# Automatic Puzzle Solver

## ECE 445 Senior Design

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Team 71
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# 1 Introduction

## 1.1 Problem

In the realm of recreational activities assembling jigsaw puzzles remains a popular pastime. There are many times when we are in the middle of solving a jigsaw puzzle and get stuck. For some people like children, manually solving jigsaw puzzles can be a daunting task. Many pieces look similar to the human eye, and this can be frustrating when trying to do what is deemed a relaxing activity.

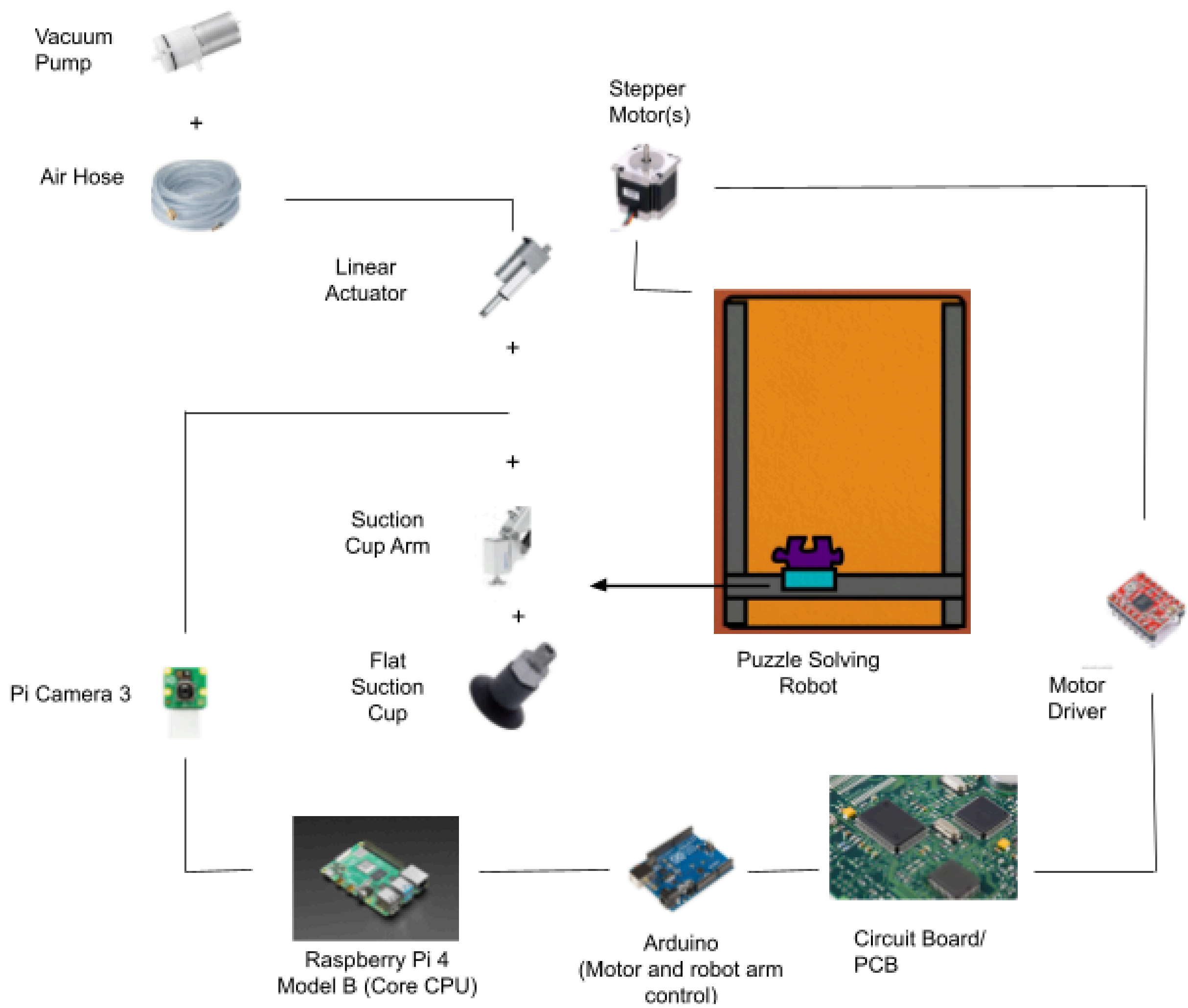
## 1.2 Solution

Our project aims to develop an innovative solution for puzzle enthusiasts and those facing challenges in manually assembling jigsaw puzzles. The project involves designing and implementing an Automatic Jigsaw Puzzle Solver equipped with a precision-controlled robotic arm attached to a suction device. The objective is to create a user-friendly device capable of autonomously solving puzzles of varying complexities. Our goal will be to be able to solve a 3x3 puzzle.

The setup will be as follows, a robot machine overlay will be placed over the jigsaw puzzle. We will have a series of pulleys and belts to move a robotic arm capable of extending in z direction via a linear actuator to pick up puzzle pieces. This robotic arm will be moved in the x and y direction using the belt and pulley system which is powered by stepper motors (reference visual aid). The robot will start by scanning each puzzle piece using an OpenCV-compatible camera. Our circuit board which is attached to a computer will then calculate exactly where each puzzle piece should be connected. Using computer vision, we will then grab each puzzle piece and move it to the desired location to complete the puzzle.

The robotic arm uses a linear actuator, suction cup, and camera to pick up the puzzle pieces. The linear actuator is needed so we can move puzzle pieces over each other and not drag the pieces along the table. The suction cup will be small enough to form a seal on the puzzle piece and it will be powered by a vacuum pump through a pipe. The camera will be used to identify the pieces and precisely place them together.

## 1.3 Visual Aid

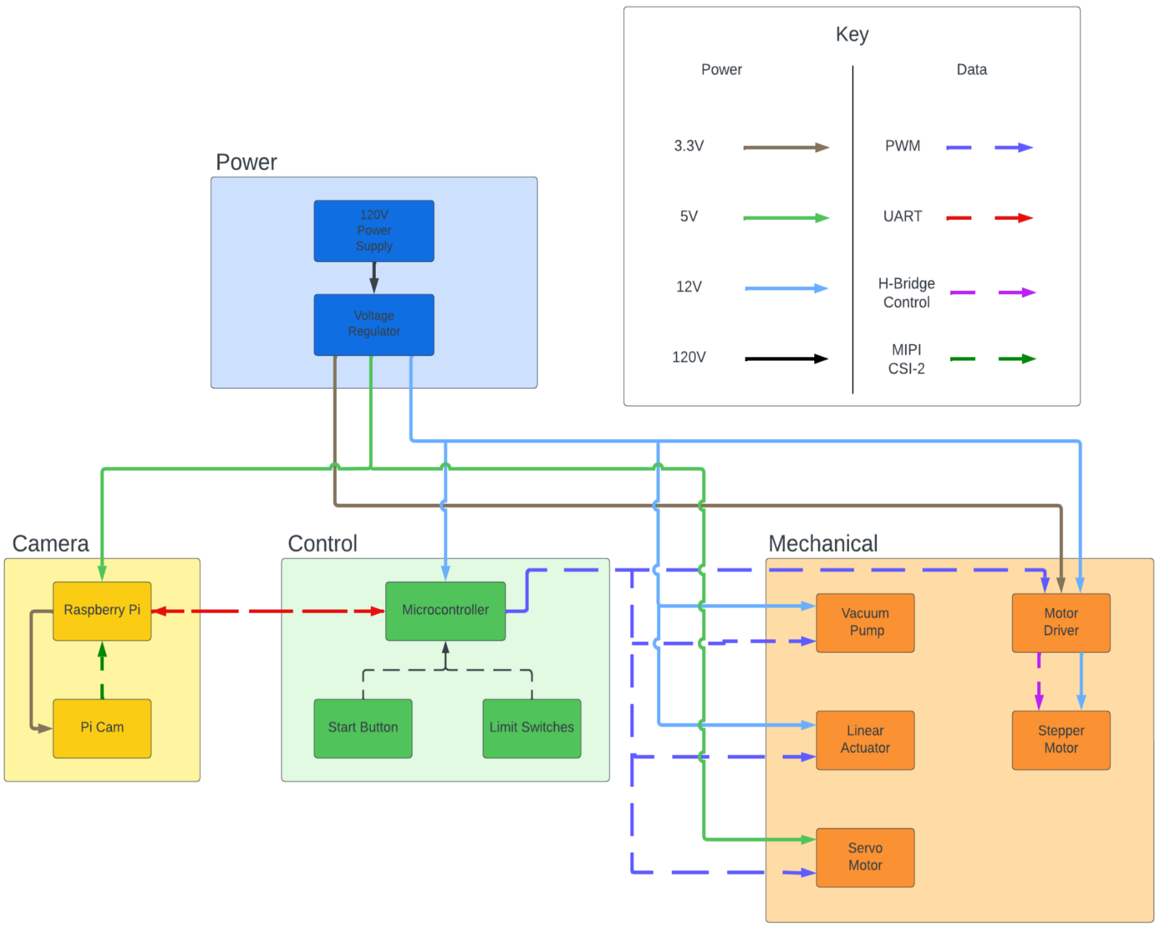



## 1.4 High-level requirements list

- The mechanical movement will be precise to 1 mm of movement
- We can correctly identify where individual puzzle pieces are located on the puzzle
- We can complete the whole 3x3 piece puzzle in 7 minutes

# 2 Design

## 2.1 Block Diagram



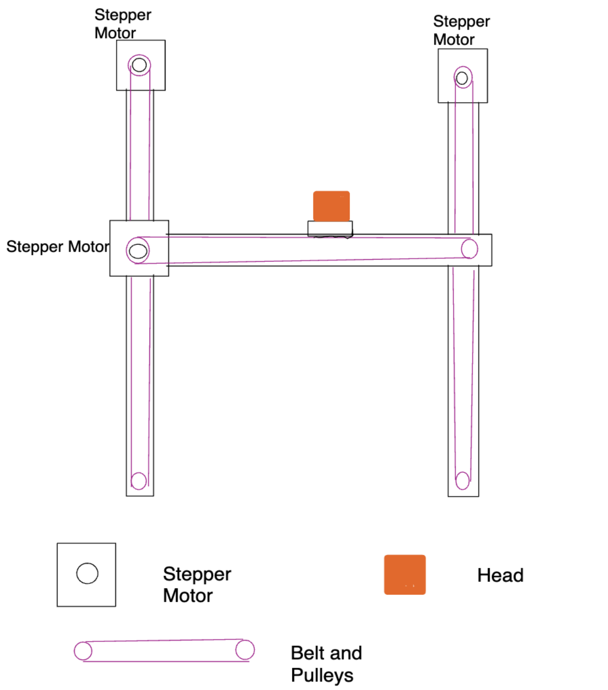



Figure 1: Robotic Movement Scheme Overhead View

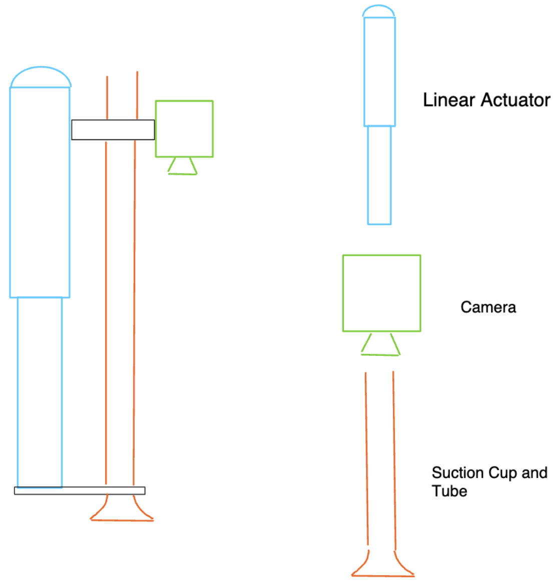



Figure 2: Robotic Arm Side View

## 2.2 Subsystem Overview

### 2.2.1 Power Subsystem

The subsystem will contain the circuitry to convert power to the needed voltage levels to power our puzzle-solving robot machine and all of its parts. This system will distribute power to the appropriate parts of the robot such as the stepper motors (powering the belts and pulleys to move the arm), the linear actuator to extend the robot arm in the z-direction, and all the components of the PCB and our camera used for computer vision.

### 2.2.2 Control Subsystem

The control subsystem provides the microcontroller, an Atmega32U4, necessary to efficiently operate all mechanical components including the motor driver, linear actuator, and vacuum pump. The limit switches will detect the number of steps our motors have taken to communicate the movement of the arm to our controller. The OV7670 camera will provide the image we analyze in OpenCV to correctly identify puzzle pieces and their orientation.

### 2.2.3 Mechanical Subsystem

The mechanical subsystem executes physical actions based on instructions from the control system to manipulate the arm. This subsystem contains stepper motors controlled by the motor driver to precisely control the movement of the belt system. The linear actuator provides vertical movement for the arm, which in turn allows a flat suction cup to pick up the puzzle pieces. The suction will be provided by an air hose connected to the vacuum pump.

## 2.3 Subsystem Requirements

### 2.3.1 Power Subsystem

The power subsystem will provide power using a voltage regulator connected to a 120V power supply. The regulator will output a 12V line to our mechanical components and a 5V line to our microcontroller. This system will also output any required voltage to our stepper motors to control the x and y-axis movement of the robot arm. We have not decided on the exact model of the stepper motor to use yet, so the voltage level needed is to be determined in the future of our project. To test our stepper motors, we will need to ensure that 1 amp of power is going through the motors at all times, this is the listed operating amperage.

### 2.3.2 Control Subsystem

The control subsystem contains the Atmega32U4 microcontroller which will be compatible with our OV7670 camera sensor. The camera will need to accurately collect color data to differentiate the various pieces and backgrounds. The microcontroller will send necessary data to our computer which will need to have sufficient power to run OpenCV.

### 2.3.3 Mechanical Subsystem

The mechanical subsystem will require stepper motors with the precision necessary to pick up and place the puzzle pieces on the board. From the tolerance analysis we know a motor with 200 steps per revolution attached to a pulley with a radius smaller than 31 mm, will have a precision less than 1 mm. Another key requirement is to have a suction cup with the correct size to pick up the puzzle piece with the right amount of pressure provided by the vacuum pump. From the tolerance analysis we have determined 15 gram puzzle pieces will be able to be picked up with a suction cup that has a 2.54mm radius with only 7.630kPa of pressure. We plan to use a vacuum pump that can provide 56kPa of pressure. The linear actuator will simply need to extend and retract to a sufficient height that allows it to move around the grabbed pieces from place to place.

### 2.4 Tolerance Analysis

Mechanical Precision: One of our high-level requirements is that we will be able to move the suction cup with 1mm precision in any direction. We will be moving the arm with the suction cup attached to it with a belt and pulley system powered by stepper motors. We have chosen a stepper motor with 200 steps per revolution. The steps are the base unit of movement of the stepper motor. The distance of one revolution is determined by the radius of the pulley the belt is attached to. $2\pi r/200 = 1mm$. To get this level of precision we will need the radius of the pulley to be less than 31.83mm. We plan to have pulleys with a radius of only 10-20mm.

Vacuum Suction: We will be using a vacuum suction cup to pick up the puzzle pieces. The vacuum holding the puzzle piece will need to be strong enough to hold the puzzle piece when we are lifting it off the table since that is when the vertical acceleration will be greatest. The force needed to lift the piece will be $F = m * (g * a)$, where m is the mass of the puzzle piece, g is the acceleration of gravity, and a is the acceleration of the puzzle piece being lifted. The large 3x3 puzzle we are going to use is listed on amazon with a total weight of 4.6oz or 0.5111oz per piece. This is equivalent to about 14.49 grams which we will round to 15 grams or 0.015kg. The acceleration of gravity is 9.81 m/s^2. We approximate that we will pick up the piece with a max acceleration of 0.5 m/s^2. We will need 0.15465 N to pick up the piece. The pressure of the vacuum needed is determined through this equation, $P = F/A$. The pressure we need is based on the size of the suction cup we choose. We are thinking of using a suction cup with a .2 inch diameter which is a 5.08mm diameter and 2.54mm radius. The area of the suction cup is $A = \pi r^2$ so the area of the suction cup will be 0.00002026829m^2. With this force and area the pressure of the vacuum pump will need to be 7630.14 Pa. The vacuum pump we plan to use will have a max vacuum pressure of 420 mmHg or 56 kPa. The parts we plan to use will be able to lift the puzzle pieces.

## 3 Ethics & Safety

There are a few ethical and safety concerns that we must consider when building our automatic puzzle solver.

### 3.1 Ethical Concerns

- Privacy (IEEE 8.7, ACM 1.2): Camera data might capture sensitive information unintentionally.

    - Mitigation: We will minimize data collection, anonymize data wherever possible, obtain informed consent, and adhere to data privacy regulations.
- Transparency and Explainability (IEEE 8.3, ACM 2.7): Understanding the robot's decision-making process is crucial.
    - Mitigation: We will develop explainable algorithms, provide visualizations of the robot's reasoning, and allow for human intervention if needed.

### 3.2 Safety Concerns

- Physical Safety (IEEE 8.1, ACM 2.1): Moving parts and potential pinch points pose risks to people and property.
    - Mitigation: Ensure safe operation around people, adhering to safe distances and clear communication protocols.
- System Reliability (IEEE 8.8, ACM 2.3): Malfunctions or errors could lead to safety hazards.
    - Mitigation: Rigorous testing, fail-safe mechanisms, and regular maintenance are crucial.

### References:

"IEEE code of Ethics," IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 07-Feb-2024].