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

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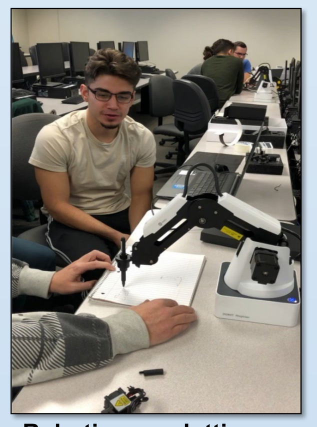
Abstract

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.

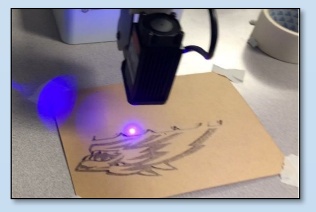
Introduction

One of the modules in the ME150 class at UNM 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. 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.

3D Printing with DOBOT's Robotic Arm



Robotic arm plotting engine design

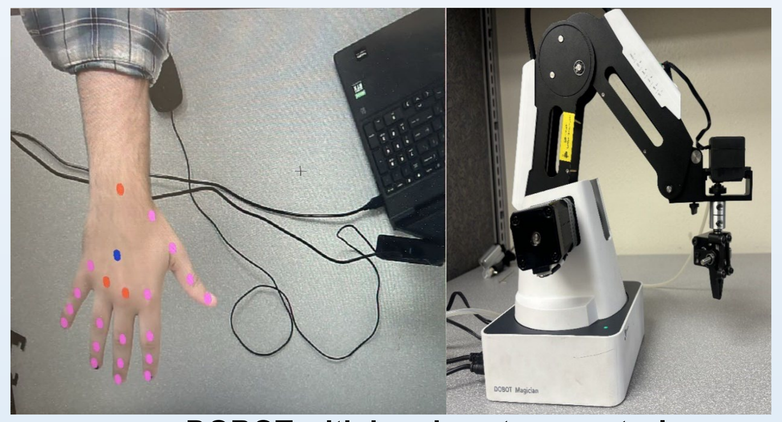


DOBOT Robotic arm with laser engravement

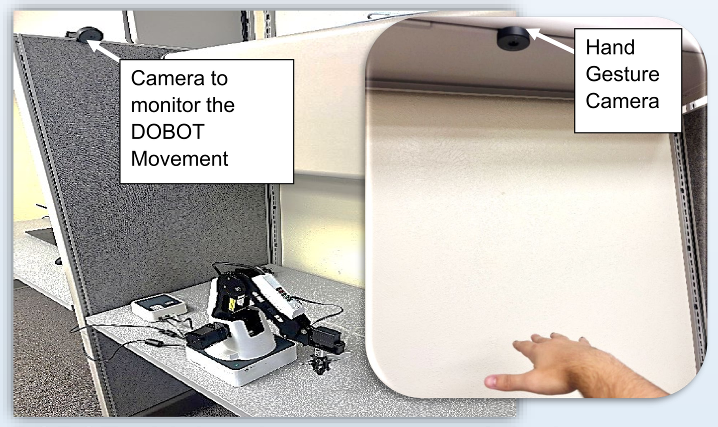
This project explores a novel application in human-robot integration using computer vision tools, OpenCV and Google's MediaPipe, in Python to control a DOBOT Magician robotic arm with hand gestures. By detecting and mapping hand movements in real-time, the system enables robotic arm manipulation, providing an innovative solution for performing hazardous tasks remotely and affordably. 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.

Methodology

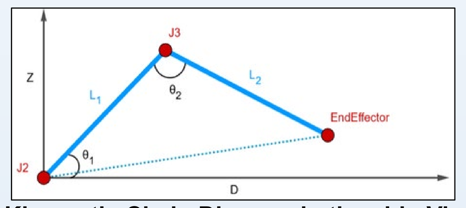
The DOBOT is controlled through Python scripting, which interacts directly with the arm via imported python and dynamic-link library (DLL) files. The script incorporates MediaPipe's libraries for hand-tracking and gesture capabilities utilizing 2 webcams: one to detect, map, and interpret hand movements in real-time, specifically calibrated for the DOBOT Magician, and a second to monitor the arm's environment. OpenCV processes input from the primary camera, identifying 21 distinct hand landmarks. 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.



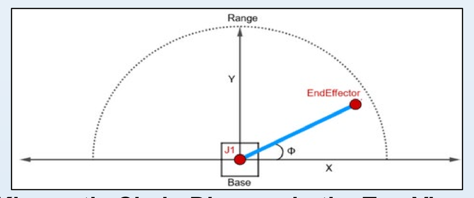
DOBOT with hand gesture control



DOBOT with hand gesture control design



Kinematic Chain Diagram in the side-View



Kinematic Chain Diagram in the Top-View

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. Desired movements were separated into horizontal and vertical planes, focusing specifically on the end-effector's range of motion (ROM) limits. For the vertical plane, two parametric equations were derived from recorded positions to model the end-effector's vertical ROM. 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.

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%	

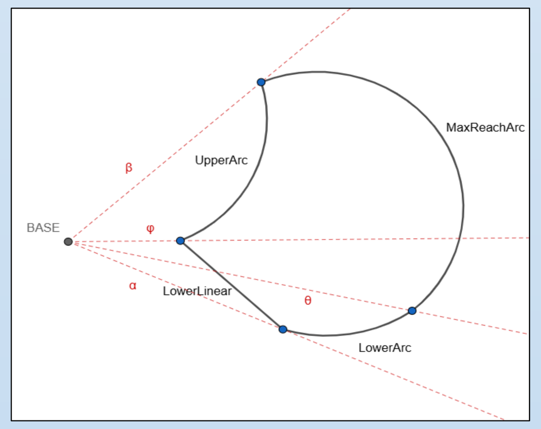
Endeffector ROM Max. (Lower Arc)

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%	

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%	

Endeffector ROM Min. (Lower Linear)



Endeffector ROM in the Side-View

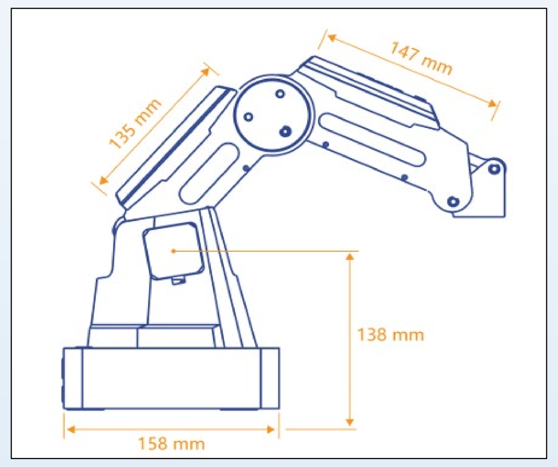
Additionally, end-effector attachments, such as the suction cup or grip arm, respond directly to open and closed hand gestures, allowing precise control over gripping and other attachment functions. When all fingers are detected as closed, the script signals the end-effector to close; an open hand gesture 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.

Hand Gesture Variations

DOBOT picking up phone case

Results

Preliminary results demonstrate successful hand tracking, gesture interpretation, and corresponding robotic arm and linear rail manipulation within manufacturer specifications. 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.



DOBOT specifications

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

DOBOT motion range and specifications

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. 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.

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.

The enhanced capabilities of the DOBOT Magician will expose students in the ME-150 course to a broader spectrum of engineering technologies that are specifically tailored to reduce human exposure to hazardous environments while enabling critical tasks. The additional DOBOT's capabilities will continue to refine future students' skills in problem-solving and integrated design and advancing the curriculum of the ME-150 course.