International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 3s,2025
https://theaspd.com/index.php

# Sensor-Based Control Of A Robotic Prosthetic Limb

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***Abstract***
*Robot anthropomorphism and precision are improved by teleoperation technology. In order to improve overall control and effectiveness, perception technology—especially multimodal sensor systems with tactile feedback—is essential for giving operators a greater grasp of the robot's condition and environment. It is used more often in medical rehabilitation, such as when prosthetic hand sensors trigger nerves to produce natural touch. Robot finger pads with tactile sensors can sense pressure from the outside, facilitating accurate engagement. Anthropomorphism is still difficult to achieve, though, especially when it comes to recognizing human motion and incorporating it into the robot's decision-making process, which is essential for smooth control and human-like functionality. The complex biomechanical structure of the human arm, which includes flexible joints and multiple degrees of freedom, enables people to perform a variety of challenging tasks. In order to achieve anthropomorphic control and replicate human-like movements, precise kinematic mapping is crucial because robotic arms frequently have rigid constructions and few degrees of freedom. Its solution plays a key role in increasing the versatility of robotic arms in many applications.*
***Keywords:*** *sensor fusion, anthropomorphic, control, robotic arm.*

## 1. INTRODUCTION

Because of its many uses in virtual reality, industrial automation, medical rehabilitation, and hazardous environment operations, remote-controlled manipulators have attracted research attention in the last ten years [1].

These systems enable teleoperation or anthropomorphic control by precisely transmitting operator movements to manipulators through the use of sensors and control algorithms [2]. Researchers like Lorenzo Scalera have investigated cutting-edge interfaces that let users operate robots with their eyes, using eye-tracking sensors. proposed using motion capture suits and digital tablets to control a tele-robot that would paint portraits with even, fluid strokes [9]. Additionally, the greatest platform for humanistic control is humanoid robots. Humanoid upper-limb robots are flexible and adaptive, which makes them appropriate for a range of uses. Drones with pliable robotic arms for airborne maneuvers are one example. An upper-limb robot's adaptability can be increased by integrating it onto a mobile platform to enable anthropomorphic control [3].

## 2. REVIEW OF LITERATURE

Teleoperation technology allows for humanistic control by fusing robotic accuracy, speed, and reproducibility with human flexibility and cognition [10]. Systems that use assistive robots like NAO in conjunction with gadgets like Nintendo Switch controllers, Kinect V2, Meta Quest glasses, and IMU-based control techniques for remote robotic arm operation are examples of recent developments [13][5].

Accurate arm pose estimation is made possible by vision-based sensors such as the Microsoft Kinect and Leap Motion Controller, which measure posture, identify multiple arm joints, and monitor movement trajectories[4]. In a variety of applications, these technologies are being investigated to provide precise and seamless control. Electromyography (EMG) and other myoelectric-based sensors provide accurate and instantaneous muscle activity assessment. However, it can be difficult to create a complete arm kinematics model with only one modality; multimodal sensor integration is frequently necessary for precise tracking and control. Myoelectric sensors can readily detect hand movements, while vision sensors have trouble detecting wrist and finger movements since hand motion is typically modest. Myoelectric sensors assess muscle activity, whereas visual sensors immediately track important joints like the elbows and shoulders. For complex situations, combining numerous sensors improves accuracy, robustness, and applicability by allowing for full kinematic models of the entire arm, including the hands, wrists, elbows, and shoulders. To confirm the efficacy of their techniques, researchers have employed data gloves/belts to measure exact joint motions and IMU with Kinect for upper limb rehabilitation. However, research into using IMU to operate robot arms anthropomorphically is still ongoing. Additionally, we have done analogous work to integrate data gloves with Kinect [11].

We obtained very precise estimations of these joint angles by successfully fusing data from many sources, including Kinect and IMU sensors, using Kalman filters[6]. Smooth robotic arm movement is made possible by the fusion process, which improves accuracy and flexibility. In order to achieve great dexterity and precision, especially in gripping motions, the robotic hand can imitate human gestures by using data gloves to record comprehensive joint data (shoulder, elbow, wrist, and fingers).

## 3. MATERIALS AND METHODS

A robotic arm with a dexterous hand and five degrees of freedom—two shoulder joints, two elbow joints, and one wrist joint—is used by the system. Because of this configuration, the robotic hand can move and control precisely, completing complex tasks.

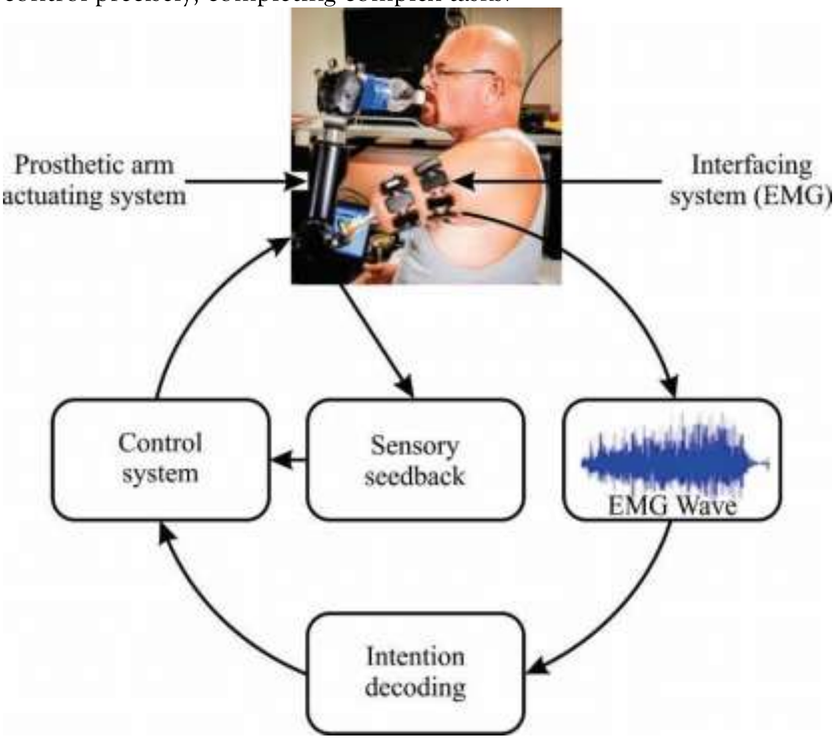



**Figure 1: proposed design**

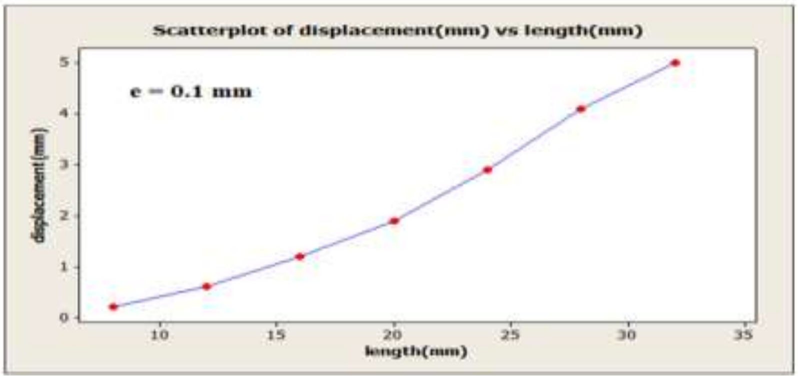
Two STM32 controllers with extension boards are part of the control system, and the remote host uses a variety of protocols to get data from the motion tracking components: USB 3.0 for the Kinect, Bluetooth BLE 5.0 for the IMU system, and LAN for the data glove. The robot host and control system communicate with each other using TCP/IP. Coordinated robot movement is made possible by the remote host processing and fusing data, broadcasting upper limb joint angles to the ROS (Robot Operating System) network. The fingertip pressure is transmitted via UDP/IP to the remote host from the manipulator's tactile feedback.

By projecting human motion postures onto the robot, incorporating automation and intelligence for a variety of applications, and attaining a high degree of intuitive control, the technology makes it possible for the robot arm to be controlled similarly to a human. With its many potentials uses in industry, medical treatment, and specific environment sensing, this system opens up new avenues for robotics advancement. To put it briefly, the IMU can record more delicate movements. The IMU can detect shoulder rotation because of its great sensitivity. Arm posture affects the Kinect's accuracy; for example,

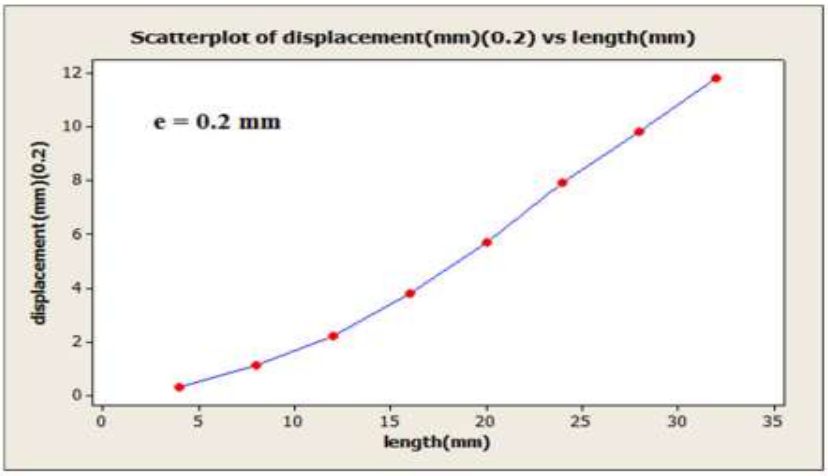
a bent elbow allows for greater shoulder roll tracking, whereas an extended arm limits shoulder rotation tracking. Overall tracking accuracy is improved by the system's ability to estimate joint angles more precisely and consistently by merging Kinect and IMU data. By offsetting the limits of individual sensors, combining data from several sensors improves system reliability and resilience. For robotic arms to be anthropomorphically controlled, human movements—from delicate hand gestures to wide upper body motions—must be accurately replicated [15].
The test evaluated how well the anthropomorphic control system replicated delicate hand motions, including pouring and grabbing [12]. The data glove allowed for precise control and human-like movement mimicking by measuring the angles of the fingers, thumb, and wrist. Both thumb bending angle rotation and thumb bending angle rotation were mapped to make the dexterous hand easier to use [8]. Since the robotic arm's wrist servo can rotate 180 degrees, the wrist rotation angle's starting value at neutral is zero degrees. To make mapping onto the robotic arm easier, a range of values was selected for the wrist rotation angle. Pronation was represented by an angle that grew from 0 to 90 degrees as the wrist pronated, which corresponded directly to the movement of the mechanical arm [14]. The robotic arm rotated externally with an angle change of -90 to 0 degrees, mimicking the action of a human wrist. The control system's great operability and adaptability for precise hand movement control are demonstrated by the stable data.

## 4. RESULT AND DISCUSSION

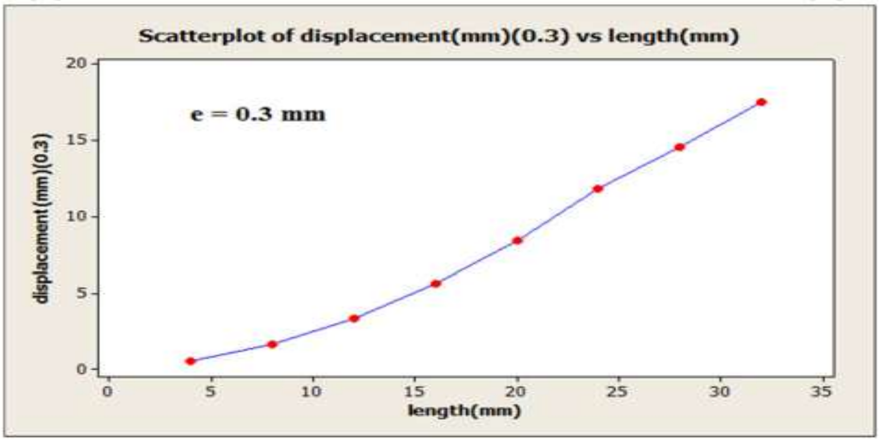
The trajectory of the robotic arm mimics particular motions, such picking up and dropping a water bottle. With its low latency (0.05s) and pressure feedback via tactile fingertip sensors, the system allows for precise control and interaction. The index finger's pressure value rose to more than 104×1/3000 N when the finger was bent, as shown in Figure 19b. The manipulator is uncontrollable if the pressure exceeds a particular threshold. The control returns when the pressure falls below this specific threshold.




(a)




(b)




(c)

**Figure 2: performance plot**

The ability of the anthropomorphic control system to replicate human-like movements was demonstrated when it accomplished grabbing tasks with accuracy and security while steadily arriving at target locations. The technology's promise for technical applications requiring accuracy, such industrial production and warehousing management, is demonstrated by the experiment's success. It creates a strong basis for next studies and uses, opening the door for robotics breakthroughs.

The Kalman filter we created integrates two sensors, which smoothes the fusion result while still allowing for mobility in the shoulder joint's three axes. The fusion method decreased jitter and increased the robotic arm's smoothness of movement. But for best results, it necessitates rigorous movement standardization and control, usually restricting the arm's range of motion to a single quadrant.

## 5. CONCLUSION

Using multi-sensor data fusion, this study successfully created an anthropomorphic control system that replicates human-like movement and allows for high-precision control of a robotic arm. The testing findings confirm the system's strong performance and wide range of potential applications. This article makes a significant contribution to the fields of robot control and multisensory fusion. In order to meet the growing demands of automation and cooperation, future work will continue to expand the application sectors and optimize system performance. We list potential avenues for future development in view of the aforementioned limitations. Future research can focus on improving sensor fusion methods for enhanced precision and optimizing sensor placement or exploring advanced fusion algorithms to address quadrant-specific inaccuracies, ultimately increasing the system's overall accuracy. Additionally, we can enhance the control system's response time and data collecting speed for quick movements or changes, allowing the system to adapt to the operator's needs more quickly. The anthropomorphic control system will function better and be easier to use as a result of all these improvements. Additionally, in order to further improve the system and reduce costs while increasing scalability, we want to design unique glove sensors in the future. Our specific needs will guide the creation of this homemade glove sensor, which will better meet the anthropomorphic control system's performance requirements. Robots of many types can be controlled by human motion tracking systems. Flexible grasping tasks are made possible by the extension of the motion tracking system to control soft robotic arms and graspers. Human joint movements (shoulders, elbows, and wrists) can be mapped to target parameters for a multi-segment soft robotic arm using a relationship model, resulting in anthropomorphic postures. To make gripping more convenient, the adaptive grippers allow the gripper structure to be moved by bending the finger to open or close the gripper. The human body can be operated remotely in a wide variety of ways and is more convenient and user-friendly.

**REFERENCES**

1. McGhee, R. B. "Future prospects for sensor-based robots." In Computer Vision and Sensor-Based Robots, pp. 323-334. Boston, MA: Springer US, 1979.
2. Wei-Liang, C., & Ramirez, S. (2023). Solar-Driven Membrane Distillation for Decentralized Water Purification. Engineering Perspectives in Filtration and Separation, 1(1), 16-19.
3. Miller, W. "Sensor-based control of robotic manipulators using a general learning algorithm." IEEE Journal on Robotics and Automation 3, no. 2 (2003): 157-165.
4. Gonzalez, M., & El-Sayed, A. (2024). Impact of Terminology Standardization on Diagnostic Consistency in Multicenter Studies. Global Journal of Medical Terminology Research and Informatics, 2(1), 13-15.
5. Deng, Hua, Xiaolei Xu, Wendi Zhuo, and Yi Zhang. "Current-sensor-based contact stiffness detection for prosthetic hands." IEEE Access 8 (2020): 29456-29466.
6. Supriya, S., & Dhanalakshmi, K. (2024). Review of Task Offloading and Dynamic Scheduling Methods in Edge-Cloud Computing. International Journal of Advances in Engineering and Emerging Technology, 15(1), 13–18
7. Gaetani, F., R. De Fazio, G. A. Zappatore, and P. Visconti. "A prosthetic limb managed by sensors-based electronic system: Experimental results on amputees." Bulletin of Electrical Engineering and Informatics 9, no. 2 (2020): 514-524.
8. Rathore, N., & Shaikh, A. (2023). Urbanization and Fertility Transitions: A Comparative Study of Emerging Economies. Progression Journal of Human Demography and Anthropology, 1(1), 17-20.
9. Kruse, Daniel, John T. Wen, and Richard J. Radke. "A sensor-based dual-arm tele-robotic system." IEEE Transactions on Automation Science and Engineering 12, no. 1 (2014): 4-18.
10. Baggyalakshmi, N., Harrsini, M. S., & Revathi, R. (2024). Smart Billing Software. International Academic Journal of Innovative Research, 11(1), 51–60. https://doi.org/10.9756/IAJIR/V11I1/IAJIR1106
11. Cherubini, Andrea, and David Navarro-Alarcon. "Sensor-based control for collaborative robots: Fundamentals, challenges, and opportunities." Frontiers in Neurorobotics 14 (2021): 576846.
12. Thanoon, S. R. (2024). Application of the Proposed Technique to Estimate the Bivariate Gamma Model. International Academic Journal of Science and Engineering, 11(1), 19–24. https://doi.org/10.9756/IAJSE/V11I1/IAJSE1104
13. Weiss, L. E. E. E., A. R. T. H. U. R. C. Sanderson, and C. H. A. R. L. E. S. P. Neuman. "Dynamic sensor-based control of robots with visual feedback." IEEE Journal on Robotics and Automation 3, no. 5 (1987): 404-417.
14. Rao, I., & Saxena, M. (2025). Exploring the Connections of the Mental Health and Sustainability. International Journal of SDG's Prospects and Breakthroughs, 3(1), 8-14.
15. Kermorgant, Olivier, and François Chaumette. "Dealing with constraints in sensor-based robot control." IEEE Transactions on Robotics 30, no. 1 (2013): 244-257.