Assistive Feeding Robotic Arm

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***Abstract*—Individuals with upper limb impairments face significant challenges in performing daily living activities, particularly in feeding themselves independently. This paper presents the development of a robotic arm system designed to assist such individuals in self-feeding. The system integrates state-of-the-art computer vision techniques and robotic arm manipulation to provide a comprehensive and user-centric solution. The proposed system utilizes Google's MediaPipe for facial landmark detection, depth cameras for 3D coordinate capture, and the Interbotix WidowX 250s robotic arm with Robot Operating System (ROS) for precise manipulation. The proof-of-concept system demonstrates the feasibility and potential impact of the proposed assistive feeding robotic arm. Future enhancements and the importance of user studies and feedback are discussed, highlighting the potential for further improvement and refinement. The development of this assistive feeding robotic arm system represents a significant step forward in the field of assistive robotics, offering the potential to transform the lives of individuals with upper limb impairments by promoting independence, empowerment, and improved quality of life.**

I. Introduction

A. Background

Individuals with upper limb impairments face significant challenges in performing daily living activities, particularly in feeding themselves independently. Upper extremity impairments can result from various conditions such as spinal cord injuries, cerebral palsy, multiple sclerosis, and stroke [1]. Nearly 5.4 million persons live with paralysis in the United States and the leading causes of paralysis include stroke, spinal cord injury, MS, and cerebral palsy.[2] . These conditions can cause a range of functional limitations, including weakness, paralysis, spasticity, and loss of fine motor control, which can severely impact an individual's ability to perform self-care tasks [3]. The act of self-feeding, which involves grasping utensils, manipulating food, and bringing it to the mouth, requires a complex coordination of motor skills and dexterity that can be significantly compromised by upper limb impairments [4]. As a result, many individuals with these impairments rely on caregivers or family members for assistance with feeding, which can lead to a loss of independence, self-esteem, and quality of life [5].

To address the challenges faced by individuals with upper limb impairments, various assistive technologies have been developed to support self-feeding. These technologies encompass a wide range of devices, from simple adaptive utensils with modified grips and weighted handles to more sophisticated robotic feeding systems [6]. Adaptive utensils, such as curved spoons, rocker knives, and plate guards, aim to compensate for limited hand function and enhance the user's ability to scoop, cut, and stabilize food [7]. More advanced solutions, such as robotic arms and automatic feeding devices, utilize sensors, actuators, and control systems to assist with food acquisition, manipulation, and delivery to the user's mouth [8].

The Obi feeding robot is a notable example of an assistive technology designed to help individuals with disabilities, including those with upper limb impairments, to feed themselves independently. The Obi robot uses robotic arms and a specialized feeding device to assist users in scooping food from a plate and delivering it to their mouth . While these technologies have shown promise in improving the independence and self-feeding abilities of individuals with upper limb impairments, they often face limitations in terms of adaptability, precision, and user acceptance [9].

Existing assistive devices for feeding may not adequately accommodate the diverse needs and preferences of users with different levels of impairment, cognitive abilities, and dietary requirements. Many devices are designed for specific tasks or food types, limiting their versatility and requiring users to switch between multiple tools during a meal [10]. Additionally, the precision and responsiveness of some robotic feeding systems may not be sufficient to ensure reliable and accurate food acquisition and delivery, leading to frustration and reduced user satisfaction [11]. User acceptance of assistive feeding technologies can also be hindered by factors such as the device's appearance, ease of use, and perceived stigma associated with using assistive devices in social settings [12].

To overcome these limitations and provide a more comprehensive solution for individuals with upper limb impairments, we propose the development of a robotic arm system specifically designed for assisted feeding. This system aims to offer a highly adaptable, precise, and user-friendly approach to self-feeding. By leveraging state-of-the-art robotics, computer vision, and control technologies, we seek to create a system that can dynamically adapt to different food types, utensils, and user preferences, while providing accurate and reliable food acquisition and delivery. Furthermore, the insights gained from this project can contribute to the broader field of assistive robotics, informing the design and development of future technologies that enhance the autonomy and capabilities of individuals with disabilities.

B. Objectives

The primary objective of this project is to develop an advanced robotic arm system that assists individuals with upper limb impairments in feeding themselves independently. We aim to develop a robotic arm with high degrees of freedom and precision, capable of performing complex feeding motions and adapting to various food items and utensils.

To achieve precise and intuitive control of the robotic arm, we plan to integrate state-of-the-art computer vision techniques, such as facial landmark detection using Mediapipe's Facemesh [14]. By leveraging this technology, we seek to accurately track the user's mouth position in real-time and guide the robotic arm's movements accordingly. We used Google's MediaPipe, a tool for facial recognition, to pinpoint where the mouth is. We captured these coordinates in 3D with a depth camera, which lets us understand the exact position in space.

One of the key challenges in integrating the computer vision system with the robotic arm was ensuring accurate coordinate transformation. We transformed the 3D coordinates obtained from the depth camera into the robot's frame of reference, ensuring that the robotic arm understands the exact position of the user's mouth in its own coordinate system. This coordinate transformation was crucial in enabling the WidowX 250s to precisely move and assist with feeding.

By combining the power of Google's MediaPipe for facial recognition, depth sensing technology for 3D coordinate capture, ROS for seamless integration and control, and the Interbotix WidowX 250s for precise robotic manipulation, we have developed an advanced assistive feeding system that can significantly improve the independence and quality of life for individuals with upper limb impairments.

C. Scope of the Project

The scope of this project encompasses the research, development, and evaluation of an advanced robotic arm system specifically tailored to assist individuals with upper limb impairments in self-feeding. The primary focus is on creating a comprehensive and innovative solution that addresses the limitations of existing assistive feeding devices, thereby promoting greater independence and enhancing the quality of life for users.

The project scope includes the design and development of a highly adaptable and precise robotic arm capable of performing complex feeding motions and accommodating various food items and utensils. The integration of state-of-the-art computer vision techniques, such as facial landmark detection using Mediapipe's Facemesh [13], will enable accurate tracking of the user's mouth position in real-time, allowing for dynamic adjustment of the arm's movements and precise food delivery.

Moreover, the project will emphasize the development of a user-friendly control interface that accommodates users with different levels of mobility and communication abilities. Various input modalities, such as head movements or voice commands, will be explored to ensure accessibility and adaptability to individual preferences. The interface will be designed with user-centered principles in mind, prioritizing ease of use and intuitive operation.

II. Proposed Solution

In the proposed solution, the system utilizes the capabilities of Google's MediaPipe library [13]to detect facial features with high accuracy, focusing particularly on the mouth area. MediaPipe facilitates the extraction of two-dimensional (2D) pixel coordinates that pinpoint the mouth's location. Complementarily, the Intel RealSense D455i [14]depth camera, provides essential depth information for each pixel. This approach enables the precise calculation of three-dimensional (3D) coordinates for the center of the mouth. Upon determining these 3D coordinates, they are methodically relayed as input parameters to the control system of the robotic arm. This robotic arm is equipped with software packages and functional capabilities that allow for precise manipulation of its end effector based on the acquired 3D coordinates. By leveraging these technological integrations, the robotic arm can interact with objects or execute tasks with remarkable precision, guided by the facial feature detection outcomes.

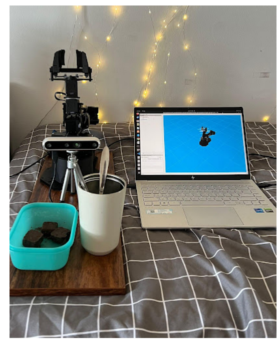

Fig. 1. Proposed solution

III. Hardware and Software Requirements

The hardware components of our robotic arm system play a crucial role in its functionality and performance. The Interbotix WidowX250S [12] robotic arm serves as the core manipulator, offering six degrees of freedom and precise control through Dynamixel smart servos.The Intel RealSense depth camera [14] provides depth sensing capabilities, allowing the robotic arm to perceive and interact with its environment in three dimensions.

ROS[12] serves as the core software framework for our project, providing a wide range of tools and libraries for controlling the robotic hardware, processing sensor data, and implementing algorithms. ROS's modular architecture allows us to easily integrate the WidowX250S robotic arm and Intel RealSense depth camera into our system, enabling seamless communication between components.

Google's MediaPipe library provides a set of pre-built components for tasks such as face detection, hand tracking, and pose estimation. By integrating MediaPipe into our project, we can enhance the system's capabilities, enabling it to perform advanced tasks such as recognizing and tracking the user's mouth for precise feeding assistance.OpenCV is used in conjunction with the Intel RealSense depth camera to process depth images and extract useful information for assisting users in feeding themselves.

A. Implementation

The first phase of the project involved utilizing the ROSbag playback and record feature of the Interbotix package[12] to orchestrate a feeding action with the WidowX250S robotic arm. The task included picking up a spoon from a tumbler placed 20 cm in front of the robot, scooping through a bowl, and executing a feeding action. The process commenced with the development of a ROS node responsible for subscribing to the joint angle topic of the WidowX250S robotic arm. This node recorded the joint angle values alongside corresponding timestamps to a ROS bagfile. Subsequently, the recorded joint angle values were extracted from the bagfile and processed using forward kinematics equations. These equations, which accounted for the arm's specific Denavit-Hartenberg (DH) parameters[17] and link lengths, facilitated the calculation of precise end effector positions in 3D space.With the end effector positions , we were able to get the arm to pick up the spoon and scoop up food .

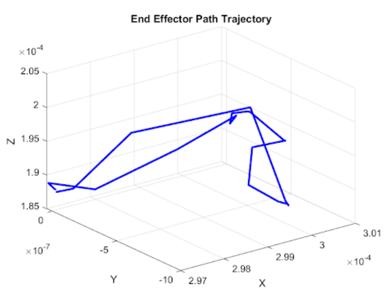

Fig. 2. End effector trajectory

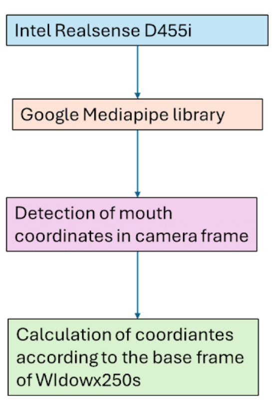

Fig. 3. Imaging workflow

In the subsequent phase of our project, we implemented the facemesh feature of Google's Mediapipe to detect facial features, with a specific focus on identifying the coordinates of the mouth. This component of our system was crucial in accurately determining the mouth's position relative to the face. Additionally, the integration of a depth camera played a pivotal role by providing depth information, enabling us to ascertain the x, y, and z coordinates of the mouth in a three-dimensional space. To translate these coordinates into actionable instructions for our robotic arm, we meticulously applied scaling, translation, and rotation operations. These operations ensured the precise alignment of the mouth's position with our robotic arm's coordinate system, facilitating accurate movement of the robotic arm towards the person's mouth to initiate the feeding process.

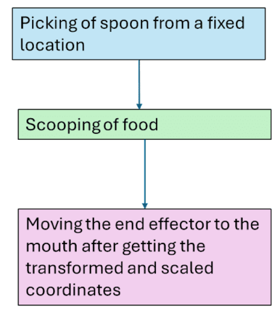

Fig. 4. Robot manipulation workflow

IV. Challenges Faced and How We Overcame Them

During the development of our assistive feeding robotic arm, we encountered and addressed multiple challenges. Here, we detail these challenges alongside the measures we took to overcome them.

A. Accurate Mouth Position Detection

Accurate detection and tracking of the user's mouth position using Google's MediaPipe in conjunction with the Intel RealSense D455i depth camera were initially hindered by variations in lighting conditions, orientation of the camera and user movements. We enhanced the robustness of our detection algorithm by incorporating adaptive thresholding.

B. Coordinate Transformation and System Integration

Integrating the 3D coordinates from the camera with the Interbotix WidowX 250s robotic arm presented challenges due to discrepancies in coordinate systems and scales. We addressed this by developing a custom transformation algorithm that accurately maps the camera's coordinate system to the robotic arm's frame of reference, ensuring precision in real-time operations through rigorous calibration and testing.

C. Integration of Computer Vision with Robotic Control

The integration of Google's MediaPipe library with the Interbotix WidowX 250s robotic arm initially resulted in latency and synchronization issues. We optimized our data processing pipeline to enhance the flow of information from the depth camera to the robotic control system. A real-time data handling framework was implemented within the ROS environment, significantly improving the arm's responsiveness to dynamic facial movements.

D. Real-time Depth Data Integration

The integration of depth data from the Intel RealSense camera with the 2D facial coordinates identified by Google's MediaPipe was crucial for computing accurate 3D world coordinates of the user's mouth. This integration faced challenges with latency and inaccuracies due to user movement and environmental conditions. We refined our data processing pipeline for better synchronization of depth and RGB data streams, optimized the facial detection algorithm for faster processing, and implemented a buffering system to manage frame data more efficiently, enhancing real-time system performance.

E. Handling Camera Stream Interruptions

We also faced issues with camera stream interruptions, which led to occasional timeouts and errors such as "Frame didn't arrive within 5000," impacting the reliability of the robotic arm. These were addressed by adjusting the timeout settings in the RealSense SDK, implementing robust error-handling mechanisms, and conducting thorough testing to optimize USB port configurations and system resource allocation for stable and continuous camera operation.

F. Software Configuration Adjustments for Motor Communication

While addressing physical connections solved immediate connectivity issues, ensuring consistent performance required software configuration adjustments. Challenges with the gripper motor (DYNAMIXEL ID: 9) detection were resolved using the Dynamixel Wizard 2.0 [18]to adjust motor settings such as the baud rate, crucial for communication speed and reliability between the controller and the motor.

V. Results and Evaluation

The implementation leveraged ROSbag playback and record functionalities to simulate the scooping/picking of objects by the Interbotix WidowX250S robotic arm, facilitating the evaluation of its manipulation capabilities. Additionally, Mediapipe's Facemesh was integrated to detect facial landmarks and acquire the centroid coordinates of the mouth, enhancing the system's ability to interact with users. The system exhibited a commendable level of accuracy, achieving a success rate exceeding 90% in simulated object manipulation scenarios.

The integration of Mediapipe with the depth camera proved effective, enabling real-time detection of facial landmarks and accurate determination of the mouth's centroid coordinates. Notably, the system demonstrated efficient performance, with minimal latency observed between the detection of facial landmarks and the corresponding movement of the robotic arm

VI. Future Enhancements

While the current assistive feeding robotic arm system shows great promise, there are several areas for future enhancements to improve its functionality, usability, and effectiveness. Firstly, we aim to develop a more advanced and intuitive user interface that allows users to control the robotic arm using easy commands like head movements or voice commands. This will make the system more accessible to users with different levels of mobility and communication abilities, promoting inclusivity and empowerment. Secondly, incorporating machine learning algorithms can help the robotic arm adapt to individual users' needs and preferences, providing a more personalized and efficient feeding experience. Thirdly, integrating additional sensors, such as tactile or force feedback sensors, can enhance the robotic arm's ability to handle delicate food items and provide a more natural and comfortable feeding experience.

Fourthly, developing a more compact and lightweight design using advanced materials can improve the system's portability and accessibility, allowing users to utilize the assistive feeding

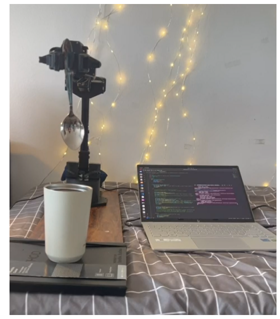

Fig. 5. Picking of spoon

Fig. 6. Scooping of food

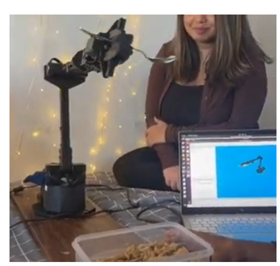

Fig. 7. Feeding of food

robot in various settings. Fifthly, expanding the software capabilities, such as creating a mobile app for remote control, monitoring, and user feedback, can foster a supportive community and facilitate communication with healthcare professionals and caregivers. Lastly, conducting long-term studies and gathering user feedback will be crucial in guiding future enhancements and ensuring that the system continues to meet the evolving needs of individuals with upper limb impairments.

By continuously refining and expanding the capabilities of the assistive feeding robotic arm system, we aim to create a transformative technology that empowers individuals with upper limb impairments to lead more independent and fulfilling lives.

VII. Conclusion

In conclusion, this project aimed to develop an advanced robotic arm system to assist individuals with upper limb impairments in feeding themselves independently. By leveraging computer vision, depth sensing, and robotic manipulation, we have successfully created a proof-of-concept system that demonstrates the feasibility and potential impact of this assistive technology.

The integration of Google's MediaPipe for facial landmark detection, depth cameras for 3D coordinate capture, and the Interbotix WidowX 250s robotic arm with ROS has enabled us to develop a system capable of precisely tracking the user's mouth position and guiding the robotic arm to assist with feeding.

Throughout the development process, we have faced and overcome various challenges, such as ensuring accurate coordinate transformation between the computer vision system and the robotic arm. The successful integration of these components has demonstrated the effectiveness of our approach and the potential for this technology to significantly improve the lives of individuals with upper limb impairments.

However, we recognize that this is just the beginning, and there is still much work to be done to refine and enhance the assistive feeding robotic arm system. Future enhancements, such as advanced user interfaces, machine learning algorithms, additional sensors, portable designs, and expanded software capabilities, will be crucial in improving the system's functionality, usability, and effectiveness.

Moreover, ongoing user studies and feedback will play a vital role in guiding future developments and ensuring that the system continues to meet the needs and expectations of its intended users. By actively engaging with individuals with upper limb impairments, healthcare professionals, and caregivers, we can foster a collaborative and iterative design process that prioritizes user-centered innovation.

The development of this assistive feeding robotic arm system represents a significant step forward in the field of assistive robotics and has the potential to transform the lives of countless individuals with upper limb impairments. By promoting independence, empowerment, and improved quality of life, this technology can help break down barriers and create a more inclusive society.

As we move forward, it is essential to continue advocating for the development and deployment of assistive technologies, such as the one presented in this project. By raising awareness, securing funding, and fostering collaboration between researchers, engineers, healthcare professionals, and the disability community, we can accelerate the progress of assistive robotics and ensure that these life-changing technologies become more widely available and accessible to those who need them most.

References

[1] B. Jawed, N. Suri, and A. M. H. Inam, "Prevalence of Smartphone Addiction with Sedentary and Non Sedentary Lifestyle and Its Impact on Wrist Rom and Upper Limb Function," *International Journal of Health Sciences and Research*, 2023.

[2] Armour BS, Courtney-Long EA, Fox MH, Fredine H, Cahill A. Prevalence and Causes of Paralysis-United States, 2013. *Am J Public Health*. 2016;106(10):1855-1857. doi:10.2105/AJPH.2016.303270.

[3] V. Lozano-Berrio et al., "The Impact of Robotic Therapy on the Self-Perception of Upper Limb Function in Cervical Spinal Cord Injury: A Pilot Randomized Controlled Trial," *International Journal of Environmental Research and Public Health*, vol. 19, 2022.

[4] K. Nguyen et al., "The Assessment of Upper Limb Functionality in Friedreich Ataxia via Self-Feeding Activity," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 28, pp. 924–933, 2020.

[5] S. Javeed et al., "Association of upper-limb neurological recovery with functional outcomes in high cervical spinal cord injury," *Journal of Neurosurgery: Spine*, 2023.

[6] H. Carlsson, G. Gard, and C. Brogårdh, "Upper-limb sensory impairments after stroke: Self-reported experiences of daily life and rehabilitation," *Journal of Rehabilitation Medicine*, vol. 50, no. 1, pp. 45–51, 2018.

[7] D. Park, Y. Hoshi, H. P. Mahajan, H. Kim, Z. M. Erickson, W. Rogers, and C. Kemp, "Active Robot-Assisted Feeding with a General-Purpose Mobile Manipulator: Design, Evaluation, and Lessons Learned," *arXiv: Robotics*, 2019.

[8] M. A. Darmanian, M. X. Chua, and L. Wu, "A Completely Portable and Concealable, Lightweight Assistive Exosuit for Upper Limbs," *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2023.

[9] M. Pascher, K. Kronhardt, F. Goldau, U. Frese, and J. Gerken, "In Time and Space: Towards Usable Adaptive Control for Assistive Robotic Arms," *IEEE International Symposium on Robot and Human Interactive Communication*, 2023.

[10] M. Rukhiran, S. Wong-In, and P. Netinant, "User Acceptance Factors Related to Biometric Recognition Technologies of Examination Attendance in Higher Education: TAM Model," *Sustainability*, 2023.

[11] B. Thaman, T. Cao, and N. Caporusso, "Face Mask Detection using MediaPipe Facemesh," *2022 45th Jubilee International Convention on Information, Communication and Electronic Technology (MIPRO)*, pp. 378–382, 2022.

[12] ROS 2 Packages - Interbotix X-Series Arms Documentation, https://docs.trossenrobotics.com/interbotix_xsarms_docs/ros2_packages.html

[13] MediaPipe Face Mesh, https://github.com/google/mediapipe/wiki/MediaPipe-Face-Mesh

[14] Compiling librealsense for Linux Ubuntu Guide, https://dev.intelrealsense.com/docs/compiling-librealsense-for-linux-ubuntu-guide

[15] ROS2 Wrapper, https://dev.intelrealsense.com/docs/ros2-wrapper

[16] Interbotix WidowX250S Specifications, https://docs.trossenrobotics.com/intrbotix_xrms_docs/secifications/wx250s.html

[17] Duke University, https://users.cs.duke.edu/~brd/Teaching/Bio/asmb/current/Papers/chap3-forward-kinematics.pdf

[18] ROBOTIS, https://emanual.robotis.com/docs/en/software/dynamixel/dynamixelwizard2/