

Design of a micromanipulator for repairs of printed circuit boards

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Abstract: This work deals with design of micromanipulator based on pantographic mechanism with electronic control. The main purpose of this micromanipulator is repairing printed circuit boards, but it has been designed to be universal for any use case. The main focus is on creating device that will have the highest possible accuracy, while still being able to provide necessary force to carry out mechanical repairs of printed circuit boards. The work contains the design of the pantographic mechanism, stepper motor based electrical drive section and control circuits with power supplies.

Keywords: Micromanipulator, Pantograph, Repair of printed circuit boards, Design

1. INTRODUCTION

Printed circuit boards are the main building block of most electrical devices. Modern printed circuit boards are being made with focus on minimalization. The effort is to fit same or more complex circuits on the same, or smaller space, with utilizing the use of smaller and smaller conductive traces, vias, embedded components etc. This is increasing the complexity of printed circuit boards and also increasing the chance for failure to appear in manufacturing process, soldering process, desoldering process and during repairs. Since the printed circuit boards are so complex and the occurring failures are so small, the repairs can't be done using normal tools like tweezers etc. This process requires usage of specialized equipment designed for this purpose. The equipment in question is called micromanipulator. It is a device that allows user to manipulate with instruments in very small distances, mainly in order of micrometers.

Commercially available micromanipulators can be really expensive, so the main focus of this work is to design a special kind of micromanipulator with usage of mechanical pantographical mechanism to scale down the movement of electrical drive section, that will be significantly less expensive, while still approaching the parameters of the ones commercially available.

Pantograph is a simple mechanism that was mostly used for recreating and redrawing pictures while simultaneously changing their size. The most basic one is consisting of 4 arms that are connected in specific shape that is pictured in figure 1 [1].



Figure 1: Example of pantographic mechanism [1]

2. DESIGN

The designed micromanipulator is intended to be used for repairs of printed circuit boards, but the way it is designed in allows it to be used in any scenario. The output of this mechanism is designed as a shaft on which can be mounted anything from knives for scraping, to attachments for wirebonding. The workspace is around 25 mm x 25 mm x 25 mm, but not strictly limited to it. This is the minimal workspace with which was this device designed, the real usable workspace will be determined when the device is constructed. This device only purpose is to serve as “arm” that can move desired tool in desired space, with desired accuracy. This means that this device needs to be used alongside with some means of holding the repaired object and because of the small nature of the movements, use of some type of microscope is recommended. Because of that, this device can be used alongside with any other device, which makes it truly universal.

2.1 REQUIREMENTS

The main requirement was to create micromanipulator, that would be capable of moving tools in the order of micrometers. Second requirement was the use of pantographic mechanism to scale the movement down. Last requirement was to design electronic drive section that would allow the use computers or joysticks for the control of the movement.

Theoretically the designed mechanism would be able to move in steps as small as 150nm, in reality this number will be much bigger because of the backlash and tolerances introduced because the mechanism will be handmade on lathe and mill. The aim will be to achieve tolerance of somewhere about 1-10um.

Pantographic mechanism is used to scale down the movement. The design of the pantographic mechanism is inspired by design of company SINGER which is called MK1 Manipulator and it is based on patent from 1950 made by Robert Barer and A.E.Saunders-Singer [2]. This design is on figure 1. Basically, it contains two basic pantographic arms connected via ball bearings. This allows to translate and scale down movement in every axis including tilting. The design of electrical drive section was inspired by the design of Novel 5-DOF spatial parallel micromanipulator, created by Daniel Prusak, Konrad Kobus and Grzegorz Karpel from the AGH university of Science and Technology from Krakow [3]. Their design is on figure number 2. This design was chosen because it allows full movement in all three axes, and it also allows tilting of the tip.



Figure 2: Manipulator MK1 [2]

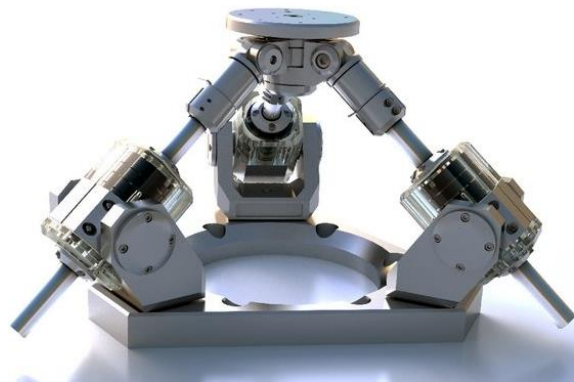


Figure 3: Novel 5-DOF micromanipulator [3]

The last requirement was to allow the use of computer or joysticks to control the micromanipulator. Because of that, the Raspberry PI ZERO control board was chosen. It is basically a small computer, so it covers the first part, and it is equipped with USB connectivity. Thanks to that it will be possible to use any kind of joystick, or other device, equipped with USB to control the micromanipulator.

2.2 MODEL

The model shown on figure 3 was created in program called Autodesk Inventor 2022. Aluminium extrusions were chosen for the construction of the main body. Electric drive section has the same motor and axis placement as Novel 5-DOF micromanipulator. Everything else was customized in a way to be constructed from commonly available parts and or from parts that can be created on mill or lathe. Our design is made up of three identical legs. Each leg contains one stepper motor, mounted on bearings for smooth movement and trapezoidal screw for transferring rotational movement of the

motor to linear movement. The chosen stepper motor has higher strength, which is essential for any kind of mechanical repairs. The trapezoidal screws were chosen with gradient of 2 mm per rotation, for smaller sizes of steps. For now, the mechanism used for leading the nut on the screw it designed as piece of machined aluminium. If it proves to be the bottleneck in terms of accuracy and tolerance, it will be replaced with linear guides. All three legs are connected via magnetic ball bearings to one single base, which then moves just like an ordinary delta 3D printer. Thanks to the addition of ball bearings, the whole base can be tilted in any direction.

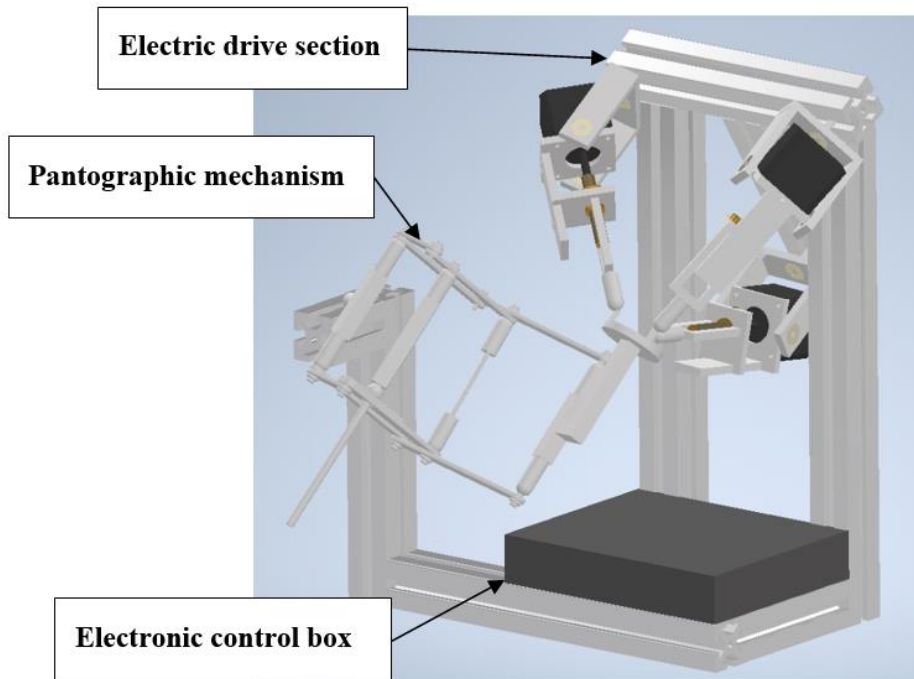


Figure 4: 3D model of designed micromanipulator

The design of pantographic mechanism is similar with Manipulator MK1 with the use of two pantographs parallel to each other and connected via ball joints. The dimensions of our design were calculated using mathematical model created in Microsoft EXCEL to find the correct lengths of arms to ensure no distortion of movement and to find out the size of movement reduction. The final movement reduction was chosen to be 4x. Similarly, to the electric drive section, the pantographic mechanism uses magnetic ball bearings.

2.3 ELECTRONICS

As was stated before, the main control board was selected to be Raspberry PI ZERO. The control program is created in Python. To power the stepper motors, specialized stepper motor drivers had to be chosen. Driver called A4988 was chosen, because it is capable to support the nominal current of our chosen stepper motors and it also allows the use of microstepping, which allows even smaller step sizes. Endstop switches were also added to the electric drive section to allow for quick calibration.

The stepper motors each require current of around 2 A at 12 V. The Raspberry PI ZERO requires around 1 A at 5 V and the stepper motor drivers require around 10m A at either 3,3 V or 5 V. Because of the currents required to run the motors, a primary source of 12 V was chosen, which is capable of supplying 6 A. To supply the control circuits, a DC-DC step down converter was chosen for supplying 5 V.

3. CONCLUSION

This work deals with the design of pantographic micromanipulator. The final design is shown on figure 4. The design is made up of three parts. The pantographic mechanism was designed to scale down the movement of the electric drive section by the factor of four and at the same time to not distort the movement. The design of electric drive section powered by stepper motors is using ball bearings and trapezoidal screws with the gradient of 2 mm to allow for the smallest possible steps with as small play and backlash as possible. Finally, the control circuits and power supplies were chosen to accommodate the used stepper motors and to allow smooth control via any device supporting USB, mainly joysticks.

The device is currently under construction. The electric drive section is completed, alongside with the main chassis. Right now, we are waiting for ordered parts to be delivered.

The control program is also in development. The mathematical model that determines the correct movements of the motors is currently being written and tested.

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