AI-Enhanced DOBOT Magician for Classroom Education: Hand Gesture Control for Hazardous Material Handling Simulation

Alex Maynes and Ahmed Hasan
Mechanical Engineering Department
University of New Mexico

ABSTRACT

Students in the ME-150 class in the Mechanical Engineering Department at the University of New Mexico get engaged in engineering research using experimental tools to learn about machine programming and control, Newton's three laws of motion, advanced tribology, propulsion and engines, and bioengineering [1,2]. Desktop robotic arms called DOBOT Magicians are used to conduct algorithmic programming to run manufacturing simulations. However, the DOBOT capabilities are limited to manufacturing simulations and do not extend to other applications, such as decommissioning of hazardous plants, remote handling of hazardous materials, or working in hazardous environments to humans.

A research project was developed to explore a novel application in human-robot integration using computer vision tools, OpenCV and Google's MediaPipe, in Python to control a DOBOT Magician robotic arm with hand gestures. Preliminary results demonstrate successful hand tracking, gesture interpretation, and corresponding robotic arm manipulation. The new capabilities allow the students in the ME-150 class to develop simulations to remotely control the DOBOTs to work in hazardous environments, perform precise tasks gripping, transporting and packaging hazardous materials, perform confined space inspections, and conduct specific tasks within hazardous environments.

Introduction

The mechanical engineering department at UNM introduced a new course in the spring of 2019 titled "An introduction to modern Mechanical Engineering, ME-150" to increase the retention of engineering students. The objective of this course is to introduce engineering freshman students to the various Engineering technologies related to mechanical engineering careers, while describing the science and math behind them [1,2]. The class offers non-traditional education experience to the students, where more than 80% of the class time is spent on conducting interactive hands-on research. Students get engaged in research using experimental tools to learn about machine programming and control, Newton's three laws of motion, advanced tribology, propulsion and engines, and bioengineering [1,2].

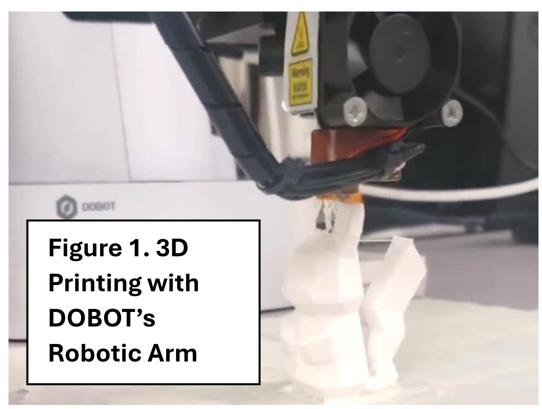

Figure 1. 3D Printing with DOBOT's Robotic Arm

One of the modules in this class requires students' teams to work on a bench scale robotic arm called DOBOT Magician to conduct algorithmic programming to run manufacturing simulations using attachments such as laser engravement, plotting, and 3D printing, figures 1-3. These simulations highlight the importance of the integration between hardware, software and design innovations in engineering applications. However, the DOBOT capabilities are limited to few simulations related to manufacturing automation and does not emphasize the wide range of potential applications in areas such as decommissioning of hazardous plants, remote handling of hazardous materials, or working in hazardous environments to humans.

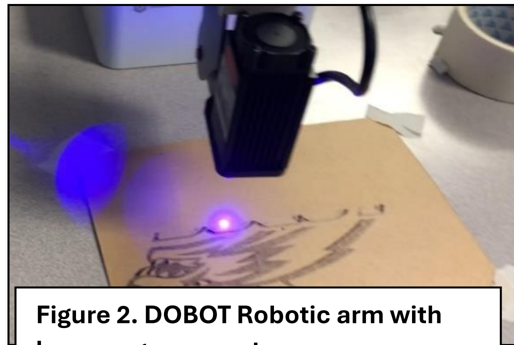

Figure 2. DOBOT Robotic arm with laser engravement

Human exposure to hazardous environments and the risk of life-altering injuries have been persistent challenges for centuries. Recent advancements in robotic technology offer more affordable and practical solutions. The National Safety Council (NSC) explored in its white paper published in 2023, the use of robotics in hazardous environments, health and safety applications, and how the deployment of such technologies can reduce the risk of serious injuries and fatalities. One of the keys findings in this paper stated that "Remote-controlled robots offer high-value use cases for confined entry inspections, working from height and hazardous material handling, reducing the risk of human exposure to toxic gases, high temperatures, electric shock hazards and falls from height [3]."

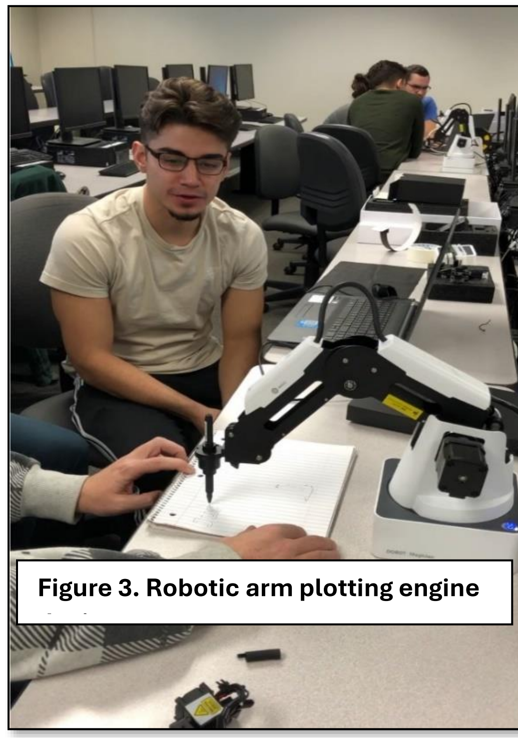

Figure 3. Robotic arm plotting engine

Historically robotic arm systems have been known to be an expensive solution to often relatively simple tasks. While the extreme costs may be justifiable for a high stake applications such as the medical robotic arm, many other applications cannot accommodate such expenses. This project explores a novel application in human-robot integration using computer vision tools, OpenCV and Google's MediaPipe, in Python to control a DOBOT Magician robotic arm with hand gestures. The goal is to enhance the DOBOT capabilities to include remote control using hand gestures and allow the students to design simulations relating to handling hazardous chemical and radioactive waste, confined space inspections, and the remote handling of toxic, high-temperature, and explosive materials from a safe distance [3].

Notably, the DOBOT Magician is drastically more affordable than its counterparts, enhancing its overall versatility and accessibility. By detecting and mapping hand movements in real-time, the system enables robotic arm manipulation, providing an innovative solution for performing hazardous tasks remotely and affordably. While similar systems exist for other robotic arms, this is the first known integration specifically with a DOBOT Magician, which supports various stock or custom end-effector attachments. This approach not only improves operator safety but also demonstrate the effective integration of modern open-source AI tools in a practical, more affordable, and thus more adaptable manner.

MATERIALS AND METHODS

The DOBOT is controlled through Python scripting, which interact directly with the arm via imported dynamic-link library (DLL) files [8]. The script incorporates MediaPipe's libraries for hand-tracking and gesture capabilities utilizing 2 webcams: one to detect, map, and interpret hand movements in real-time, specifically calibrated for the DOBOT Magician, and a second to monitor the arm's environment, figures 4 & 5 [4]. OpenCV processes input from the primary camera, identifying 21 distinct hand landmarks with camera resolution-specific pixel coordinates [5]. Furthermore, an approximate palm position is calculated by averaging the coordinates of the wrist and the two center-most knuckles, creating a 22nd landmark (shown in blue), which serves as the primary tracking point due to its central location on the hand. To ensure compatibility across a variety of cameras, these pixel coordinates are normalized, allowing the system to adapt to various camera models.

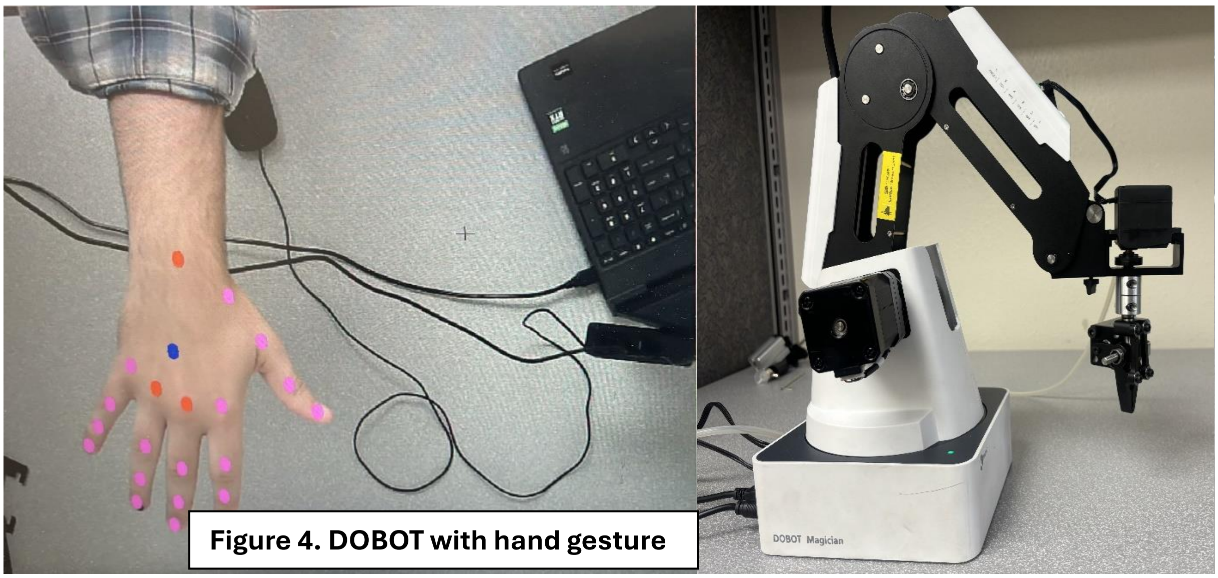

Figure 4. DOBOT with hand gesture

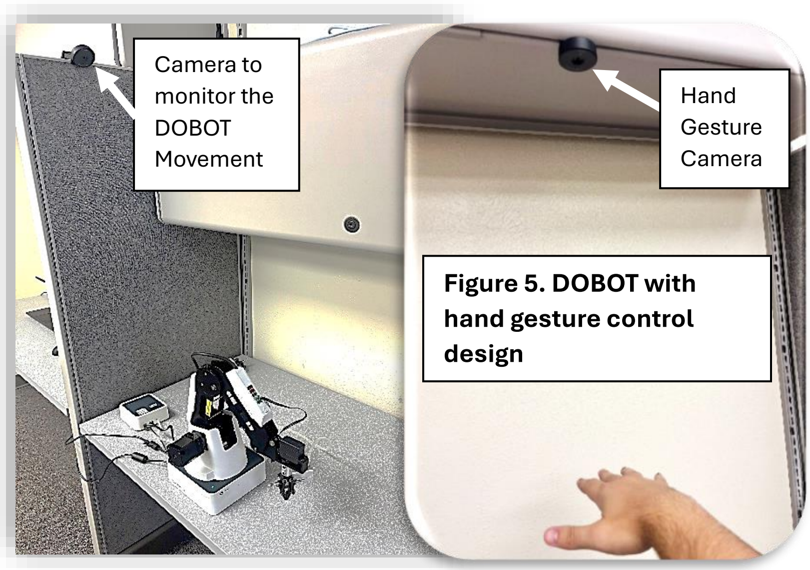

Figure 5. DOBOT with hand gesture control design

The normalized coordinates are then converted into 3 dimensional (3D) Cartesian coordinates for the robotic arm's manipulation that ultimately translates into the end-effectors desired position coordinates. Through inverse kinematics, these coordinates predict joint angles, thereby determining 3D spatial reachability. Initially, the prediction algorithms and calculations were derived intuitively using trigonometric laws and subsequently validated against established inverse kinematics research, figure 6 & 7 [6,7]. Upon calculating the predicted joint angles Φ, θ_1, and θ_2 using equations 1, 2, 3, and 4, the DOBOT movement commands are executed only when the requested position is confirmed to be physically and mechanically feasible, preventing over-stressing or exceeding the DOBOT Magician's joint limits.

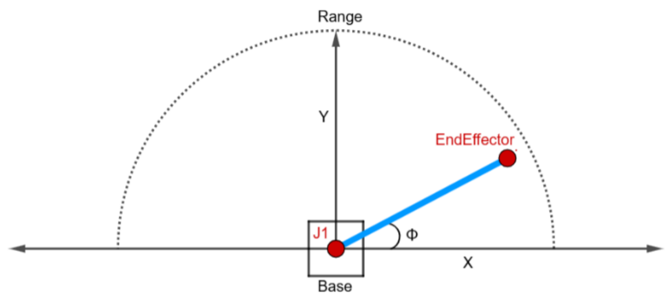

Figure 6. Kinematic Chain Diagram in the Horizontal Top-View Plane

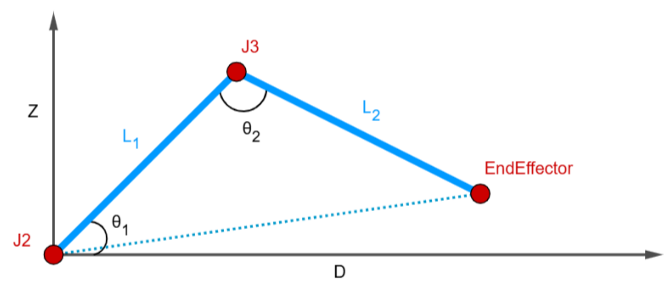

Figure 7. Kinematic Chain Diagram in the Vertical Side-View Plane

$$\Phi = tan^{-1}\left(\frac{y}{x}\right) \text{------------------------ Equ. (1)}$$

$$\mathrm{D} = \sqrt{x^2 + y^2} \text{ ------------------------ Equ. (2)}$$

$$\theta_1 = cos^{-1}\left(\frac{L_1^2+D^2+Z^2-L_2^2}{2L_1\sqrt{D^2+Z^2}}\right) \text{---------------- Equ. (3)}$$

$$\theta_2 = cos^{-1}\left(\frac{L_1^2+L_2^2-(D^2+Z^2)}{2L_1L_2}\right) \text{--------------- Equ. (4)}$$

Additionally, end-effector attachments, such as the suction cup or grip arm, should respond directly to open and closed hand gestures, allowing precise control over gripping and other attachment functions. This functionality is achieved by analyzing the distances between key hand landmarks to interpret hand gestures. The script compares the y-coordinates of each fingertip with the y-coordinates of their corresponding knuckles. If the fingertip's y-coordinate is farther from the base than the knuckle's y-coordinate, the finger is considered open; if it's closer, the finger is considered closed. By checking each finger individually, the system can determine if the entire hand is open or closed. When all fingers are detected as closed, the script signals the end-effector to close; an open hand gesture signals it to open.

RESULTS AND DISCUSSION

Preliminary results demonstrate successful hand tracking, gesture interpretation, and corresponding robotic arm manipulation within manufacturer specifications excluding J4, figure 8 & table 1 [9]. This includes depth perception analysis algorithms to provide accurate end-effector height tracking. The DOBOT Magician effectively mimics hand positions, offering reliable control for remote handling. The system's gesture control is highly responsive, nearly instantaneously activating attachments when desired, which is promising for real-world applications where quick actions are essential.

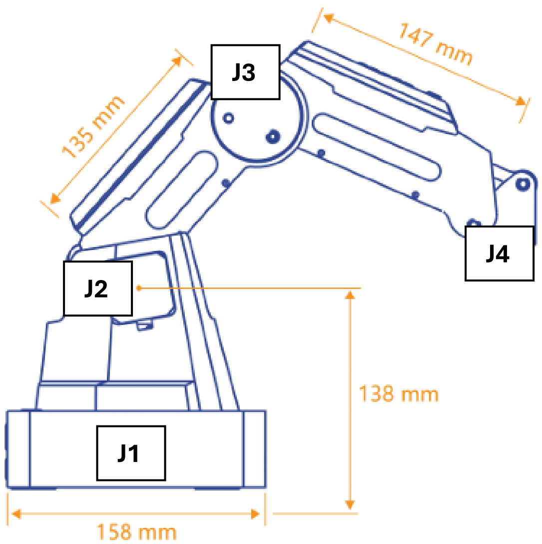

Figure 8. Dobot specifications [9]

Joint	Motion Range	Max Speed (with max 250g)
J1	- 90° ~ +90°	320°/s
J2	0° ~ +85°	320°/s
J3	- 10° ~ +90°	320°/s
J4	0°	0°/s

Table 1. Dobot motion range and specifications [9]

While the current gesture interpretation functionality has been refined for high responsiveness, ongoing work aims to improve performance for various hand orientations relative to the camera. Additionally, the joint angle prediction algorithm demonstrates a precision of ± 1.0-3.0 degrees, influenced by dynamic offset variations in the Euclidean distance variable that change with the z-coordinate. This results in a 5–10% variance when approaching joint limit boundaries. Currently, fixed average offsets maintain stability, though dynamic offset calculations through polynomial interpolation could further enhance precision.

Ongoing development focuses on optimizing joint angle accuracy, improving tracking fluidity, and refining command handling for seamless control. At this early testing stage, further expansion opportunities have been identified, including linear rail integration for extended reach, wireless transmission evaluation, medical application potential, and a versatile control package for other desktop robotic systems.

These enhancements aim to make the DOBOT Magician fully capable of performing complex tasks in hazardous environments, such as gripping, transporting, and packaging dangerous materials and conducting confined space inspections. This project represents the first application of its kind for the DOBOT Magician, showcasing the adaptability of human-robot integration tools. These methods are anticipated to be transferable to any two-link robotic manipulator that supports compatible Python processes, with calibration tailored to each robotic arm's specifications.

CONCLUSION

This project successfully demonstrates the potential of AI-driven hand gesture control with the DOBOT Magician, broadening the scope of human-robot integration and AI applications. The enhanced capabilities of the DOBOT Magician will introduce the students in the ME-150 class to wider spectrum of engineering technologies that are customized to reduce human exposure to hazardous environments while performing necessary and important tasks in the industry, performed by first responders, and environmental cleanup.

Future efforts will involve designing and testing several simulations using the additional capabilities of the DOBOT such as the rail and conveyor belt attachments, use these simulations as a test base for the students to mimic them, and adding additional simulation for remote handling of materials using the hand gesture control. The additional capabilities of the DOBOT will gain future students' skills in problem solving and integrated design.

This project will introduce cheap alternative for equipping any desktop robotic arm with remote controlled and gesture capabilities to be used in actual applications. Therefore, future efforts also will explore testing with other types of two-link robotic manipulators and developing a multi-modal control interface to further enhance intuitive control by integrating electro-encephalography (EEG) and other control modalities. This approach will be simulated across safety-critical industries to maximize its adaptability, precision, and versatility for various high-risk environments.

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