**University of Toronto**
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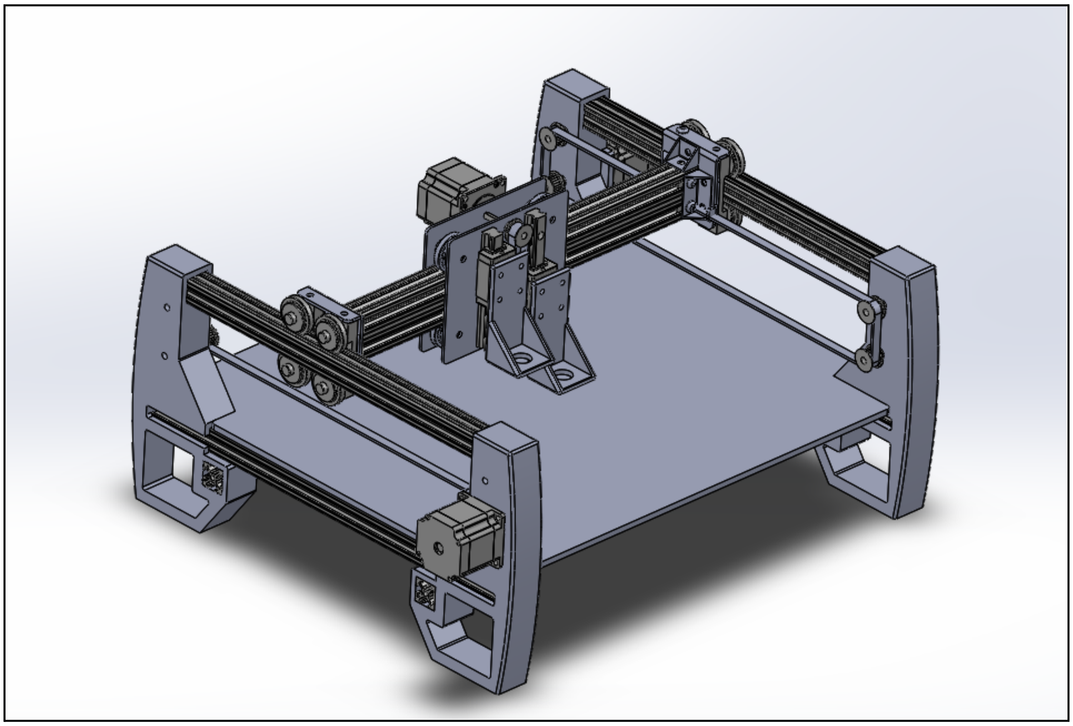

# Pick and Place Machine Design Report


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## Introduction

Pick and place machines are a common machine that are used in a variety of applications. Pick and place machines are often used in the realm of surface mount printed circuit board (PCB) for assembly and manufacturing.They offer a higher degree of accuracy and much higher speeds compared to hand placing. However, there are currently not many surface mount assembly pick and place machines available for educational usage at a desktop scale. Our client has commissioned a small batch, desktop pick and place machine. This document outlines the design process our team used in order to design a CAD model of a functioning surface mount pick and place machine. Multiple designs were considered and explored. Each design was then evaluated using a series of metrics outlined in the functions, objectives, and constraints section. Upon a rigorous review, it was decided a ‘printer’ like design would be the optimal choice, due to its high performance in speed, accuracy, and cost metrics. The design our team has created applies a series of standardized parts in order to save cost. These parts have been carefully selected and the reasoning behind them has been analyzed in this document as well.

## Problem Statement

Our client wants a small batch desktop pick and place machine for surface mount PCB assembly in university based settings. The device will aid in electronic education and thus must be somewhat versatile. The device should pick and place automatically, and do so reliably and with little set up. Input to the device would be surface mount components stored on standardized reels. The device will be applied in university settings with small scale fabrication in mind.

## Service Environment

As education is a focus for the design, the service environment will have a focus on university based settings. Specifically, our design is intended to be used in university lab settings in North America. Our design should utilize a 120V, 60Hz electric input, and can use internet access. As lab property, the design is also unlikely to move often.

## Functions, Objectives, and Constraints

The purpose of explicitly stating the functions, objectives, and constraints of the design is so that during the design process, these metrics can be used to guide the design process. Furthermore, these metrics can be applied to evaluate the successfulness of the design after the design process.

The functions listed below are essential to achieve automated PCB assembly. The design should be able to fulfill the two primary functions shown in table 1. These primary functions can then be broken down into the following secondary functions to further explain the necessary functionality of the design. To optimize our design, we've selected objective metrics and goals based on functions, service environment and context, as well as research on existing standards. These objectives are ranked top to bottom in terms of importance in table table 2. It is important to note that if an objective is not met, the design could still be valid, the design is only disqualified if it does not pass a constraint. In table 3 below, the design constraints are listed. If any design constraint is not met, a design will be disqualified from consideration.

| Primary Functions | Secondary Functions |
|---|---|
| Pick up components from reels | • Store reels<br>• Feed reels<br>• Fetch components from reels |
| Accurately place components | • Movement of components along horizontal plane<br>• Movement of components vertically<br>• Detach components at desired locations |

Table 1: List of Functions Design Should Accomplish

| Objective | Metric | Goal | Justification |
| --- | --- | --- | --- |
| Cost | Minimize cost ($) | $5000 | A lower cost will enable the design to be more accessible. Goal based on existing mid-range desktop designs |
| Accuracy | Minimize repeatability (mm) | 0.05mm | Accuracy will allow for a wider range of applications and less assembly failure. Goal based on existing desktop models. [1][2][3][4] |
| Placement speed | Maximize speed of placement (PCS/h) | 5000PCS/h | A higher placement speed will allow for more usage. Goal based on existing models. [1][2][3][4] |
| Weight | Minimize weight of the machine (N) | (238-89)*2=298N | Less weight is desirable as it allows for easier movement of the machine if required [5]. |
| Desktop footprint | Minimize machine base size (square inches, length by width) | 24” by 32” | Should be smaller in size—able to fit on an average lab desktop [6]. |
| Working space | Maximize compatible board size (inches by inches) | 18” by 24” | Machine base should be able to support common PCB sizes [7]. |
| Configuration speed | Minimize setup time of a single operation | 5 minutes | Less time to set up the design will enable more usage. |

Table 2: List of Objectives Design Seeks to Perform

| Constraint | Metric | Limit | Justification |
|---|---|---|---|
| Assembly speed | Minimum parts/components per hour (PCS/h) | 2000PCS/h | PCB assembly shouldn't take too long, must be suitable for educational settings. Value based on existing models, and adjusted for design context. |
| Cost | Maximum price (dollars $) | $8000 | Must be affordable to educational institutions that cannot afford industry level machines [8]. |
| Electric compatibility | Electrical input compatibility (Volts, amps, KWh) | 120V, 60Hz | PnP machine must be compatible with outlets in labs |
| Working Space | Minimum compatible board size (inches by inches) | 9" by 12" | Machine must be able to work within the size of a PCB [9]. |
| Safe movement | Maximum force applied by machine (N) | 34.2-19.5=14.7N | Machine movement should not exceed a force threshold for hands to avoid causing safety hazards and board damage. [5] |
| Placement accuracy | Maximum repeatability (millimeters) | 0.1mm | Placement of components must be within a tolerable radius for the board to successfully accept the component. |
| Safe & responsive | Should be equipped with sensors that stop the machine when pressure is sensed | As soon as the sensor detects pressure. | Forceful contact between the nozzle and board should be avoided to prevent board damage and safety issues. |

Table 3: List of Constraints the Design must meet

## Engineering Specifications

The design must be able to pick up, rotate and place parts for PCBs from 8mm reels with an accuracy of 0.05mm and at a minimum speed of 1500 CPH without disturbing any parts that have already been placed on the board. The motor itself requires a stopping accuracy of 0.1°in order to achieve that. Any parts on 12mm feeders or on stick feeders and matrix tray holders will be hand placed by the user. The machine will be used in a university setting where it should be able to fit on a 24’’ by 32’’ desk and have minimal setup from the user. The device should be resistant to wear, and is expected to be easily serviceable and maintainable.

## Candidate Designs

### Parallel Manipulator

This design applies multiple non planar linkages to form a parallel manipulator. The design functions with three electric motors acting to give 3 different axes of movement. Range of movement is fairly high but the size (height) of the design must be fairly tall [10]. In addition the math behind controlling them is complex. Due to the nature of applying lightweight linkages, parallel manipulators often reach extremely high speeds in industry [11].

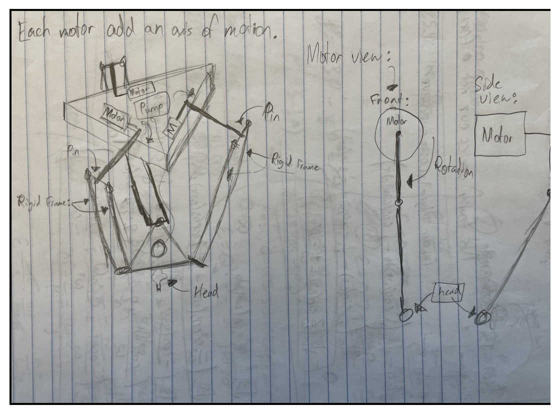


Figure 1: Sketch of a parallel manipulator

### Printer

This design makes use of 2 long belt and pinion systems each with their own motor to give the nozzle holder 2 axis of movement, and the last axis is achieved by a gear train connected to another motor in order to move the nozzles themselves in the vertical axis. These movements are fast and highly controllable due to the lack of noise between the belt and pinion system [12]. The system’s simplicity also lends itself to easy maintenance or repair as eventually the belts of the design will wear. [13]

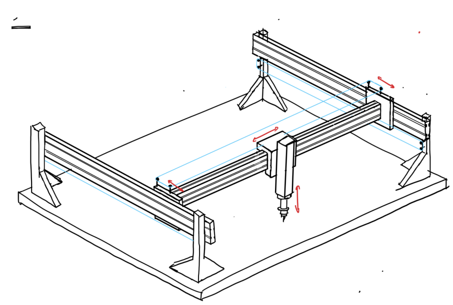

Figure 2: Sketch of the printer design

### Robotic Arm

This design uses a robotic arm, either linear/cartesian or rotational/multi-axes. The robotic arm could be made using a system of rails and motors—somewhat similar to the printer design—or by buying existing arm components and fitting them. This design can be very compact and lightweight, and is decent in terms of accuracy and speed.

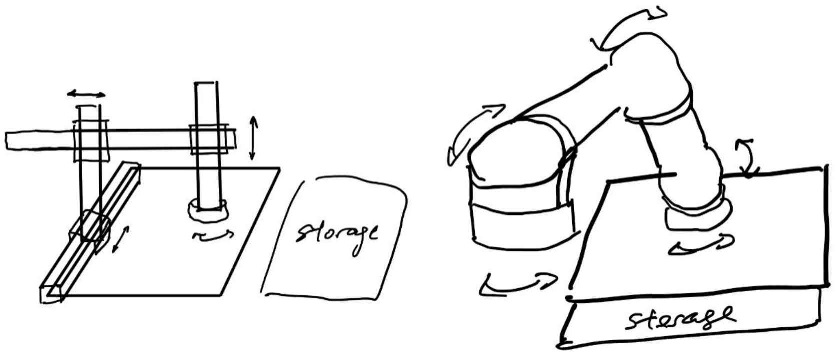


Figure 3: Sketches of possible robotic arm designs

## Candidate Selection

| Objectives | Parallel Manipulator | Printer | Robotic Arm |
| --- | --- | --- | --- |
| Speed | Extremely high. Unclear on desktop speeds. Industry: speed = 5.5m/s, Acceleration = 165m/s^2 | The belt and pinion systems used to control movement in all directions are able to accelerate and decelerate quickly. Around 5000PCS/h. | Speed is not prioritized, not mention in available models found. |
| Accuracy | With proper setup, it can be extremely precise. Depends deeply on components, not a limiting factor. Existing models' repeatability | Desktop models usually have a repeatability of around 0.02mm-0.05mm | 0.2mm (0.1-1mm) repeatability [14] |

| | | | |
|---|---|---|---|
| | around 0.1mm | | |
| Weight | Lightweight materials must be used. Depending on material choice, weight varies. | Lightweight yet durable materials would be used as the guiding arms. It should be able to be picked up and moved. Existing models are around 50kg | Around 5-10kg for the arm, but will also need base and feeder mechanism [14][15] |
| Cost | Development costs are high however material costs are low. Due to the requirement of 4 motors compared to the 3 of printers, will most likely be more expensive. | Due to the simplicity of the linear actuators, the design will be relatively cheap to create. Existing models are around $5000, and parts are more common. | $1000+ for one that fits constraints, not including base and feeder. |
| Size | Large due to scaling requirements to create more working space. See above images… | For typical PCB board sizes (within 30” by 30”) this design will easily be able to fit on regular desk sizing (within 80” by 80”). | Desktop: up to 50cm long, within a 10cm by 10cm base. |

Table 4: Comparison of Candidate Designs According to Primary Objectives

To select a proposed design, we compared the three candidate designs according to the main objectives of speed, precision, weight, cost, and space. Research and analysis for the estimated capabilities of each design are listed in the table above, with dark green indicating the most desirable design for each criteria and light green indicating second desirable.

For speed, the printer design excels with an efficient use of motors along simplistic axes of motion. The parallel manipulator design is likely to match this standard, being the top choice for speed in the context of manufacturing. However, a scaled down parallel manipulator design may suffer more in terms of speed due to a more difficult optimization process and more complex motion patterns based on arm rotation. Desktop robotic arms tend not to prioritize speed, and even industrial models cannot move as fast as the other designs due to less support for motion.

For accuracy, the printer also tops the three designs, boasting the lowest repeatability. The parallel manipulator is also highly accurate with slightly higher repeatability, indicating slightly lower accuracy. Robotic arm designs usually have a repeatability about an order of magnitude higher than printer designs because their motion is more complex and reliant on rotational movement.

As for weight, desktop robotic arms models have been optimized to be very lightweight, with some weighing only 5-10kg. Parallel manipulators can use lightweight material, and have a relatively minimal frame, however they don’t scale well, so to achieve a good working space will require more material and weight than a light robotic arm. Printer designs generally have a relatively heavy base and components, but are still light enough to be lifted by 1-2 average university students.

Regarding costs, a printer design would be cheapest, with the most standardized parts and available market alternatives. A robotic arm design comes in second as it would require more customization to adapt to the reel feeding system and component retrieval, but the arm itself is available for cheap from producers. Lastly, a desktop scale parallel manipulator is not widely produced, and would require the most customization to put together, leading to the greatest costs.

Finally, robotic arms tend to be the most minimal in terms of size, with a printer design coming in second, referencing available options online. A parallel manipulator would come in last due to its poor size scaling when it comes to increasing working space.

## Design Analysis

| **Design Choice** | **Primary Selection Reason** | **Explanation** |
|---|---|---|
| Legs made of plastic | Cost, Weight | The legs have been chosen to be made of cheap plastic as they just need to be able to support the weight of the overall design. |
| Linear rails made of aluminum, t-slot framing + rollers | Cost, Ease | The part used is a standardized part taken from McMaster Carr. |
| Plates, brackets, gussets, flanges; as made of aluminum | Weight, Cost | Aluminum has been selected due to its density, cost and durability. |
| Rotational to linear converters; timing belts and pulleys | Cost | Selected are standardized parts from McMaster Carr. This will lead to a lower cost. |
| Acrylic Base | Material properties, Cost | Acrylic sheets have high durability and stiffness which means that the base will not flex easily and disrupt the PCB. The material itself is also cheap to produce and easily replaceable should an accident occur |
| Stepper motors | Performance | Stepper motors are not that expensive yet they are extremely accurate. Accuracy is vital to the design and such they have been chosen over a potentially cheaper alternative. This part is also standardized from McMaster Carr. |
| 8mm vacuum nozzle holder with interchangeable Juki nozzles | Versatility, Cost | A 8mm diameter nozzle holder was selected, to be compatible with 500 series standard application Juki Nozzles, which are commonly used for the assembly of SMT and PCB components. Nozzles are interchangeable to adapt to components of different sizes and weights. These nozzles are also relatively cheap, available online for around $5 [16]. |

Table 5: Component choices for printer design and rationale for selection

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