Project Title: MagDrop4

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Project Goal

The goal of MagDrop4 is to create an engaging and competitive Connect4-playing machine that can seamlessly interact with a human player in real-time. By integrating advanced embedded systems, mechanical precision, and strategic gameplay, MagDrop4 aims to demonstrate the capabilities of autonomous systems in responsive, interactive applications. The project also serves as a practical exploration of sensor integration, motor control, and real-time decision-making within an embedded system framework.

Progress

Mechanical Design

We have completed printing all the 3D parts and assembling the mechanical structure of the machine. The mechanical structure mainly consists out of normed aluminum profiles, which can be easily assembled. The final step remaining is to create the baseplate. We are currently deciding whether to laser-cut the plate or manually cut and drill it from plywood, depending on the availability of a laser cutter.

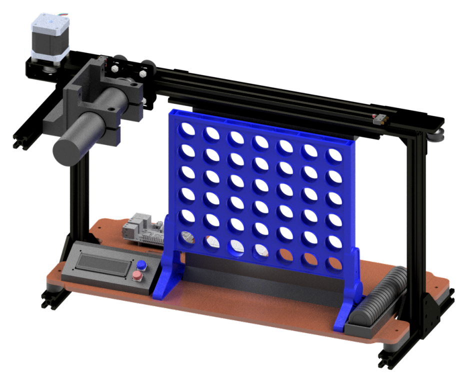

Figure 1: CAD Rendering of MagDrop4

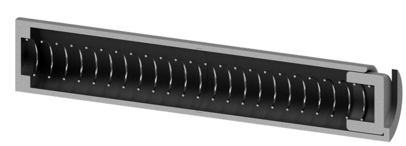

Figure 2: CAD Rendering of the Game Piece Magazine

Electrical Design

The electrical design includes the complete circuitry, with the Raspberry Pi serving as the central control unit. The display is managed via an SPI interface, utilizing GPIO pins 10, 9, 8, and 7. A stepper motor is driven by the DRV8829 driver, conveniently connected through a extension shield. The motor control uses GPIO 11 for direction, GPIO 12 (PWM) for step control, and GPIO 13 for enable. The Motor gets powered by a 24V. For the human move detection, seven IR sensors are powered by 5V. These sensors provide a simple high/low signal depending on whether a move is detected, and they are connected to GPIO pins 0 through 6. Each sensor's sensitivity can be adjusted individually using a sensitivity screw on the sensor. Two limit switches are used to mark the farthest left and right positions of the gantry cart on the linear rail. These are configured in a Normally Open (NO) setup, connected to GPIO pins 14 and 15. Each switch is connected to 3.3V through a pull-up resistor. Similarly, two additional buttons for user input are connected to GPIO pins 16 and 17 in the same NO configuration.

FSM and Machine Logic

The following FSM diagram illustrates the complete logic of the machine, starting from the initial setup to the conclusion of the game, either when there is a winner or the game ends in a draw. At the beginning, the machine moves the gantry cart away from the magazine, so there is more room to reload the magazine with the game pieces. Then the machine prompts the user to confirm if the magazine is fully loaded with game pieces and whether the game can proceed. Before starting, the user is also given the opportunity to adjust the AI's difficulty level. During Human_Turn, the system checks if the IR sensor for a specific column is triggered and after that the machine waits for up to 2 seconds for a valid new IR trigger. This allows for situations where the human player initially places a piece in one column, but then decides to retrieve it and drop it into another. The Game Engine, which handles the rules and logic for determining the next moves and checking for game completion, will be detailed in a separate section. The AI_Turn controls the movement of the gantry cart to the desired column and manages the activation and deactivation of the electromagnet to place the game piece accurately.

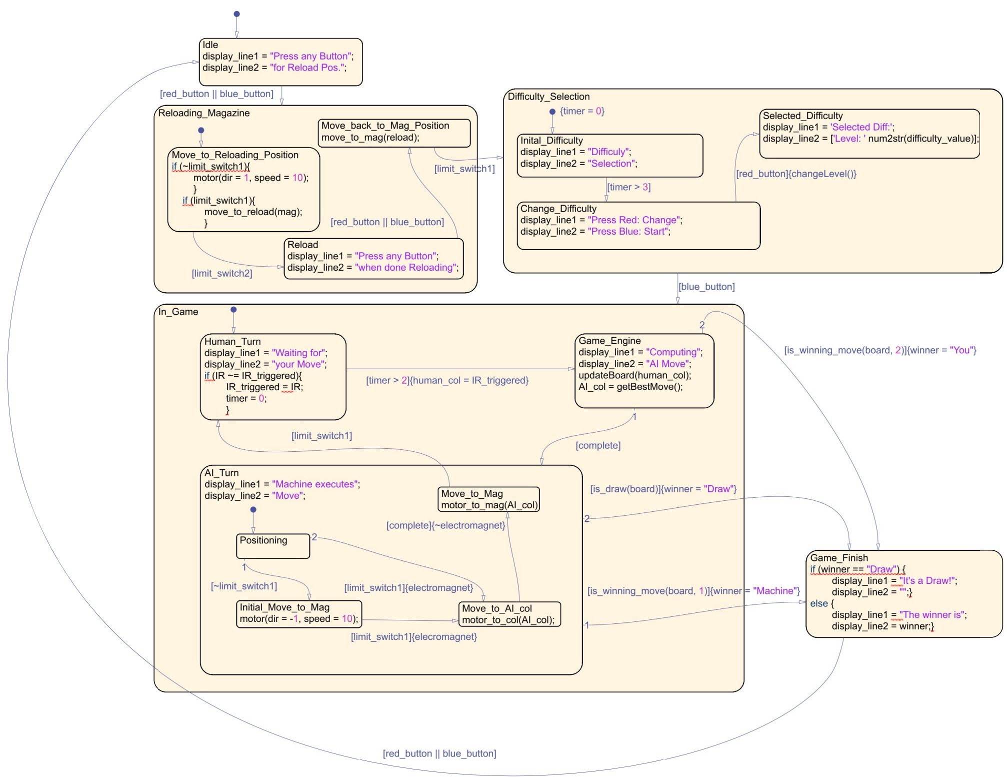

Figure 3: Finite State Machine of MagDrop4

Game Engine

We successfully developed a functional game engine prototype, which computes the computer's move in maximum 30 ms (depth = 4) on a standard laptop. This suggests it should operate within acceptable time limits on the Raspberry Pi 3+. The game engine utilizes a Minimax Search algorithm with Alpha-Beta Pruning, allowing us to implement different difficulty levels by adjusting the search depth (ranging from 1 to 4).

Minimax is a tree search algorithm that evaluates all possible moves by both the human and the computer up to a specified depth. At the terminal nodes of the tree, a scoring function determines the relative value of the board position. The scoring system is critical for the game engine's effectiveness. We have chosen the following scoring parameters, which can be fine-tuned as needed:

- AI's 3-in-a-Row with 1 Empty Space: score $+= 10$
- AI's 2-in-a-Row with 2 Empty Spaces: score $+= 5$
- Human 3-in-a-Row with 1 Empty Space: score $-= 15$
- Terminal State (AI Wins): score $+= 100,000$
- Terminal State (Human Wins): score $-= 100,000$

We also included Alpha-Beta Pruning, which enhances computational efficiency by eliminating branches in the search tree that cannot influence the final outcome. This significantly reduces the number of paths evaluated and speeds up decision-making. At a search depth of 4, the AI is already challenging to beat and sufficient for our purposes. Increasing the depth to 6 makes it basically impossible for a human to win against the machine. However, the computational cost increases exponentially, potentially exceeding the capabilities of the Raspberry Pi 3+. Further testing is required to determine the feasibility of deeper searches on the hardware.

Resources

Name	**Quantity**	**Name**	**Quantity**
400-Point Breadboard	1	M3 Screw	17
Aluminum Spacer	4	M5 Nut	25
Belt Clamp	2	M5 Screw	100
Connect 4 Game Set	1	M5 T-Nut	1
Corner Connector 2020	1	Metal Disk Inserts	42
Display	1	Limit Switch Plate	2
DRV8825 Extension Board	1	Mosfet	1
Electromagnet	1	Raspberry Pi 3 Model B+	1
Gantry Cart	1	Round Switch	2
GT2 Belt	1	Spring	1
Idler Pulley	1	Stepper Motor	1
Idler Pulley Plate	1	Stepper Motor Driver (DRV8825)	1
IR Sensor	7	Superglue	1
L-Connector	7	Timing Pulley	1
Limit Switch	2	USB 2.0 A to Micro B cable	1
M2.5 Screw	4	USB Power Supply	1
M3 Insert x 5mm	7	V-Slot 20x20 100mm	4
V-Slot 20x20 200mm	1	V-Slot 20x20 300mm	3
V-Slot 20x40 500mm	1	V-Slot Cover	2
V-Slot Endcap	2		
3D Printed Parts			
Base Plate Spacer	4	Disk Holder	1
Control Mount	1	Idler Pulley Overlay	1
Disk	42	IR Mount Plate	1
Disk Barrier	1	Raspberry Pi Standoff	4
Spring Top	1	Base Plate (Laser Cut)	1

Table 1: Purchase and Checkoff Parts List with Additional 3D Printed Parts

Timeline

- **12.10. - Completion of Wiring:** All electrical components, including sensors, motors, and actuators, are fully wired and tested for connectivity.
- **12.14. - Code Implementation Finalized:** Core logic for gameplay, motor control, and sensor integration are implemented.
- **12.16. - Bug Fixing and Full Machine Operation:** Final debugging and calibration completed. The machine is fully functional and ready for demonstration.

GitHub Repo

https://github.com/Loneli999/MagDrop4.git