Tic-Tac-Toe (X-O) Robotic Manipulator

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***Abstract*—Image processing is one of the most powerful tools that can be used to make robots able to sense what is around it, and by processing this data, an action can be taken. In this project poppy robotic arm will be used to play tic-tac-toe against a human being.**

***Keywords*-Image Processing; Robotic Arm; AI; X-O.**

I. Literature Review

Paper [1] illustrates a robot demonstrator that allows a human to play tic-tac-toe against a lightweight robot relying on several research fields in its development. These fields include, image processing, artificial intelligence, force control, programming, and human-robot interaction. The game has two players, the robotic manipulator and the human opponent, where they can place an X or an O respectively, and whoever creates a line of their shape first is the winner. The first requirement was for the robot to be able to observe the board which was done by placing a camera facing it and analysing the captured feed through image processing. Artificial intelligence is then used to determine the robot's next move that will get it closer to winning. The manipulator is then able to pick up a marker and use force control to aid it in drawing on the whiteboard. The players take turns, and should the robot win at the end, it draws a line connecting its three Xs. Finally, the robot releases the marker and uses a sponge to clean the board. The program for the robot's movement as well as the image processing was implemented using MATLAB and a graphical user interface (GUI) was used for visualization. It is possible to use the robot demonstrator as an educational tool for students regarding the various fields of robotics. A variety of lessons and training programs can be taught and demonstrated with the robot with different levels of complexity. The demonstrator is also an effective way to inspire students into pursuing a degree in robotics and other engineering avenues.

Paper [2], a technique called single-pixel imaging which is a novel optical imaging technique based on sequential pattern illuminations and single-pixel detection. To compare, a two-dimensional object image is captured by a conventional camera at one shot with a pixelated sensor array. In SPI, the object scene is illuminated by different projected structured light patterns in sequence, and the total light intensity is collected by a single-pixel detector at each time. Advantages of this technique is the low cost sensor and its suitability for imaging tasks under some unconventional conditions like underwater imaging. SPI is used as optical artificial intelligence to play tic-tac-toe. The proposed system works by detecting the state of the game by pattern illumination and single-pixel intensity recording, then it makes an optimal decision using a lookup table. Simulation and experimental result verified this scheme.

In paper [3], a noble approach for reinforcement learning and image processing was used in literature[3] with an Interactive Tic-tac-toe Board Game with Swarm of Nano-UAVs. Crazyflie drones, a Vicon Tracking system with 12 IR cameras for drone localization, a CV camera for assessing the game state, a drone landing table with a game board, and PCs with Mocap framework, drone-control framework, CV system, and decision-making system make up the created SwarmPlay system. In accordance with the Tic-Tac-Toe regulations, the gaming board is divided into 9 cells. The drones play Crosses (Xs), landing on the cells of the game board in accordance with the prescribed algorithm. A person plays Noughts (Ox) at the same time, putting cards with printed circles on the playing field. A similar CV system to determine where cell the user places circles. We utilise an image captured by an RGB camera that is installed on the ceiling of the space housing the game board as its input. The CV system takes a photograph and transforms it into grayscale at each stage. Then a 5x5 kernel is used for thresholding and erosion. The image is then separated into nine smaller pictures, one for each game cell, and cropped. A contour search is run for each little picture. As a user takes a turn, they draw a circle on a cell, which the CV system recognises as a contour and fills with black pixels. The CV system calculates the density of black pixels per game cell at the conclusion of each step. Large coloured circles in this instance exhibit a high-density value. Consequently, it is feasible to distinguish between game objects, drones, and empty spaces by employing a threshold. The CV system provides a matching game cell number, representing the most recent human turn, to a decision-making system to determine how precisely drones should behave in the scenario after recognising a new circle on the playing field.

Paper [4] discusses that Artificial Intelligence (AI) plays a relevant role in modern robotics, especially biological oriented models. By playing games, the machine intelligence can be revealed opening productive fields of study for AI and robotics. Backgammon, Chess, Checkers, Go, Othello and Tic-Tac-Toe are widely used for studying the learning ability of machines. for this paper images of the tic-tac-toe grid were acquired by the artificial vision comprised of a camera that captures color images from the real world. These images are processed using OpenCV and delivered to convolutional network specialized in recognizing Xs, Os and empty spaces. A sparse code representation of the board state, is used to train memory sub-networks, essential elements in the self-learning process that later become advisers of the driving agent. This is followed by a series of trial games to train the AI. The robot comprises an artificial vision platform that feeds sparse data to and self-taught neural agent which explores new games situation in a virtual world. Through reinforcement learning, neural models and gradient descend algorithms the agent learns by itself high level game strategies.The obtained look ahead intelligence could be useful in other robotic processes where critical visual decisions has to be taken such as autonomous surgeon, vehicle driving robots and information security

Reference [5] is concerned with developing the visual system of a Go robot. The paper is concentrated with using image processing techniques for the purpose of creating a python coded method for the recognition of a chessboard. The methodology included capturing the chess-board using a USB color camera. Projection transformation is used to correct images which where not always vertical. Image enhancement using spatial high-pass filtering is used to filter the image from noise which affects further image processing. Grayscale processing is used to convert the eliminate color from the image using opencv and then the image in binarized to differentiate and separate the chessboard from any chess pieces present. After processing the image, edge detection is by identifying discontinuities in the gray values to detect edges and the applying Hough transform which is used for recognizing chess pieces and differentiating between the black and white chess pieces. Multiple color image-based image processing techniques were used threshold segmentation, high-pass filtering and Huff transform. Experiments resulted in 100% pawn detection.

II. Hardware Design and Implementation

The system proposed for this project is composed of poppy humanoid robotic arm having and electrical magnet as an end effector to play the game against a human player. A Logitech HD Webcam C270 will be responsible of image acquisition and sending it to the laptop to process the image and using AI, a decision will be made and based on this decision, certain input for the robotic arm motors' will be sent using Arduino Uno to take the action.

A. End Effector

For this Project, we are aiming to use an electrical magnet as an end effector for poppy the humanoid robot manipulator.The specific electrical magnet used will be the 5 Vdc Electrical Magnet- Lifting Magnet 2.5 kg Holding. The X pieces that the robot will be using to play will have metallic parts affixed to them, which will allow the end effector to pick them up and then place them on the board.

Figure 1: Electrical Magnet

B. List of Components

Table I: List of Components Needed

Component	***Price***	***Qty***
FR0109M	550 EGP	4
Power Supply (5V, 20A)	130 EGP	1
Arduino Uno	370 EGP	1
Logitech HD Webcam C270	560 EGP	1
Robotic Arm 3D parts	350 EGP	1

C. Hardware Setup and Circuit Schematic

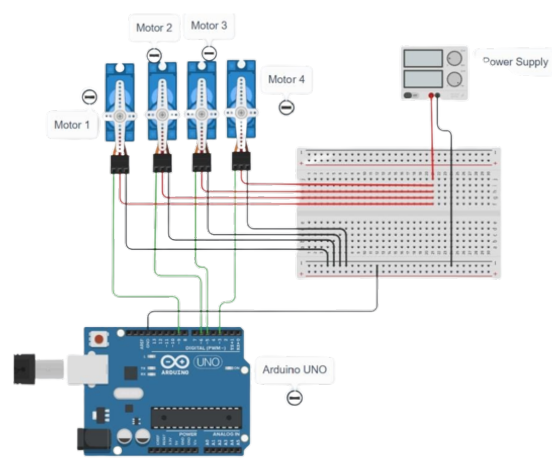

Figure 2: Circuit Schematic

The camera location and the setup of the project is designed using Solidworks and shown in the following figures.

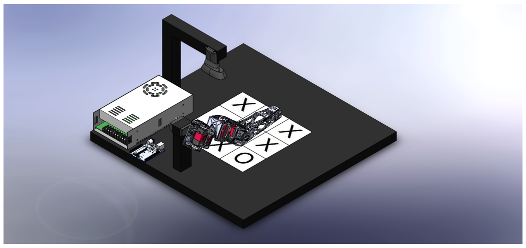

Figure 3: Hardware Setup Isometric View

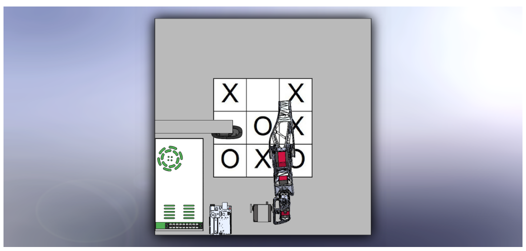

Figure 4: Hardware Setup Top View

Next we have the fully fabricated hardware intact as demonstrated in the solidworks on a 60cm by 60cm wooden block holding the arm,power supply,game board and the camera in position as it can be seen in the below figures 5 6

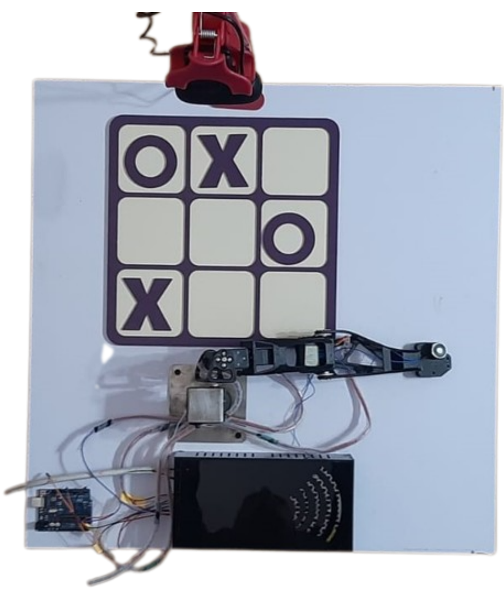

Figure 5: Fabricated Hardware Setup Top View

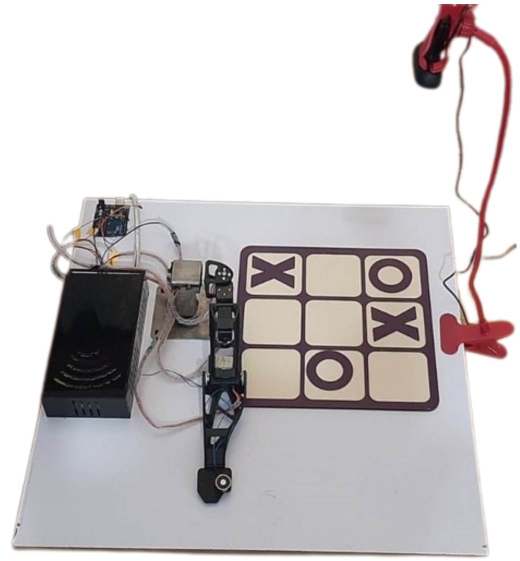

Figure 6: Fabricated Hardware Setup Front View

The overall look of our system is that the camera is connected to the laptop using USB cable sending feed that is processed by the laptop, the laptop then controls the Arduino which is second handed sending signals to the 4 servo motors and the electric magnet

III. Project Plan

A. *Project Flow*

1) Manufacturing and assembly of the hardware components.
2) Connecting the electrical components.
3) Design and simulation of robotic arm motion.
4) Applying the image processing techniques using Python.
5) Integrating the machine learning model in the system and testing it to verify success under the different XO scenarios.
6) Testing the system under different conditions of lighting.

B. *Image Processing Techniques*

The image processing techniques found in literature review are:

1) Segmentation where the image acquired by the camera is divided into pixels to differentiate between a cell with empty background and the X-O markings.
2) Color Detection: The processing is based on differentiating between a white/empty cell and a cell where a X or O marking is placed with different colors.

Either way, AI will then play a role in determining the optimal action to be taken. After deciding which cell the robot should play in, a command will be sent for the robotic arm to move from home position (which is away from XO board) to the specific cell using Arduino Uno.

The trajectory from home position to each one of the 9 possible locations on board will be designed and simulated on Simscape Multi-body first.

IV. Simulation Results

A. Initial Image Processing Trials

Before data acquisition from the image several image processing techniques can be done to enhance, better, guarantee the efficiency of the code and minimize the processing power.These image processing techniques can be divided into two subcategories which we are going to apply the filters corresponding to them to the upcoming image

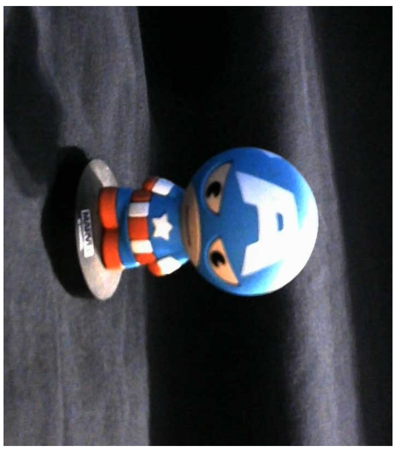

Figure 7: Original Image

1) Geometric Transformations: The cropping operation can be very useful as its used to reduce the number of pixels thus reduce image size thus reduce processing time and power and it gets rid of captured noise that is not .

Figure 8: Cropped Captain America

The following operating rotates the image about a certain axis by defaults rotates it about its origin this can be helpful if certain features can only be detected from certain orientations.

Figure 9: Rotated Captain America

2) Intensity Level transformations: Converting and image from the HSV to the Gray scale is a turning point in the image processing as it hugely reduces the image size and changes it from 3 overlapping layers of RGB to 1 layer of gray scale from ranging from 0 to 255.Speed. With modern computers, and with parallel programming, it's possible to perform simple pixel-by-pixel processing of a megapixel image in milliseconds. Facial recognition, OCR, content-aware resizing, mean shift segmentation, and other tasks can take much longer than that.

Figure 10: Gray Scale Captain America

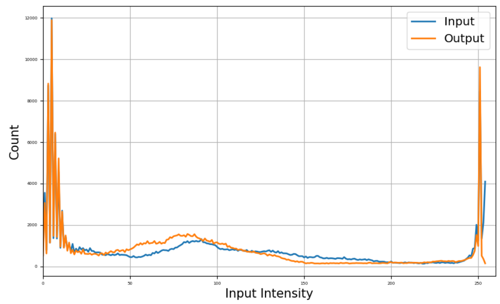

Figure 11: RGB to Gray Scale Histogram

Another intensity level transformation is the power transformation which is the brightening/darkening transformation, also refered to as gamma transformation it's used when and image is very bright than it gets darkened and vice versa in this case the image is going to get brightened as its going to be seen in the histogram to follow.

Figure 12: Brightened Captain America

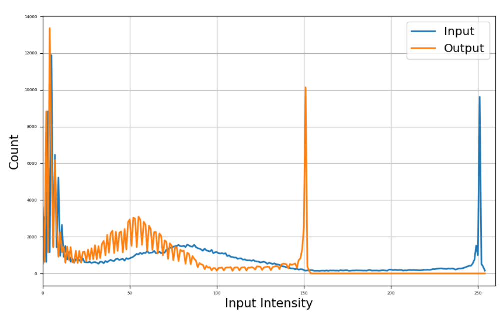

Figure 13: Brightened Histogram

At last there is the histogram equalization which is a concept merely dependant on the distribution on the number of pixels per each intensity value and aimming at equally distributing them as much as possible.

Figure 14: Equalized Captain America

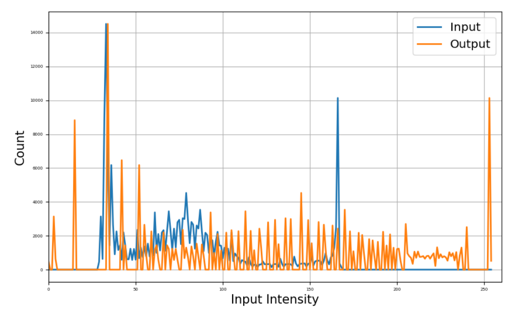

Figure 15: Equalized Histogram

V. Closed Loop Response

A. Initial Test

To test the closed loop response, two scenarios were introduced they both undergo the same image processing techniques, first converting to gray scale, applied Gaussian-Blur to reduce noise, then Adaptive Gaussian Threshold is to detect sharp edges in the Image, finally detect circles in the image using the cv2.HoughCircles functions with the appropriate parameters

1) Having the empty playing board, hence nothing would be detected by camera then the signal sent to the motors actuate it to a home position out of the field of view of the camera, but for demonstration purposed on this milestone the angle was set to 45 to be seen on camera for the validation of the functionality which can be seen on the below figure 16

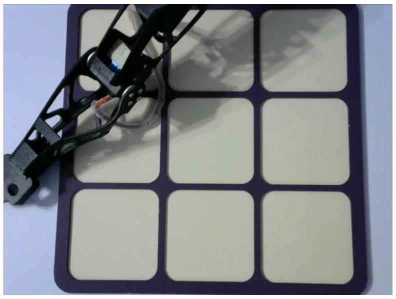

Figure 16: Empty Grid

2) The second scenario is when an O is introduced on the screen, as if A player has played his turn, when an O is placed and captured as seen in figure 17, a serial signal is sent the Arduino that in turn sends signal to actuate motor

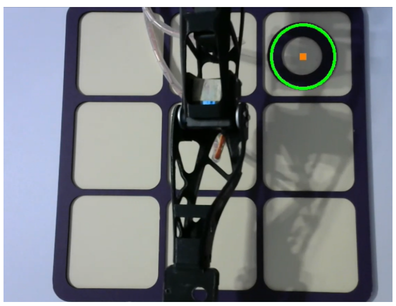

Figure 17: Detected Circle

For both scenarios after tuning the values of circle detection function they worked with minimal malfunctions, such as stuttering between detected and undetected circles.

B. Python Code

The key to the Minimax algorithm is a back and forth between the two players, where the player whose "turn it is" desires to pick the move with the maximum score. In turn, the scores for each of the available moves are determined by the opposing player deciding which of its available moves has the minimum score. And the scores for the opposing players moves are again determined by the turn-taking player trying to maximize its score and so on all the way down the move tree to an end state this algorithm is recursive, it flips back and forth between the players until a final score is found.

C. System Integration

After the initial test of the closed loop the next step was to put the system all together which was to include the Python Code discussed in the section above, together with the code responsible of the circle detection and serial communication mentioned earlier and then communicating with the Arduino which will have the code allowing the robot to go to the 9 different positions on the grid and the pickup position.

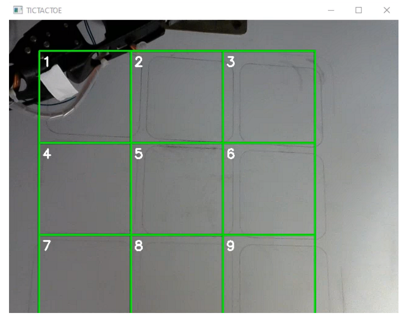

Figure 18: X-O Board

The arm manipulator delivers the X peace to the desired space highlighted by a square in the below figure and the sequence continues

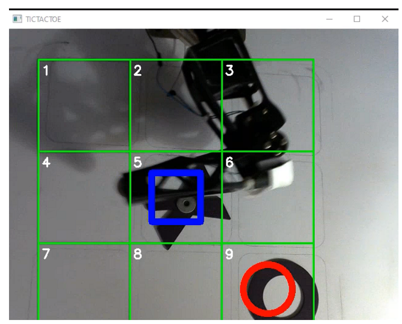

Figure 19: One X and One O

The system continues with the same sequence until a winner is determined or the game ends in a tie then after 15 seconds the system reboots to start a new game.

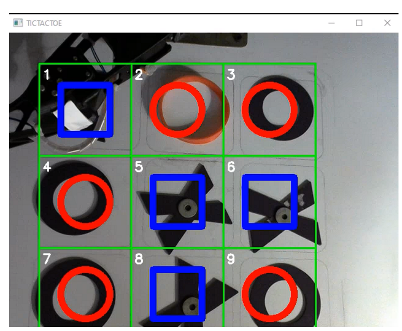

Figure 20: Full Board

References

[1] C. Thormann and A. Winkler, "Playing tic-tac-toe with a lightweight robot," in *Robotics in Education: RiE 2022*. Springer, 2022, pp. 150–160.

[2] S. Jiao, J. Li, W. Huang, and Z. Zhang, "Playing tic-tac-toe games with intelligent single-pixel imaging," *arXiv preprint arXiv:2205.03663*, 2022.

[3] E. Karmanova, V. Serpiva, S. Perminov, A. Fedoseev, and D. Tsetserukou, "Swarmplay: Interactive tic-tac-toe board game with swarm of nano-uavs driven by reinforcement learning," in *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)*. IEEE, 2021, pp. 1269–1274.

[4] O. Chang and L. Zhinin-Vera, "A wise up visual robot driven by a self-taught neural agent," in *Proceedings of the Future Technologies Conference (FTC) 2020, Volume 1*. Springer, 2020, pp. 606–617.

[5] Y. Gui, Y. Wu, Y. Wang, and C. Yao, "Visual image processing of humanoid go game robot based on opencv," in *2020 Chinese Control And Decision Conference (CCDC)*. IEEE, 2020, pp. 3713–3716.