and actively used in medical sciences, sports, and the military. This system is a cost-effective solution for understanding the transhumeral motion of a human arm. With the data provided by the system, one can understand each joint's rotation angle used to control and train robots efficiently.

TABLE I. STATE OF THE ART COMPARISON

Functionality	Performance Metrics	Sensors Used	Advantages	Disadvantages	Ref number
Wrist band for walking speed estimation and sensor carrying mode estimation	Average error about 5%	IMU	Sleek design with a power system	Performance evaluation is based on treadmill experiments	[4]
Upper Limb Tracking Band	Angular accuracy over 5 deg	BNO080 IMU	Reduced Battery Consumption and reduced footprint	must be kept at least 30 cm away from ferromagnetic materials to avoid errors	[5]
Gesture recognition through combining Vision based and sensor-based system	Average accuracy of 0.81	RGB-D camera and inertial sensor Sens Hand	Sensor fusion improves the recognition	Not portable	[7]
Human Finge Tracking by two sensor systems	Average error of 3%	Leap Motion Sensor and Flex Sensors	Improved Accuracy over just using a leap motion sensor	Requires additional hardware along with the Leap motion sensor	[9]
Multi-mode English Sign Language Detection	-	Flex Sensors	Can work in three modes to detect signs, words and letters	Limited to English Language only	[10]
Quantitative detection of Finger Motion	Signal sensitivity of 0.556 mV/lb	EMG Sensors	Different intensity finger movements can be considered as different finger commands for external applications	Detects only mild motions	[11]
Sensory Band that can be used to control a 7 DoF robotic Arm.	Average error below 2%	Flex Sensors and IMU	Sleek Design, cost efficient, customizable to be used in different fields of technology	Use of hobbyist sensors instead of industry grade sensors	This paper

II. Proposed System

As shown in Figure 1, the proposed system is divided into three portions: an upper arm portion covering 3 DoFs of the shoulder joint, one elbow portion covering 1 DoF of the elbow joint, and a wrist portion covering 3 DoFs of the wrist joint. The data from these three portions are obtained through different sensors, which are processed through the Arduino Uno, which then transmits the commands to the robot to operate. Arduino on the robotic arm receives the signal and controls the 7 Servos duly. The two Arduinos communicate through two RF transceivers called nRF24L01. The ADC from the Arduino in the sensory band takes the raw voltages from the sensors and converts them into data of range 1 to 1024. This data is again normalized into a range of 0 to 180 for the servos to operate. This system reads a human arms motion with a limitation of 180 degrees at maximum. The following equation is used to convert the values from 0-1024 to the 0-180 range, where value = current value, oMin = minimum value of the current range, oMax = maximum of the current range, nMin = minimum of the new range, and nMax = maximum value of the new range:

$$Normalized\ Value = \frac{value - oMin}{oMax - oMin} * (nMax - nMin) + nMin$$

III. System Design

The wearable sensory band system is designed to extend from the shoulder to the palm, where the sensors and the microcontroller are placed, as shown in Figure 2. The MPU 6050 sensor below the shoulder is used to record the movement of the shoulder joint. The potentiometer is placed on the elbow's side to record the flexion-extension elbow angle.

Two Flex sensors on the wrist are used to record the yaw and pitch of the wrist. Another Gyroscope module (GY-271) is used to record the roll. Overall, MPU 6050 records 3DoFs of the shoulder, one potentiometer records the elbow's 1DoF, one GY-271 records 1DoF of the wrist, and two flexes sensors record the other 2DoFs of the wrist motion.

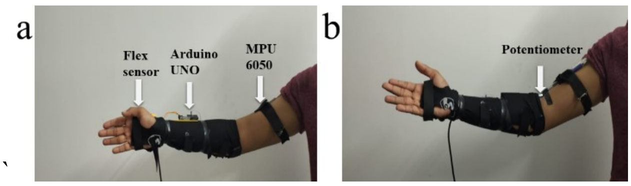

Fig. 2. a) Placement of Arduino, Flex Sensor, and MPU6050 (b) Placement of potentiometer on the sensory band's elbow

The sensory system is connected to a robotic arm, which moves accordingly. The robotic arm with 7 DoF is designed using an MG995 servo motor and SG90 motors. The data from the sensory band is transmitted and received by the robotic arm to control the servo motor using the nRF241021 transceiver.

IV. Robotic System

The robotic system resembles a human arm with 7DoFs focusing on the orientation and movement of a human arm, excluding finger movements. This system can be split into the shoulder, elbow, and wrist joints. Hence, we do not incorporate an end effector. The shoulder joint has 3 DoFs, where 3 MG995 servo motors generated rotation in three axes. The elbow joint is a hinge joint with movement in one plane, achieved using one MG955. Finally, 3 SG90 servo motors were used to mimic the wrist's yaw, pitch, and roll movement.

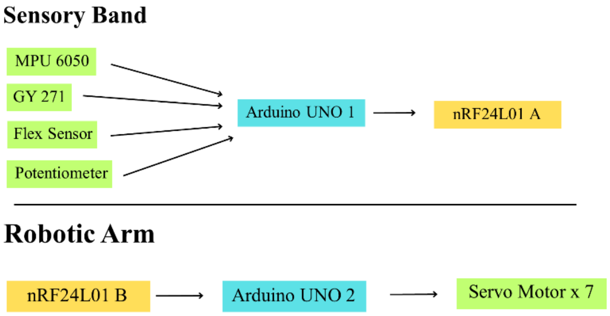

Fig. 3. Depiction of the flow of information

Figure 3 shows a simple understanding of how the system works. The sensory system looks for any motions or movements in the human arm. If any motion is detected, the data is collected and normalized into a range of 0-180. This normalized data is used to control the servo motors of the robot.

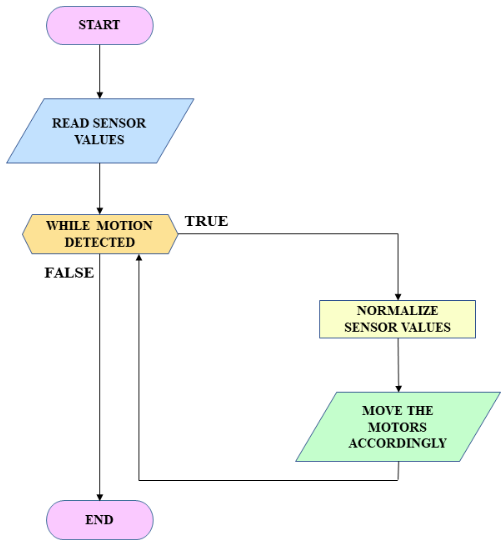

Fig. 4. Flowchart representing the flow of data through the Robotic arm

Figure 4 shows the functioning of the Robotic arm that was used to test the sensory band. As shown in the figure, the values are senses by sensory band, the values are normalized. This normalized value is used to control the motors. The Sensory band and the robotic arm operate in a Master-Slave combination where the robot is connected to the sensory system through the nRF24l01 transceiver module.

V. Sensory System

The sensory system plays a crucial role as it needs to capture all human motions without inconveniencing the user. The design was intended to be sleek and fashionable to wear. The Sensors include two MPU6050 modules, one Compass module, one potentiometer, and two flex sensors. The system is divided into Wrist Sensing, Shoulder sensing, and Elbow Sensing portions.

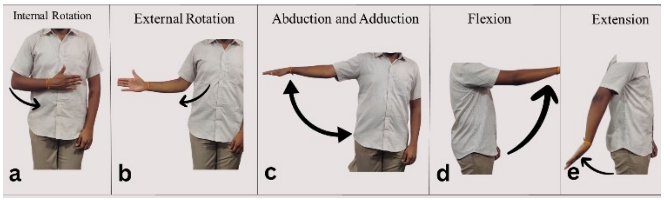

Fig. 5. Illustration of basic shoulder movements

The Should movement has seven significant activities as follows (Figure 5):
1. Abduction and 2. Adduction (Fig. 5c): The movements are sensed using the Y-axis readings of the Gyroscope.
3. Flexion (Fig. 5d), and 4. The extension (Fig. 5e): The movements are sensed through the Y-axis readings of the GY-271 module.
5. Internal/Medial (Fig. 5a) 6. External/Lateral (Fig. 5b) is sensed through the X-axis readings of the Gyroscope.
The wrist movement is divided into yaw, pitch, and roll. The yaw and pitch are acquired using two flex sensors, and the roll is measured through the MPU6050.

VI. Experimental Results

The robotic arm's performance was validated by comparing the sensor bands' values to the actual rotation of the robotic arm, and the results were plotted in Fig. 7 and 8. These graphs help us realize that the proposed system mimics the motions to a fairly reasonable range with minimal deviations. The angle moved by the servo motor is the angle of motion of each joint. The angle moved by the wearer's arm joints were measured through a projection of a protractor on the wall. The user made these movements against this projection and required angles were noted. The human arm limits the elbow's motion between 0 to 135 degrees, the wrist's yaw to 45 to 135 degrees, and the wrist's pitch to 10 to 170 degrees. The human flexion and extension motion extend beyond 180 degrees, but the system limits them to 180 degrees, as shown in Fig. 6. The figure shows the limitation of each wrist joints' motion and the elbow motion.

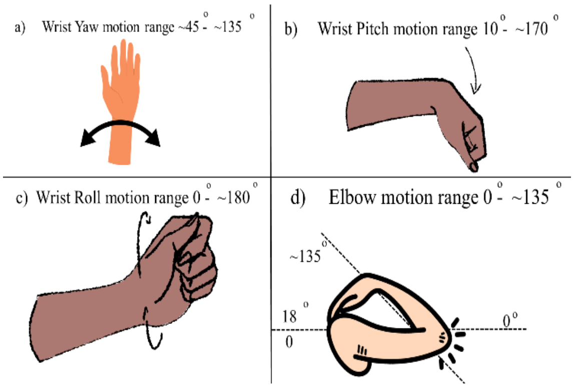

Fig. 6. Illustration of wrist motion

Figure 7 shows the graph representing the angles obtained in the elbow joint and the shoulder's flexion, abduction and rotation joints represented as shoulder x, y, and z. Figure 8 shows the graph representing the angles obtained in the wrist's yaw pitch and roll motion. The robotic arm movement and the user's arm movement was observed. The readings collected, were used to plot the graphs shown in figures 7 and 8. These two graphs show that obtained results are linear and provide accurate movements.

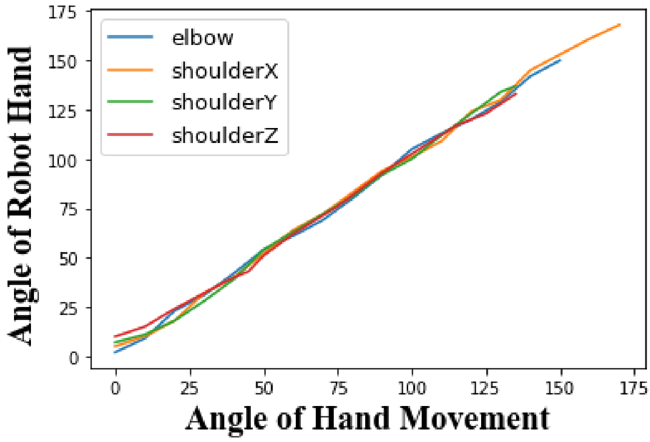

Fig. 7. Graph representing the Angle of the robot hand against the Angle of the upper hand movement

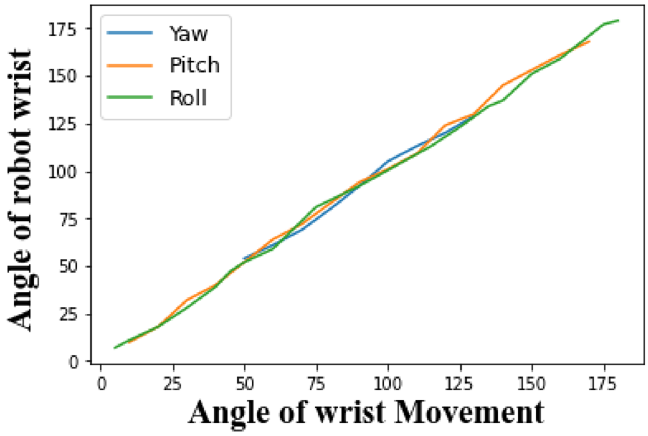

Fig. 8. Graph representing the Angle of the robot hand against the Angle of wrist movement

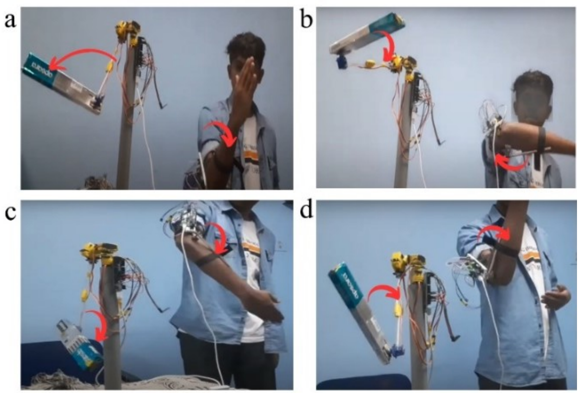

Fig. 9. Actions mimicked by the robot: a) Elbow motion b) internal rotation of the shoulder c) Internal rotation d) Flexion motion

An experimental analysis was conducted in this proposed work to test the sensory band's ability to recognize repetitive human motions. The sensory band was tested against the robot's action to ensure that the robot repeated the exact action of the wearer. The sensory band was linked to the robot, and the wearer performed various regular motions. The acceptable performance of the robotic arm was ensured by comparing the sensory band's repeatability and the robot's response. Fig. 9 and Fig. 13 show a user wearing the sensory and band testing out the Robotic arm. Figure 9 shows how the user can manipulate the robotic arm to move along with the elbow motions. Fig 9b and 9c show the robot mimicking the internal and external rotation of the shoulder. Figure 9d shows the Flexion motion of the user. Figure 13 shows the robot mimicking the wrist motion. The wrist motion includes the wrist yaw, wrist pitch and wrist roll. The robot was able to mimic the user's motion through the sensory band with minimal deviation.

TABLE II. SUMMARY OF REPEATABILITY METRICS

	Standard Deviation	Variance	Average Error	Mode (Degrees)
Shoulder flexion	0.78	0.61	0.98%	177
Shoulder Abduction	1.72	2.99	0.51%	133
Shoulder Rotation	1.39	1.94	1.06%	134
Wrist Yaw	1.88	3.5	1.02%	136
Wrist Pitch	1.09	1.2	1.21%	170
Wrist Roll	0.79	0.63	0.62%	178
Elbow	1.37	1.87	0.55%	134

While validating, the end angles of each of the seven motions were repeated 100 times to ensure repeatability, and the response of the robotic arm regarding servo motors' motion was recorded. The number of times tested against the equivalent servos' response is plotted in Fig. 10, 11, and 12. As the graphs represent, the deviation is negligible, and the results are consistent throughout the graph. The variance and standard deviation of the system are calculated as shown in Table 1. The table shows that the standard deviation is less than 2 for all the joint movement. The average error also doesn't exceed 1.5 %. These metrics show that the sensory band's repeatability is appreciable.

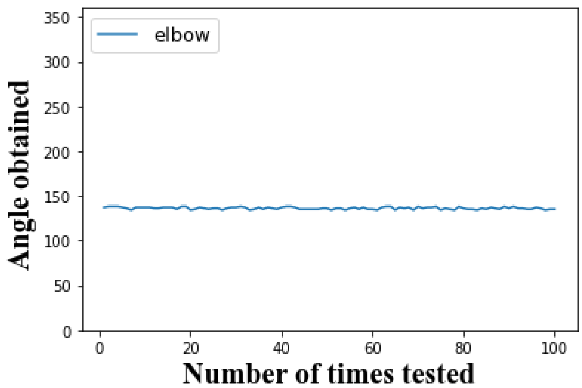

Fig. 10. Graph representing the repeatability of the elbow's motion

Figure 10 represents a graph that shows the repeatability of the elbow movement. As the graph shows, the angle is close to 135 degrees with a minute error. The average error is 0.55% and the mode of the 100 readings is 134.

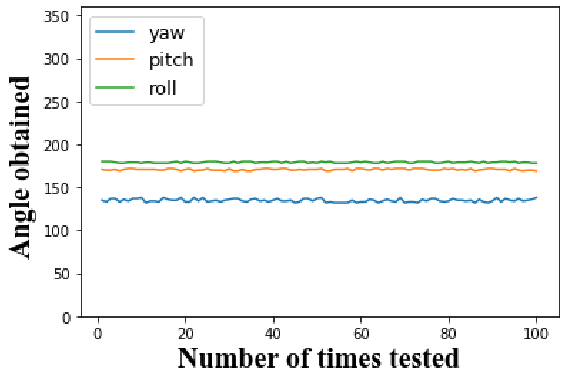

Fig. 11. Graph representing the repeatability of the wrist's motion

Figure 11 represent a graph that shows the repeatability of the wrist's yaw, pitch and roll motion. The number of times the readings was collected is plotted against the collected readings. The average for the yaw, pitch and roll is 1.02%, 1.21%, and 0.62% respectively, and the mode of the 100 readings is 136.170. and 178 respectively.

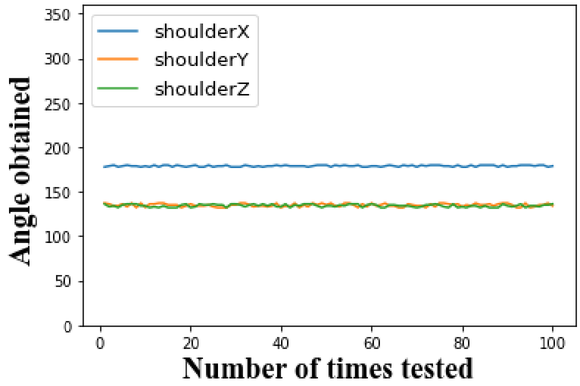

Fig. 12. Graph representing the repeatability of the shoulder motion

Figure 12 represent a graph that shows the repeatability of the shoulder's flexion, abduction and rotation motion as shoulder x, y and z respectively. The number of times the readings was collected is plotted against the collected readings. The average for the yaw, pitch and roll is 1.02%, 1.21%, and 0.62% respectively, and the mode of the 100 readings is 136.170. and 178 respectively.

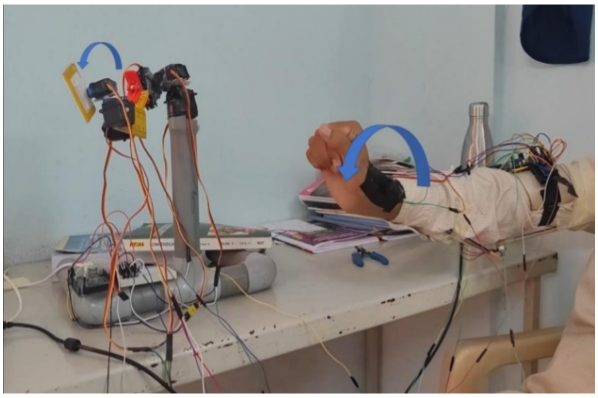

Fig. 13. Actuators mimicking wrist movements

VII. LIMITATIONS

Though the proposed model is useful in various ways, there were certain places where the model could be improved. The sensory band was only able to detect 180 degrees of the motion Flexion and Extension motion as shown in Figure 5, whereas the human shoulder is capable of around 200 degrees of rotation in that motion. The system doesn't have a mobile power system that reduces the mobility to certain extent. The sensors were connected through wires which have the disadvantage of getting disconnected in tough situations or through wear and tear. A future upgrade could include the use of printed circuit boards along with wires to improve the durability and sleekness and portable power system to enhance mobility.

VIII. CONCLUSION

This work presents the design for a sensory system and a robotic arm that can be controlled through the sensory system. The objective was to design a weightless and minimalistic sensory band that individuals could wear to analyse their arm motions, orientations, and limitations. This sensory band could be a model to control co-bots and analytic systems requiring direct human arm reading or control. The sensory band was linked to the robotic arm, and the repeatability was appreciable. The robotic arm mimicked the wearer's motions effectively, and the system worked conveniently. The average error for the joints was below 2%, exhibiting appreciable repeatability. Though the sensory system was expected to sense all motions of a human arm, the far ends of the flexion and extension motions were not captured by the sensory system. The sensory band was sleek and comfortable to wear though the comfort level can be improved in future iterations. Future works will include developing a compact sensory system that athletes and medical personnel could wear with their regular gear to analyse their motion.

REFERENCES

[1] Y. Zhang, P. D. Haghighi, F. Burstein, L. Yao, and F. Cicuttini, "On-Device Lumbar-Pelvic Movement Detection Using Dual-IMU: A DNN-Based Approach," *IEEE Access*, vol. 9, pp. 62241–62254, 2021, doi: 10.1109/ACCESS.2021.3074755.

[2] Y. Peng *et al.*, "A Flexible Dual-Modal Sensing System for Synchronous Pressure and Inertial Monitoring of Finger Movement," *IEEE Sens J*, vol. 21, no. 9, pp. 10483–10490, May 2021, doi: 10.1109/JSEN.2021.3060318.

[3] C. Yi *et al.*, "Detecting and Correcting IMU Movements During Joint Angle Estimation," *IEEE Trans Instrum Meas*, vol. 71, pp. 1–14, 2022, doi: 10.1109/TIM.2022.3167771.

[4] Y. Cho, H. Cho, and C.-M. Kyung, "Accurate and Robust Walking Speed Estimation With Adaptive Regression Models for Wrist-Worn Devices," *IEEE Sens J*, vol. 20, no. 18, pp. 10744–10755, Sep. 2020, doi: 10.1109/JSEN.2020.2994616.

[5] R. Stanzani, P. Dondero, A. Mantero, and M. Testa, "Measurement Accuracy of an Upper Limb Tracking System Based on Two Hillcrest Labs BNO080 IMU Sensors: An Environmental Assessment," *IEEE Sens J*, vol. 20, no. 17, pp. 10267–10274, Sep. 2020, doi: 10.1109/JSEN.2020.2992733.

[6] T. Li and H. Yu, "Upper Body Pose Estimation Using a Visual–Inertial Sensor System With Automatic Sensor-to-Segment Calibration," *IEEE Sens J*, vol. 23, no. 6, pp. 6292–6302, Mar. 2023, doi: 10.1109/JSEN.2023.3241084.

[7] L. Fiorini *et al.*, "Daily Gesture Recognition During Human-Robot Interaction Combining Vision and Wearable Systems," *IEEE Sens J*, vol. 21, no. 20, pp. 23568–23577, Oct. 2021, doi: 10.1109/JSEN.2021.3108011.

[8] J. Marina-Miranda and V. J. Traver, "Head and Eye Egocentric Gesture Recognition for Human-Robot Interaction Using Eyewear Cameras," *IEEE Robot Autom Lett*, vol. 7, no. 3, pp. 7067–7074, Jul. 2022, doi: 10.1109/LRA.2022.3180442.

[9] G. Ponraj and H. Ren, "Sensor Fusion of Leap Motion Controller and Flex Sensors Using Kalman Filter for Human Finger Tracking," *IEEE Sens J*, vol. 18, no. 5, pp. 2042–2049, Mar. 2018, doi: 10.1109/JSEN.2018.2790801.

[10] N. T. Muralidharan, Rahul Ram S., Rohidh M. R., Senthil Nadhan M., and Harikumar M. E., "Modelling of Sign Language Smart Glove Based on Bit Equivalent Implementation Using Flex Sensor," in *2022 International Conference on Wireless Communications Signal Processing and Networking (WiSPNET)*, IEEE, Mar. 2022, pp. 99–104. doi: 10.1109/WiSPNET54241.2022.9767137.

[11] H. Su, T.-H. Kim, H. Moeinnia, and W. S. Kim, "A 3-D-Printed Portable EMG Wristband for the Quantitative Detection of Finger Motion," *IEEE Sens J*, vol. 23, no. 7, pp. 7895–7901, Apr. 2023, doi: 10.1109/JSEN.2023.3247695.

[12] A. Balachandran, C. Nutakki, S. Bodda, B. Nair, and S. Diwakar, "Experimental Recording and Assessing Gait Phases Using Mobile Phone Sensors and EEG," in *2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, IEEE, Sep. 2018, pp. 1528–1532. doi: 10.1109/ICACCI.2018.8554790.

[13] Akhila Padmanabhan Nayer, Devika M, Balamurali P, Nandagopal S, Sreenidhi P R, and Baby Sreeja S D, "Skin Mimicked Sliding Triboelectric Sensor to Detect Caressing Touch for Prosthetic Users," in *2021 5th International Conference on Trends in Electronics and Informatics (ICOEI)*, IEEE, Jun. 2021, pp. 812–820. doi: 10.1109/ICOEI51242.2021.9452891.

[14] K. Nizamis *et al.*, "Transferrable Expertise From Bionic Arms to Robotic Exoskeletons: Perspectives for Stroke and Duchenne Muscular Dystrophy," *IEEE Trans Med Robot Bionics*, vol. 1, no. 2, pp. 88–96, May 2019, doi: 10.1109/TMRB.2019.2912453.

[15] A. Tognetti, F. Lorussi, N. Carbonaro, and D. de Rossi, "Wearable Goniometer and Accelerometer Sensory Fusion for Knee Joint Angle Measurement in Daily Life," *Sensors*, vol. 15, no. 11, pp. 28435–28455, Nov. 2015, doi: 10.3390/s151128435.

[16] Y. Wang, S. Cang, and H. Yu, "A Data Fusion-Based Hybrid Sensory System for Older People's Daily Activity and Daily Routine Recognition," *IEEE Sens J*, vol. 18, no. 16, pp. 6874–6888, Aug. 2018, doi: 10.1109/JSEN.2018.2833745.

[17] L. Sbernini, L. R. Quitadamo, F. Riillo, N. Di Lorenzo, A. L. Gaspari, and G. Saggio, "Sensory-Glove-Based Open Surgery Skill Evaluation," *IEEE Trans Hum Mach Syst*, vol. 48, no. 2, pp. 213–218, Apr. 2018, doi: 10.1109/THMS.2017.2776603.

[18] S. Potluri, S. Ravuri, C. Diedrich, and L. Schega, "Deep Learning based Gait Abnormality Detection using Wearable Sensor System," in *2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, IEEE, Jul. 2019, pp. 3613–3619. doi: 10.1109/EMBC.2019.8856454.

[19] Nair B. B. and Sakthivel N. R., "A Deep Learning-Based Upper Limb Rehabilitation Exercise Status Identification System," Arab J Sci Eng, vol. 48, no. 4, pp. 1237-1271, 2023. doi: 10.1007/s13369-022-06702-y.

[20] R. Kristof, V. Ciupe, C. Moldovan, I. Maniu, M. Banda, and A.-M. Stoian, "Arduino mobile robot with Myo Armband gesture control," in *2019 IEEE 13th International Symposium on Applied Computational Intelligence and Informatics (SACI)*, IEEE, May 2019, pp. 000294–000297. doi: 10.1109/SACI46893.2019.9111627.

[21] S. Noor *et al.*, "Real time hand movement controlled robotic arm for risk prevention," in *2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*, IEEE, Dec. 2017, pp. 465–469. doi: 10.1109/R10-HTC.2017.8289000.

[22] J. P. Gomez-Arrunategui, J. J. Eng, and A. J. Hodgson, "Monitoring Arm Movements Post-Stroke for Applications in Rehabilitation and Home Settings," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 30, pp. 2312–2321, 2022, doi: 10.1109/TNSRE.2022.3197993.