ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #49555

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

Dr. Ahmed Hasan, University of New Mexico

Experience in the interaction of inorganic contaminants with mineral surfaces, colloidal transport of radioactive and metal contaminants and their applications to remediation, physicochemical characterization of soil and mineral surfaces, development of g

Alex V Maynes

I am an Undergraduate Computer Science student at the University of New Mexico with a passion for artificial intelligence and robotics. My goal is to develop AI-driven systems that enhance human capability, improve safety, and push the boundaries of human-machine collaboration. With experience in software development, research, and my time in the U.S. Air Force, I strive to create technology that not only solves real-world problems but also helps people overcome personal limitations. I am driven by the belief that AI can be a powerful tool for both individual and societal advancement.

Section XXXX

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

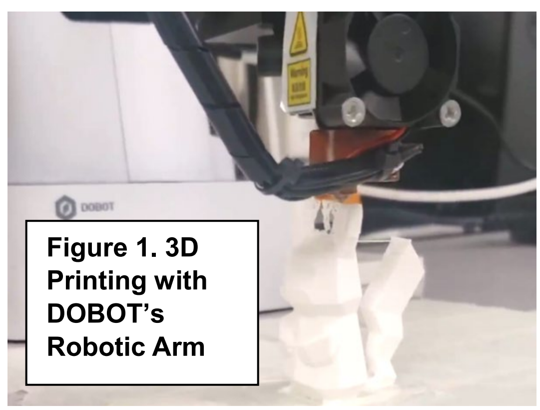

Figure 1. 3D Printing with DOBOT's Robotic Arm

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].

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]."

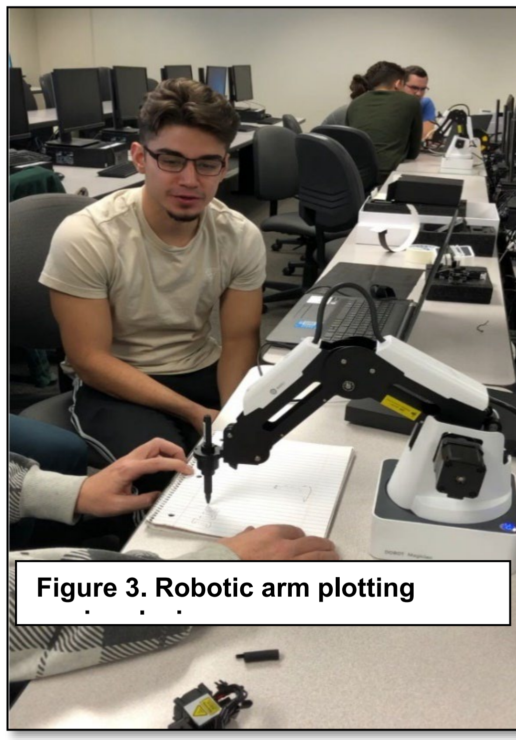

Figure 3. Robotic arm plotting

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 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 demonstrates 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 interacts directly with the arm via imported python and 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

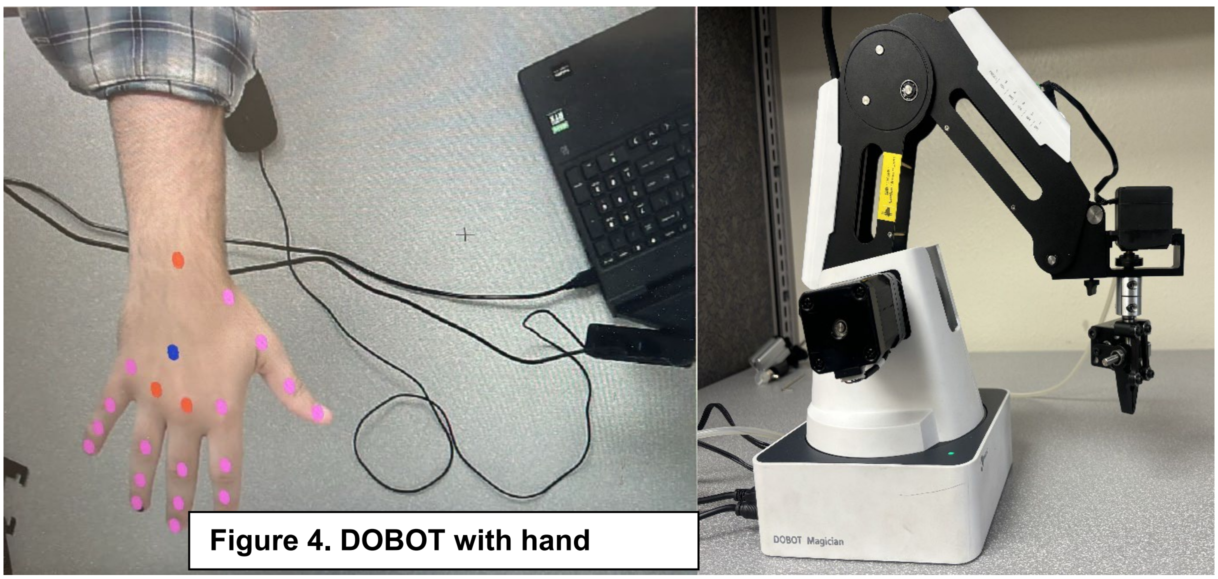

Figure 4. DOBOT with hand

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.

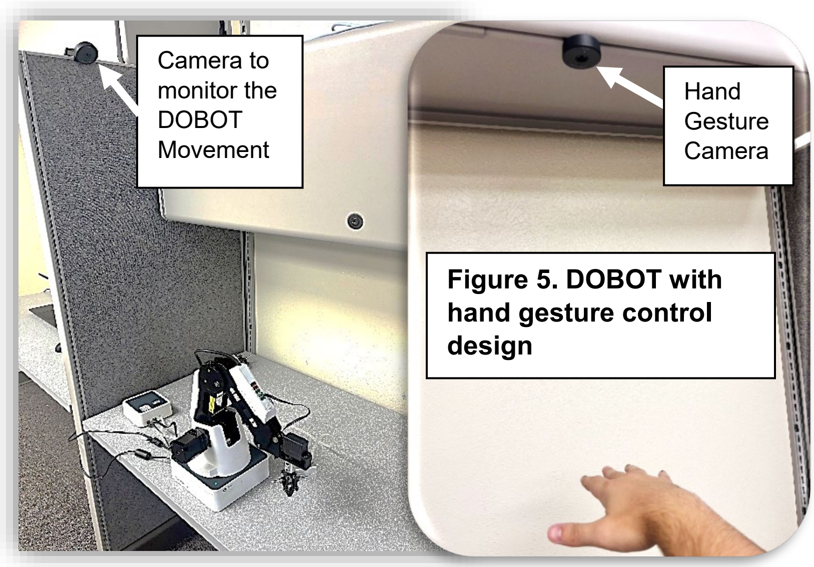

Figure 5. DOBOT with hand gesture control design

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. Initially inverse kinematics was used where these coordinates predicted joint angles, thereby determining 3D spatial reachability, equations 1, 2, 3, and 4, figure 6 & 7 [6,7]. However, significant discrepancies arose because the joint angles reported in Dobot Studio did not consistently align with their actual limits. The dynamic reference angle of Joint 3, in contrast to the fixed angle of Joint 2, added complexity, making inverse kinematic calculations more computationally demanding.

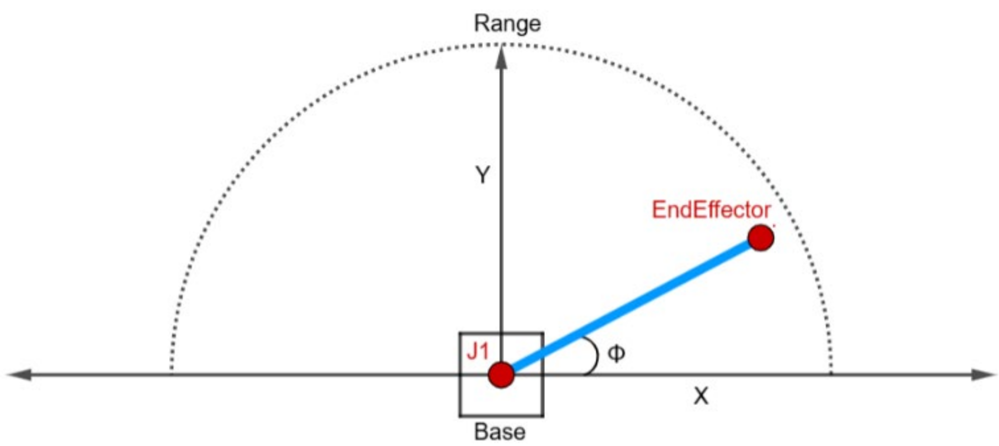

Figure 6. Kinematic Chain Diagram in the Top-View

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

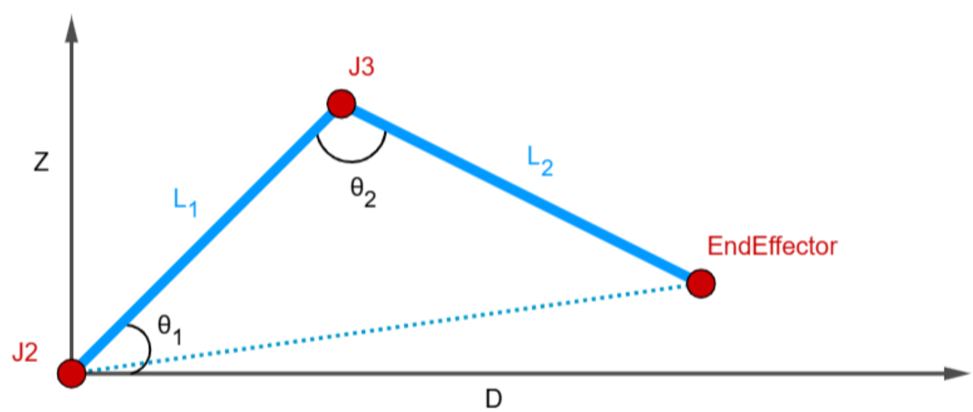

Figure 7. Kinematic Chain Diagram in the Side-View

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

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

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

To address these challenges, desired movements were separated into horizontal and vertical planes, focusing specifically on the end-effector's range of motion (ROM) limits, figures 6 & 8. For the vertical plane, two parametric equations were derived from recorded positions to model the end-effector's vertical ROM, tables 1, 2, & 3, equations 5 & 6. This method ensures that movement commands are executed only when the requested position is verified as mechanically feasible, preventing overstress or exceeding the Dobot Magician's joint limits without requiring overly complex calculations.

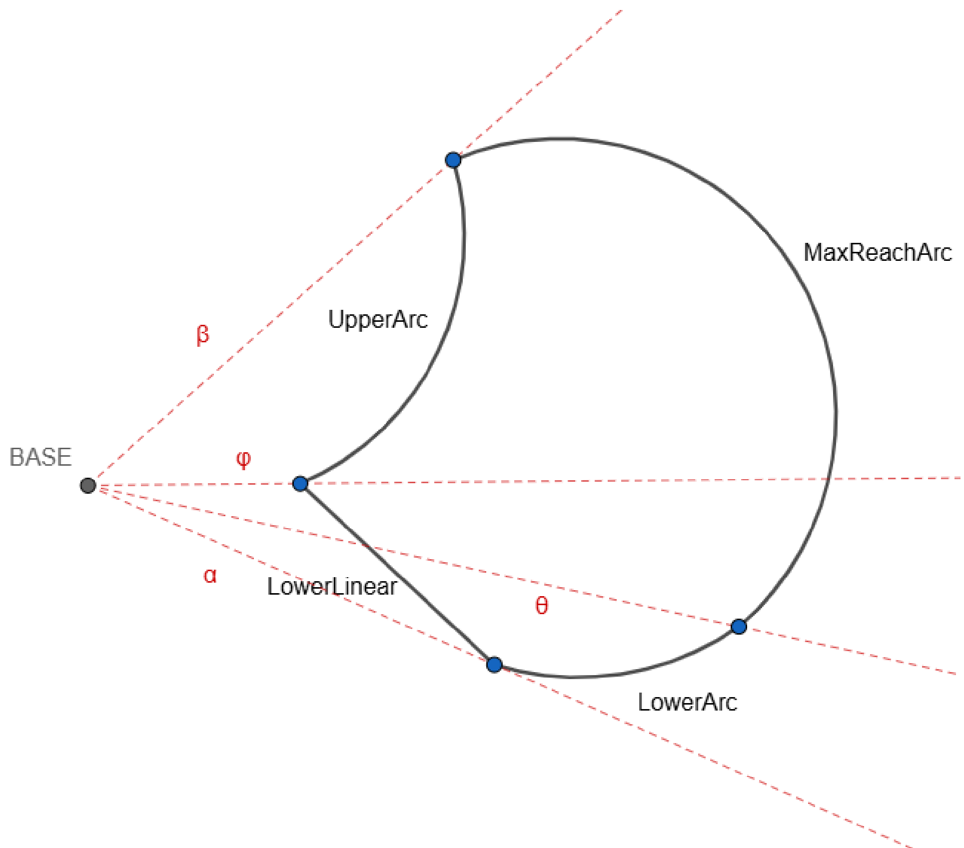

Figure 8. Endeffector ROM in the Side-View

Note: "ε" *marks the angle of the 'base to endeffector' line segment with horizontal as 0 degrees*

Max. (Lower Arc) ROM Data Table	
(D, Z)	Euclidean Distance
195, -146.7	*243.6*
206.6, -146	*252.98*
222.5, -144	*265*
243, -138.5	*279.7*
258, -132.2	*289.8*
271, -124.9	*298.4*
291, -110	*311.1*
315, -84.1	*326*
Formula derived via quadratic regression curve fitting: $f(z) = -0.024z^2 + 4.388z + 124.44$	
Coefficient of determination: 0.962 Avg. % Error: 1.619%	

Table 1. Endeffector ROM Max. (Lower Arc)

Min. (Upper Arc) ROM Data Table	
(D, Z)	Euclidean Distance
191, 170	*255.7*
192, 161	*250.57*
194, 155	*248.3*
167, 48	*173.76*
155, 34	*158.69*
135, 15.6	*135.9*
121, 6	*121.15*
111, 1	*111*
Formula derived via cubic regression curve fitting: $f(z) = 0.00002z^3 - 0.00778z^2 + 1.66z + 110.66$	
Coefficient of determination: 0.999 Avg. % Error: 0.453%	

Table 2. Endeffector ROM Min. (Upper Arc)

Min. (Lower Linear) ROM Data Table	
(D, Z)	Euclidean Distance
195, -146.7	*243.6*
111, 1	*111*
Formula derived via linear regression curve fitting: $f(z) = -0.898z + 111.90$	
Coefficient of determination: 1.0 Avg. % Error: 0%	

Table 3. Endeffector ROM Min. (Lower Linear)

$$ROM\ Minimum = \begin{cases} 0.00002z^3 - 0.00778z^2 + 1.66z + 110.66, & \varphi < \varepsilon \leq \beta \\ -0.898z + 111.90, & \alpha \leq \varepsilon \leq \varphi \end{cases} \text{-------- Equ. (5)}$$

$$ROM\ Maximum = \begin{cases} L_1 + L_2, & \theta < \varepsilon \leq \beta \\ -0.024z^2 + 4.388z + 124.44, & \alpha \leq \varepsilon \leq \theta \end{cases} \text{--------------- Equ. (6)}$$

Additionally, end-effector attachments, such as the suction cup or grip arm, respond directly to open and closed hand gestures, allowing precise control over gripping and other attachment functions. This functionality is also expanded with other gestures and 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 the hand's shape.

When all fingers are detected as closed, the script signals the end-effector to close; an open hand gesture signals it to open. The first finger open with all others closed; signals 1 dimension of movement and allows for the control of a linear track while locking the rest of the arm in place.

The first 3 fingers open with the others closed; signals 3 dimensions of movement and allows for the arm to move, locking the linear track in place if present. Lastly, all fingers closed except the thumb, toggles tracking entirely without closing the program, allowing you to re-enable it later when desired, figure 9.

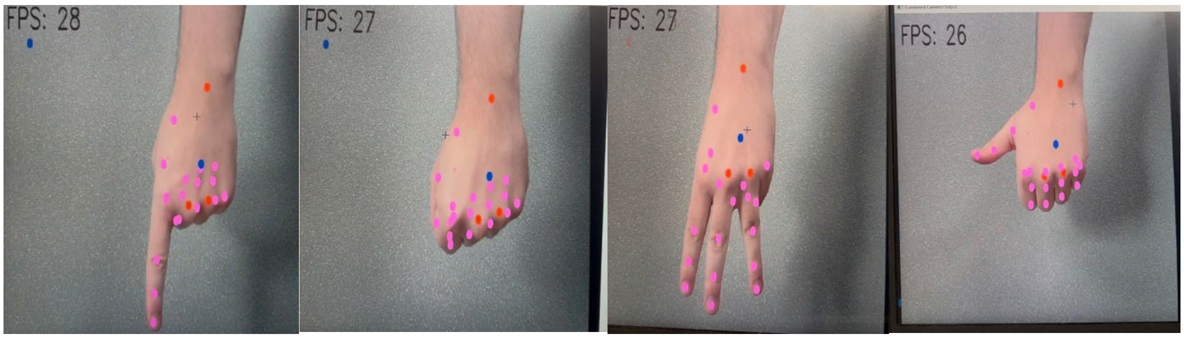

Figure 9. Hand Gesture Variations

These hand gestures allow for the control of the Dobot with a linear track, enabling it to manipulate the environment seamlessly through additional modalities of movement by switching between control modes, figures 10 & 11.

Figure 10. DOBOT with Linear Track

Figure 11. DOBOT picking up phone case

RESULTS AND DISCUSSION

Preliminary results demonstrate successful hand tracking, gesture interpretation, and corresponding robotic arm and linear rail manipulation within manufacturer specifications, figure 12 & table 4 [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.

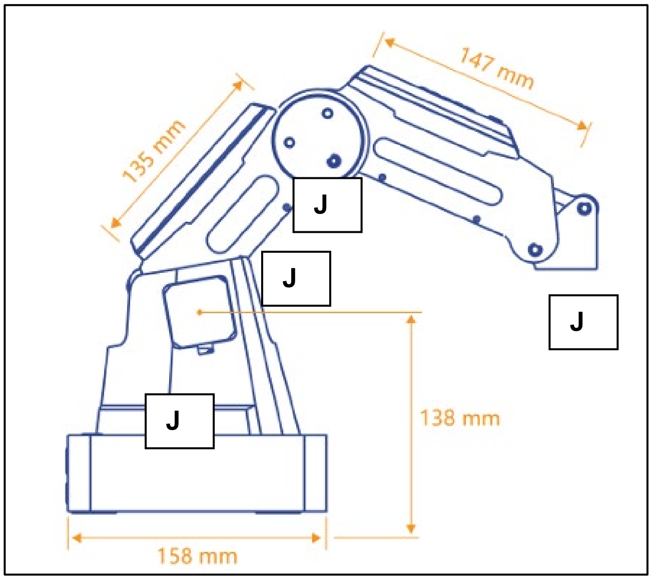

Figure 12. DOBOT specifications [9]

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 4. DOBOT motion range and specifications [9]

The primary challenges encountered involved the inverse kinematics calculations and identifying the initial Python import requirements. The inverse kinematics posed significant delays in the development of the prediction algorithm due to the dynamic reference angle of Joint 3 and the lack of clear or standardized reference angle specifications for each joint.

Additional challenges include the occasional buildup of latent movements, likely caused by hardware limitations or the improper utilization of built-in functions that were not originally designed for this type of application. With live remote control in mind, this or a similar robotic arm could be retrofitted to expand or greatly optimize its functionality at a relatively low cost using this method. This approach has already been demonstrated with the Dobot Magician's Leap Motion control mode, which relies on the Leap Motion Controller manufactured by Ultraleap. However, this controller, an expensive infrared sensor, is not included with the Dobot Magician and offers similar control capabilities at a significantly higher cost compared to the proposed solution.

The cost of outfitting a manufacturing or classroom environment can escalate quickly, especially when purchasing multiple robotic arms, as seen in the UNM ME-150 course, which requires several desktop robotic arms. This new method provides a cost-effective solution, enabling the expansion of the class's modules without the need to invest in additional expensive equipment. By eliminating the requirement for costly infrared sensors, this approach allows students to explore this innovative control method while also comparing it to preexisting systems, fostering a deeper understanding of both technologies.

Given the intricacy of the gesture recognition and its immediate responsiveness, a promising future application lies in integrating the system with a more humanoid robotic arm or hand. The algorithms can be adjusted to replicate any hand position, allowing for realistic mirroring of human gestures by a humanoid robotic hand. Additionally, the abstract nature of the script files, excluding the ROM verification function, makes this method highly adaptable. This adaptability suggests broader potential for enhancing the functionality of any desktop robotic arm that meets the compatibility requirements. With this approach, the software's capabilities would ultimately be limited only by the hardware constraints of the robotic arm itself. Its main limiting factor would be requiring an arm specific compatibility update that would focus on creating the arm specific ROM verification function.

Numerous tests have been conducted, and while further work remains to be optimized, several fronts can be explored.

CONCLUSION

This project successfully demonstrates the potential of AI-driven hand gesture control with the DOBOT Magician, significantly broadening the scope of human-robot integration and AI applications. By leveraging this technology, gross motor skills can be extended through robotics, with promising potential for expanding into fine motor skill applications. These advancements have far-reaching implications across industries, including manufacturing, medical, education, and labor-intensive fields.

In manufacturing, this technology offers workers access to safer and more affordable equipment, reducing the risk of injury in hazardous environments. In the medical field, it could enable the development of less strenuous, more precise surgical tools or innovative physical and recovery therapy systems. In education, the system provides a cost-effective, engaging tool for students, sparking interest through its theatrical comparisons while simultaneously supporting curricula focused on technological research and advancement.

The enhanced capabilities of the DOBOT Magician will expose students in the ME-150 course to a broader spectrum of engineering technologies. These technologies are specifically tailored to reduce human exposure to hazardous environments while enabling critical tasks across multiple industries. The ongoing development of the DOBOT's additional capabilities will continue to refine future students' skills in problem-solving and integrated design, ultimately advancing the curriculum of the ME-150 course and contributing to the preparation of students for real-world engineering challenges.

REFERENCES

1. Hasan, A., & Khraishi, T. (2020, July), "An Introduction to Modern Mechanical Engineering" A New Course to Introduce Students to the Dynamic and Evolving Mechanical Engineering Disciplines. Paper presented at 2020 Gulf Southwest Section Conference, Online. 10.18260/1-2-370.620-35944
2. HASAN, A. A., & Khraishi, T. (2021, March), Intro to Mechanical Engineering: A New Course To Improve Major Trajectory Paper presented at ASEE 2021 Gulf-Southwest Annual Conference, Waco, Texas. 10.18260/1-2--36388

3. Improving Workplace Safety with Robotics: https://www.nsc.org/getmedia/25023964-33a8-4c93-a906-d29702a6d931/wtz-robotics-wp.pdf?srsltid=AfmBOoomV6G5J8XdiZHd_xRuFePT_11GuJ53C4iugIKLaUoO1Joy5cyMs
4. Google-Ai-Edge. (n.d.). *Google-ai-edge/mediapipe: Cross-platform, customizable ML solutions for live and streaming media.* GitHub. https://github.com/google-ai-edge/mediapipe
5. OpenCV. (2019). *OpenCV library*. Opencv.org. https://opencv.org/
6. Aristidou, A., Lasenby, J., Chrysanthou, Y., & Shamir, A. (2017). Inverse Kinematics Techniques in Computer Graphics: A Survey. *Computer Graphics Forum*, *37*(6), 35–58. https://doi.org/10.1111/cgf.13310
7. Hock, O., & Šedo, J. (2017). Forward and Inverse Kinematics Using Pseudoinverse and Transposition Method for Robotic Arm DOBOT. *Kinematics*. https://doi.org/10.5772/intechopen.71417
8. SERLatBTH. (2019). *GitHub - SERLatBTH/StarterGuide-Dobot-Magician-with-Python: Dobot Magician with pure Python - Starter Guide*. GitHub. https://github.com/SERLatBTH/StarterGuide-Dobot-Magician-with-Python?tab=readme-ov-file#setting-parameters
9. Shenzhen Yuejiang Technology Co., Ltd. (2022). *Dobot Magician User Guide (DobotLab-based) (Issue V2.0)*. Shenzhen Yuejiang Technology Co., Ltd. https://www.dobot.cc/