

Development and construction of a 2D Laser Scanner

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1 Introduction

Many of Laser scanning systems for material processing today are based on galvanometer-actuated mirror systems and utilize fiber lasers ($\lambda = 1064nm$) for efficient and fast engraving on metals. However, galvanometers are expensive and complicated to drive. This projects goal is to create a similar system using stepper motors, which are very simple to use and laser diodes ($\lambda = 650nm$ and $\lambda = 445nm$). The secondary goal is to create a cheap but accurate drive system which should be possible to build with minimal tools (3D-Printer, lathe (optional) and basic soldering equipment) from scratch. For this sake, two versions will be built, the first one utilizing a low power laser diode and no f-theta lens for a safe proof-of-concept and the second one utilizing a high-power laser diode for engraving.

In this documentation, the mechanical, electrical, mathematical and programming side of the project will be discussed.

2 Theory

In this section, relevant theory will be discussed. The development of the scanner will be based on these details.

2.1 Laser diodes

Laser diodes are special semiconductors that emit spatially coherent and monochromatic light of a specific wavelength λ (laser beam). Laser diodes are relatively fragile components which electrically behave similar to normal diodes, meaning low resistance in one current direction and high resistance in the opposite direction. For laser diodes to work properly, they must be driven with a constant current¹. Therefore, it is good practice to use constant current sources and heatsinks for driving laserdiodes. Also, laser diodes oftentimes emit laser beams with relatively high divergence, so a collimator is required in order to reduce the divergence to a few *mrad*.

2.2 Stepper motors

Stepper motors reach high positioning accuracy by performing movements in discrete steps (usually 1.8°). The appropriate winding currents are supplied by stepper motor drivers. These drivers are given two signals: STEP and DIR. One STEP pulse from the controller advances the motor position one step, whilst the DIR signal (low or high) indicates the direction. The accuracy can be improved by using special drivers which interpolate the rotation between poles (micro-stepping).

¹Laser diodes are easily damaged by current spikes or excess heat

2.3 Optics of the scanner

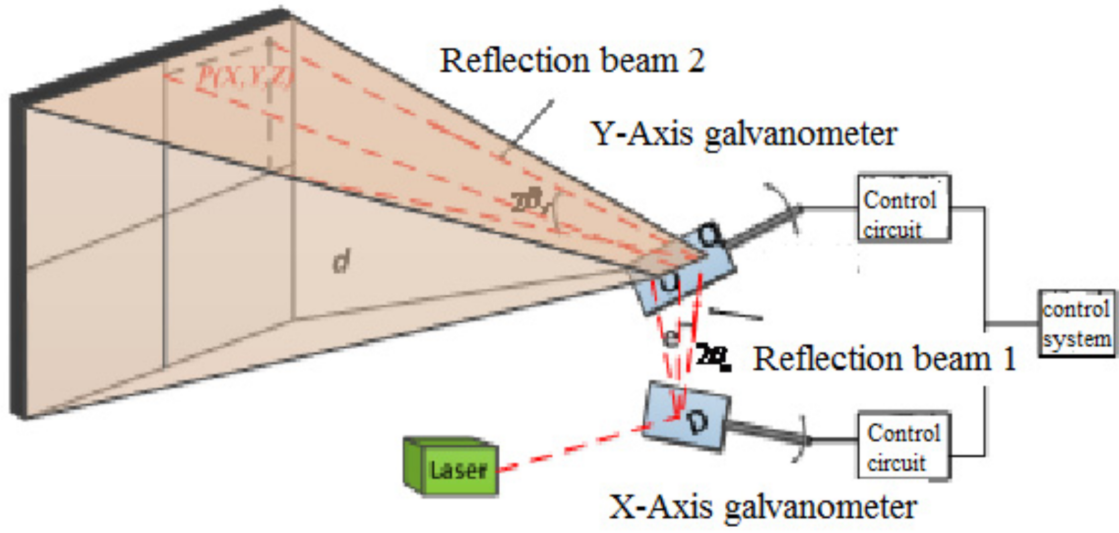


Figure 1: Model of the optical mirror system [?]

Because the scanner can only indirectly control the laser dot on the working plane by turning its mirrors, some sort of mathematical representation of this system must be derived. This representation will be used for turning XY-directions into mirror rotation angles. From [?] we get the following equations:

$$x = e \cdot \tan(2\theta_x) + \tan(2\theta_x) \cdot \sqrt{d^2 + y^2} \quad (1)$$

$$y = d \cdot \tan(\theta_y) \quad (2)$$

where x and y are the point coordinates on the plane, θ_x and θ_y are the rotations angles of the mirrors², e is the vertical distance between the mirror axes and d is the normal distance between the projection plane and the Y-mirror rotation axis.

Since x and y are given by the user (rather the gcode), equations ?? and ?? must be solved for θ_x and θ_y . These angles will be turned into step signals for the steppers. From equation ?? we can derive

$$\theta_y = \frac{\arctan(\frac{y}{d})}{2} \quad (3)$$

From equation ??, θ_x can be found:

$$\theta_x = \frac{\arctan\left(\frac{x}{e + \sqrt{d^2 + y^2}}\right)}{2} \quad (4)$$

²More specifically: θ_x is the angle between the laser beam and the first reflection beam minus 90° . Similarly, θ_y is the angle between the first and second reflection beam minus 90° .

Looking at figure ??, x and y must be zero, when $\theta_x = \theta_y = 0^\circ$ ³. Equations ?? and ?? confirm this.

3 Implementation

In this section, construction details of the galvo scanner will be explained.

3.1 Mechanics and Optics

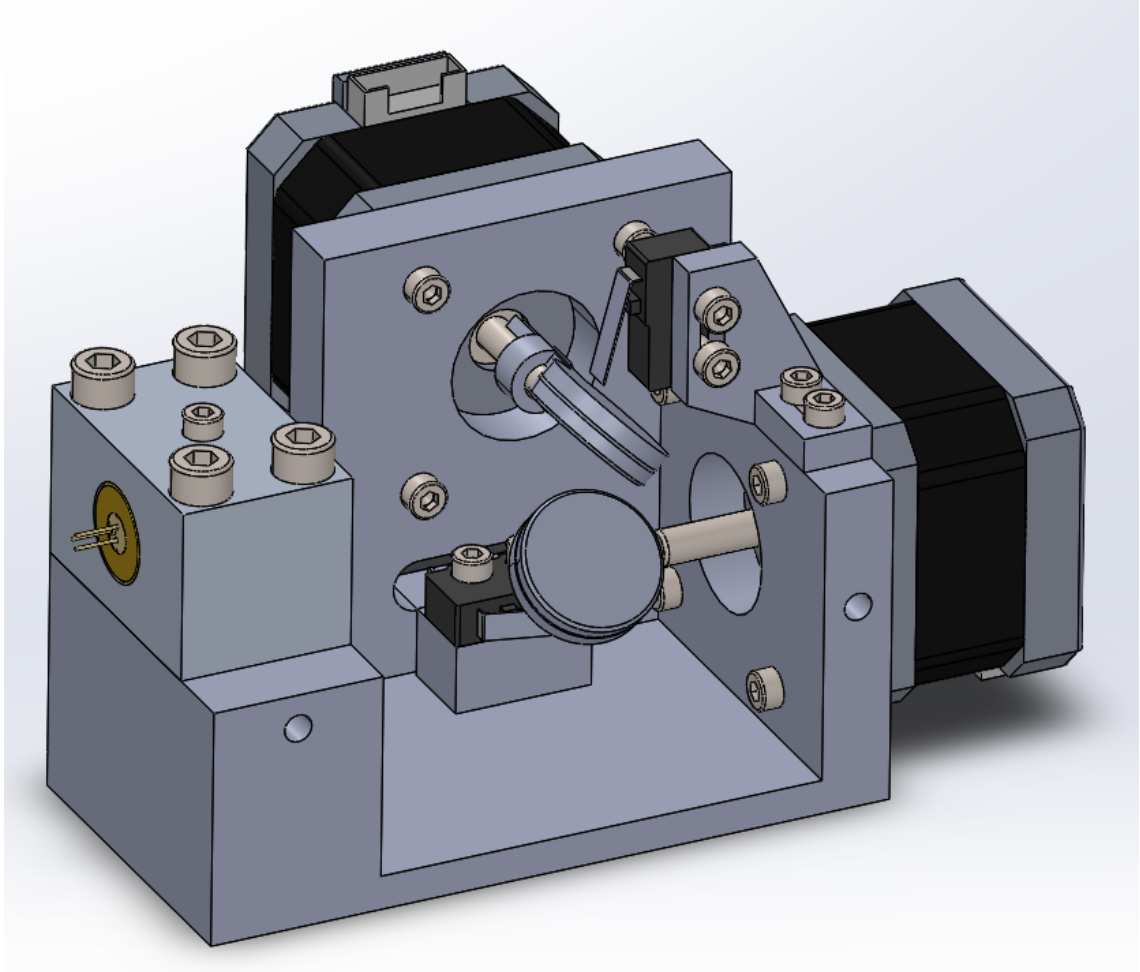


Figure 2: CAD-Rendering of the mechanical system

³with these angles, all beams are orthogonal. This configuration is referred to the neutral or home position.

The mechanics of this design are relatively simple: The mirrors are attached to stepper motors which are screwed onto the 3D-printed base. This base also has features to screw on endswitches (for homing the mirrors) and the laserdiode array. The latter consists of a machined aluminum block into which the laserdiode holder (machined brass) fits. This holder also has a M9x0.5 thread for the collimator unit. The collimator can be adjusted via this thread.

3.2 Electronics

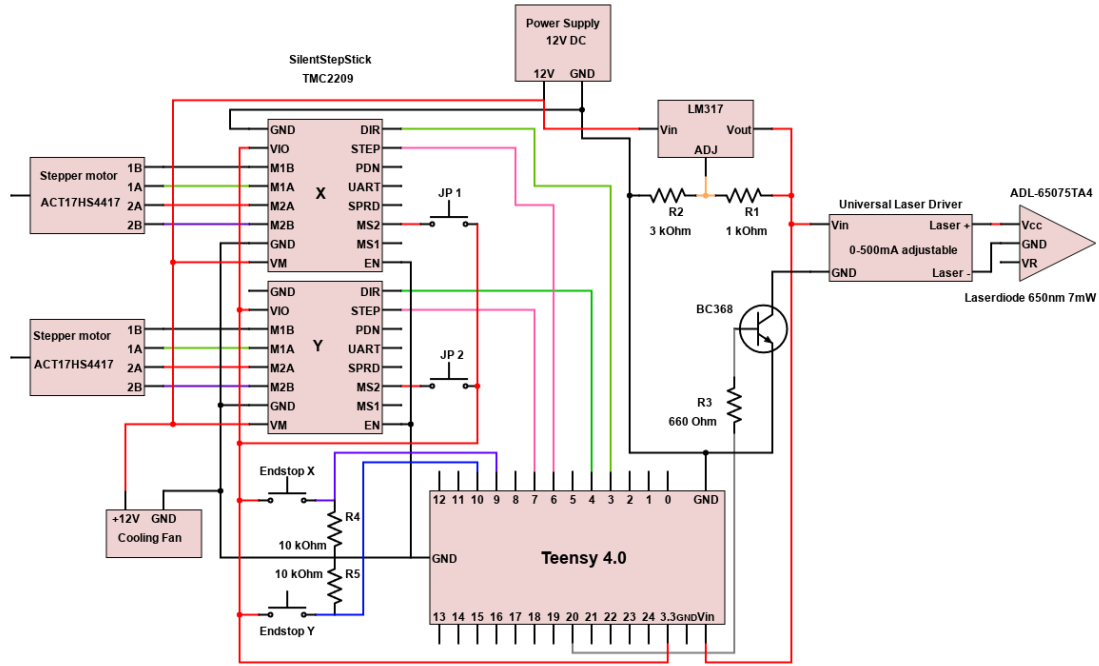


Figure 3: Wiring diagram for the system

Figure ?? shows the electrical diagram of the system. The Stepper motors are Nema-17 ACT 17hs4417 steppers. The SilentStepSticks (containing Trinamic TMC2209 ICs) were chosen as drivers because of their high micro-stepping capabilities (up to 256), extremely low noise and relatively low cost (about 10 Euros/driver).

For the main controller, a Teensy 4.0 was chosen because of the extremely high clock frequency of 600Mhz⁴ and its easy programmability through the Arduino IDE. It must be noted, that the Teensy 4.0 only tolerates 3.3V logic voltage.

⁴In comparison, an Arduino Nano only has 16MHz clock frequency!

Note: Teensy Boards and laserdiodes can be very fragile electrical components (multiple Teensies and Diodes were destroyed in this project), so it may be worth the money and effort to use an Arduino (Nano in this case) in order to test the circuits/code and use dummy loads for simulating laser diodes. Since the SilentStepStick-Drivers can tolerate 3.3V and 5V as logic voltages, the microcontrollers can be changed without changing the circuit. However, the footprints are not equal, so jumper cables are necessary for replacing the Teensy with an Arduino.

For driving the laserdiode, a special diode driver is used, which can supply 0-500mA of constant regulated current⁵.

This driver circuit is activated by a NPN-Transistor (specifially, a BC368). For calculating its base resistance R_2 , a base current of the BC368 transistor of $I_B = 5mA$ is selected [?, p. 3]. Since the Teensy 4.0 logic voltage is 3.3V, a resistance value of $R_2 = \frac{3.3V}{5mA} = 660\Omega$ is selected.

The Laser diode has three pins: V_{cc} , GND and VR . V_{cc} is connected to the output of the constant current source, GND is connected to the Collector of the transistor to switch it on or off. VR is left unconnected. For supplying V_{cc} (5V) for the Teensy, a LM317 linear voltage regulator is used in the shown configuration.

3.3 Code

The programm architecture consists of three main parts: The teensy firmware, a python script for Gcode transmission and the Gcode itself.

3.3.1 Firmware

3.3.2 Transmission script

3.3.3 Gcode

4 Results

References

- [1] Xianyu Meng, Guohua Cao, Xue Li, and Qiongying Lv. 2-D Scanning Galvanometer Error Analysis and Its Correction. *Journal of Physics: Conference Series*, 1345:022068, 2019.
- [2] LM3173-TerminalAdjustableRegulator, 1997.
- [3] NPN – BC368; PNP – BC369 Amplifier Transistors, 2007.

⁵It is possible to use a LM317 and correct resistors for a constant current source. This was tested in this project, but resulted in a lot of destroyed laser diodes, which is why a complete driver circuit was bought.