DESIGN AND FABRICATION OF SMALL SCALE LASER CUTTING MACHINE

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ABSTRAK

Pemotongan pelbagai jenis bahan menggunakan laser adalah pilihan utama dalam industri-industri sejak beberapa dekad lalu memandangkan kelebihannya dalam ketepatan kontour, kualiti, produktiviti dan fleksibility berbanding dengan pemesinan konvensional. Mesin pemotongan laser CNC automasi lazimnya mempunyai saiz besar, berat dan memerlukan modal yang tinggi. Kelemahan mesin ini telah mengehadkan aplikasinya, oleh itu jarang digunakan dalam industri-industri yang berskala kecil dan medium. Objektif thesis ini adalah untuk membangunkan satu mesin pemotongan laser skala kecil yang ringan dan mudah alih dengan harga yang berpatutan. Pelbagai jenis laser, sistem mekanikal dan firmware elektronik telah dikajikan. Mesin pemotongan laser yang dikemukakan mengunakan 5.5W diod laser, mekanisma H-bot, struktur aluminium, mikropengawal Arduino dan perisian sumber terbuka. Model ini digambarkan dalam software CAD selain simulasi dan pengiraan penting dilakukan. Prototaip selesai mempunyai kawasan kerja bersaiz A5, keberatan 1.7kg, kos RM1230.85 dan dapat memotong bahan-bahan uji seperti thermoplastics, Nomex, polypropene, kayu, kain serta kertas. Pengubahsuaan pada struktur mekanikal terutamanya pemasangan gelangsar telah dicadangkan untuk penambahbaikan. Reka bentuk ini mempunyai prospek cerah dalam meningkatkan prestasi industry-industri skala kecil dan medium, mempromosikan penyelidikan dan prototaip; dan menggalakkan individu yang lebih kreatif dalam masyarakat.

ABSTRACT

Cutting various types of material using laser has been highly preferred in industries over the decades due to its benefits in terms of contour precision, quality, productivity and flexibility compared to conventional machining. The CNC automated laser cutting machine often comes in a large size, heavy weight and demands a high capital investment. This shortcoming of the machine has limited its application and rarely used by small and medium- scaled industries as well as non-manufacturing sectors. This thesis aims to develop a small- scaled laser cutting machine which is light and portable at an affordable cost. Different types of lasers, mechanical systems and electronic firmware were reviewed. The proposed laser cutting machine utilized a 5.5W diode laser, H-bot mechanism, aluminium structure, Arduino microcontroller and open source software. The model was illustrated in CAD software besides necessary simulation and calculations were performed. The finished prototype had a working area of A5 size, weighed 1.7kg, cost RM 1230.85 and was able to cut the tested materials, which include thermoplastics, Nomex, polyproprene, wood, cloth and paper. Modification on the mechanical structure especially the slider assembly was suggested for further improvement. This design had a bright prospect in enhancing the industrial performance in small and medium-scaled industries, promoting research and prototyping; and encouraging more creative individuals in society.

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND

Laser, simply stands for "Light Amplification by Stimulated Emission of Radiation", was developed fifty years after the discovery of principle of stimulated emission the famous scientist Albert Einstein in 1916. Generally, a laser is produced through the emission of photons when excited electrons return to their normal or ground state. Differing from conventional light wave that loses its intensity inversely proportional the square of distance, a laser on the other hand is a monochromatic light that is highly collimated and coherent. These properties enable laser to have exceptional intensity and direction ability. It has low divergence and thus produces a very straight propagation. Moreover, it can travel over relatively long distances with negligible losses of energy. It can even be compressed into a stream of short pulses to enhance the energy transferred.

Due to these special characteristics of laser, laser technology has been growing rapidly over the decade. Laser cutting is one of the industry leading technologies for cutting various types of materials. It offers significant advantages over conventional machining. It is able to produce complex geometries with high precision and tight tolerances. The localized heat affected zone (HAZ) helps to produce a good cut quality. Besides, it also operates in fast cutting speed which in terms increases the productivity [1]. It even outperformed competing techniques like plasma arc cutting, punching, sawing etc. in terms of contour precision, contour flexibility, cutting speed and cut edge quality. [2] Not only that, laser cutting is a non-contact technique that does not induce abrasive forces. Therefore, the tool wear, machine-tool deflections, vibrations and cutting forces could be greatly reduced [3]. Because of this, laser is suitable to cut almost all types of materials.

Laser cutting process can be easily automated using the Computer Numerical Control (CNC) system. CNC system is basically a system that allows user to control the tool‘s or part's motion through numerical data. G-codes are the common programming language used in CNC machines as they are easy to understand by operators. It utilizes point to point operation and able to operate tool in x, y and z directions as well as linear interpolation, clockwise or counter clockwise interpolation etc [4]. Nowadays nearly all laser cutting machines apply CNC automation in order to increase precision, increase quality, reduce labour work, save time and for safety purposes.

1.2 PROBLEM STATEMENT

Although laser cutting technique has been promising, it requires a high capital investment to start up. This is the main setback in small and medium sized industries for not using laser cutting technique. The large-sized laser cutting machines also take up a lot of floor space. Moreover, laser cutting machines are often heavy and bulky, which make them hard to be moved or transported. This issue becomes more crucial whenever there is an urgent need to change the plant layout or moving to a new plant. In addition, these undesirable factors also limit the usage of laser cutting technique to majorly industries. Non-manufacturing sectors such as educational sectors, design firms etc. do not prone to choose laser cutting machine in producing their prototypes or final product. Instead, they prefer 3D printing machine for rapid prototyping although 3D printing technique is limited to certain materials such as ABS, PLA and nylon. Rather in fact laser cutting technique can be applied on more types of material such as wood, plastics, rubber, metal and leather besides having a fast processing speed.

Figure 1.1: Industrial Laser Cutting Machine

1.3 PROJECT OBJECTIVES

After analyzed the problems encountered by current laser cutting machines, the following objectives were set for further improvement so that laser cutting machines can be widely used and preferred in both industrial sectors and non-manufacturing sectors.

- To design a small-scaled laser cutting machine with a working area that suits to fabricate common products
- To design an affordable laser cutting machine in which the material cost less than RM 1500.
- To design a light weight and portable laser cutting machine that weighs no more than 3kg.

CHAPTER TWO
LITERATURE REVIEW

2.1 LASER CUTTING THEORY

In order to laser cut material, a high intensity of light generated by laser is directed and focused onto the workpiece surface using lens. The focused beam heats the material locally and when the heat input onto the material is greater than the material's ability to reflect or conduct the added energy, the temperature at that point will increase significantly. When the temperature rise is substantial enough, the input heat will melt or vaporize the material and create a hole. The removed material is subsequently ejected from the surface by a pressurized gas jet coaxially with the beam [5].

The performance of laser cutting is dependent on several parameters. One of which is the power supply. As laser cutting is a thermal process, the amount of heat generated by the given power supply directly affects the cutting performance. The higher power supply will allow a greater depth of cut as well as faster processing speed.

In addition, the type of laser beam mode (cross-section of a laser beam) is another key feature. Type of mode denotes the beam's ability to be focused, analogous to the degree of sharpness of tool. The preferred laser beam is described by TEM_{00}, which is the lowest order beam of electromagnetic wave that resembles a Gaussian distribution. Laser beam with fundamental mode theoretically can focus to its minimum spot size and produce the greatest power density. Multi-mode beam will tend to disperse the energy away from the center beam.

Moreover, polarization has a noticeable effect on cutting quality as it can influence the relative degree of absorption of the beam's energy by the material at that particular moment. It may induce inconsistent edge quality due to variations in kerf, uneven smoothness and perpendicularity [6]. To eliminate this phenomenon, laser is desired to be circularly polarized for cutting contours in two dimensions. Circular polarization provides equivalent coupling to the material regardless of the direction travelled.

Besides, wavelength of laser can have different absorptivity by different materials. Generally, most materials are able to absorb laser of shorter wavelength, especially metals. Laser with high beam quality along with shorter wavelength creates a small spot size, and thus produces a narrow cut kerf which allows for higher cutting speed.

A typical laser cutting system comprises of a laser source, beam guidance and focusing lens, gas jet nozzle and CNC-controlled motion system. The laser source produces an unfocused laser beam which is then guided via mirrors or fiber optics to the focusing lens and subsequently focused to a small spot size on the workpiece. The gas jet nozzle is located coaxially with the laser processing head. Relative motion between the workpiece and laser beam is achieved either by mechanically moving the CNC XY table, or moving the gantry that holds the laser processing head, or moving the focused laser spots via the mirrors. Hybrid system is also available whereby the workpiece is moved along one axis while the laser spot is moved in another axis [7].

2.2 BENCHMARK PRODUCT

The development of small scale laser cutting machine has gained great attention in recent years as it is playing a vital role in the market. Small scale laser cutting machine accelerates manufacturing process, promotes creativity and encourages innovation in both industrial and non-industrial sectors.

For instance, the small scale laser cutting machine is suitable for school and university use as an option for prototyping, model making and industrial design. It is another good option compared to 3D printing in terms of variety selection of materials and reduced time elapsed to make prototype. In Kansas, students use laser engraving machines to engrave footballs for homecoming as well as award medals. In Pennsylvania, students use laser beam to engrave on tiles and make coasters as a fundraiser. In Colorado, students in robotics club cut wooden models and etch logos into the bodies of their robots. [8]

Additionally, high technology industries are focusing more and more on micromachining due to the demand on complex geometry miniature feature. Miniaturization tends to minimize energy and material use, less cost, faster device, can be integrated with electronics and thus simplify systems. Advanced machining process like laser beam cutting begins to play a significant role in micromachining. Some useful applications are cutting foils, films, micro-mechanical parts, semiconductor wafers, V grooves, micro characters, slits for scientific instrumentation, DNA micropins, spinneret etc.

Other than that, small scale laser cutting machine is definitely a favorite for designers, architects, artists and craft makers. Designers and architects can easily visualize their design ideas by making models and prototypes. Artists can also produce nice piece of artwork by using the technique of laser engraving. Craft makers can easily make high quality craft by producing own jewelries, woodwork etc. In fact, small scale laser cutting machine can be applicable to every individual. Nevertheless due to the cost factor, the individual and self-employed designers and makers have the greatest barrier towards the application of small scale laser cutting machine.

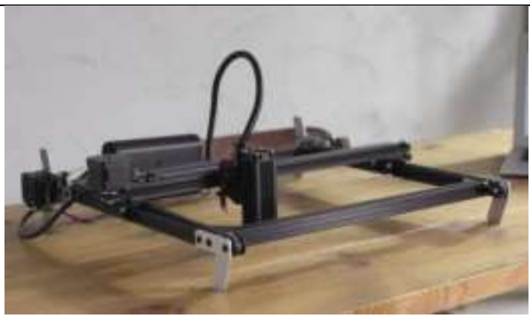
The potential market growth of small scale laser cutting machine has been discovered and several companies have started to step into this trend of scaling down CNC laser cutting systems. In year 2008, pioneer company like Epilog launches their first low cost Epilog Zing Laser. In year 2014, Glowforge laser cutting machine comes into market. Also in year 2014, Mr. Beam laser cutter and engraver has been launched. In year 2016, a Japanese company first releases their FABOOL laser Mini machine. The table below summarizes their products along with technical specifications.

Table 2.1: Existing Desktop Laser Cutting Machine

No.	Laser Cutting Machine	Technical Specfications
1	 Epilog Zing Laser	**Working Area:** 406x305mm **Maximum material thickness:** 114mm **Laser:** 30-40W air cooled CO2 laser **Frame:**

		730x 562x 298mm **Operating Mode:** Raster, Vector **Motion:** Stepper Motors, Kelvar Belts **Ventilation System:** External Exhaust **Weight:** 43kg **Resolution:** 100-1000dpi **Cut:** Wood, Acrylic, Fabric, Leather, Paper, Fiberglass, Rubber, Plastic **Engrave:** Glass, Ceramic, Marble, Painted Metal, Anodized Aluminum **Cost:** $7995
2	 Glowforge	**Working area:** 300x 500mm **Maximum thickness of material:** 13mm **Laser:** 40W CO_2 laser **Beam diameter:** less than 5mm; divergence less than1.2mrad **Frame:** 965mmx527mmx210mm **Features:**

		Factory Fixed Alignment, Sealed Optics **Cut:** Wood, Cardboard, Acrylic, Leather, Rubber, Paper, Delrin, Cork **Engrave:** Ceramic, Anodized Aluminum, Stone, Glass, Marble **Cost:** $2995
3	 Mr Beam	**Working area:** 500x400mm **Maximum object height:** 35mm **Laser:** 5W high efficiency short wave laser (Class 1) **Frame:** Full metal safety housing closed with safety glass lid (710mmx480mmx175mm) **Optional feature:** Fume extraction **Additional feature:** Camera assisted design placement, Wifi connected **Software:** Open source **Cut:** Plywood, Cardboard, Fabric, MDF,

		Balsa, Paper, Felt, Latex, Foam Rubber, Acrylic, Leather **Engrave:** Glass, Anodized Aluminum, **Cost:** $2665
4	 FABOOL Laser Mini	**Working Area:** 300x230mm **Frame:** 540x 485x140mm **Laser:** 1.6W laser diode **Supported OS:** Window 7, Window 8, Window 8.1,Window 10, Mac OS X, Linux, Raspberry Pi **Supported File:** SVG, DXF, JPEG, BMP, PNG, TIF, GIF **Operating temperature:** below 30C **Continuous operating hour:** less than one hour **Cut & Engrave:** Veneer, Balsa wood, Particle board, MDF, Cork, black acrylic **Cost:** $598

2.2.1 COMPARISON AMONG BENCHMARK PRODUCTS

Each of the laser cutting systems shown above has its own advantages as well as shortcomings. Below shows a comparison in terms of cutting ability, size and weight, safety aspects, cost and maintenance.

CUTTING ABILITY: Epilog Zing Laser and Glowforge both use CO_2 laser source whereas Mr. Beam and FABOOL use diode laser. CO_2 laser source is known to have a better cutting ability than lower power diode laser due to the high intensity and good beam quality. As listed above, CO_2 laser source is able to cut more materials such as leather, acrylic, delrin and fiberglass compared to diode laser. For common materials like wood, rubber, paper, fabric, plastic etc.; both laser types are capable to cut most of them. Mr. Beam applies 5W diode laser which performs better than FABOOL 1.6W diode laser.

SIZE AND WEIGHT: Epilog Zing Laser has the greatest weight of 43kg whereas FABOOL has the least weight of 3kg. Lightweight of machine is an attribute as it enables the user to have a portable machine. Mr. Beam has the largest working area, followed by Glowforge, Epilog Zing Laser and finally FABOOL. By having a larger working area, it simply implies that the surface area that can be cut increases. This is clearly an added advantage. Epilog Zing Laser is able to accommodate the largest material thickness, followed by Mr. Beam and lastly Glowforge. The increase of maximum material thickness may not as anticipating as it seems because the total frame size of machine has to be compensated. On the other hand, FABOOL is able to accommodate any height of material as it has an open frame structure. The desired height can be achieved by placing the FABOOL Laser Mini on top of the material itself.

SAFETY: Epilog Zing Laser, Glowforge and Mr. Beam all utilize the close frame concept which tends to minimize direct or indirect contact of laser beam with eyes, especially for those carefree users. Besides, the three laser systems also have implemented ventilation systems to extract the fumes generated during laser cutting process. Nevertheless, FABOOL does not take into account in safety aspects as it does not deal with the prevention of laser contact with human eyes as well as the extraction of fumes released.

MAINTENANCE: CO2 lasers which are used by Epilog Zing Laser and Glowforge require more maintenance compared to the diode lasers used by Mr. Beam and FABOOL. CO2 lasers are very fragile and can break easily. The lifetime of CO2 laser is much shorter than the lifetime of diode laser. Internal misalignment and power fade issue may also arise in CO2 lasers. Frequent cleaning of the mirrors is a prerequisite to avoid the presence of dust that affects the laser beam direction. To deal with this issue, Glowforge has applied sealed optics system to avoid frequent cleaning.

COST: FABOOL has the lowest price of $598, followed by Mr. Beam and Glowforge. Epilog Zing Laser has the highest price among all, which costs around $7995.

2.3 REVIEW ON LASER CUTTING SYSTEM DESIGN

A laser cutting machine consists of four main systems, namely optical, mechanical, electronics and software. Therefore, to design a small scale laser cutting machine that meets the objectives, a careful selection of components is very crucial to ensure the functionality, cost, safety and aesthetics.

2.3.1 OPTICAL SYSTEM

There are few types of laser modules suitable for cutting, i.e. CO_2 laser (gas laser), Nd:YAG laser (crystal laser), fiber laser and diode laser. The CO_2 laser is a gas laser that uses carbon dioxide gas mixture which is stimulated electrically. The molecules are excited in electric glow gas discharge at high voltage and low pressure. The gas discharge consist of a mixture of helium, nitrogen and CO_2; in which helium aids in relaxation form the lower laser level while nitrogen promotes the excitation of upper laser level due to the energy transfer via collisions [9]. During the process, the laser gas must be cooled either by diffusion or by convection. CO_2 lasers are capable of producing high beam powers up to several ten kW. Due to the axially symmetric configuration, CO_2 lasers produce good beam quality. With a wavelength of 10.6μm, it is commonly used for non-metallic materials such as wood, paper, glass, leather, stone, acrylic and most plastics.

Nd:YAG lasers are solid state lasers with neodymium-doped (ca. 1.2% wt.) Yttrium-Aluminum-Garnet crystal. The former facilitates the lasing action while the latter is the host crystal with high thermal conductivity and good optical features. The crystal is optically pumped by a flashlamp or an arc lamp, however nowadays diode pumped solid state crystal lasers are getting more popular. The crystal is in the form of a rod, with a typical diameter of 6mm or 9mm at a length of 100-200mm. By arranging a series of rods, higher beam powers can be achieved. Diode laser-pumped lasers have better beam quality and efficiency compared to conventional flashlamp-pumped because the pumping of crystal energy levels becomes more selective (quantum efficiency: 76%) compared to the broadband spectrum of a flashlamp. Additionally, the lifetime of diode lasers is much higher than flashlamps. Nd:YAG lasers emit light with a wavelength of 1.06μm, which is in the infrared region [10]. Nd:YAG lasers can operate in both continuous and pulsing mode like Q-switching. [11] Therefore, these lasers are relatively well suited to cut plastic and metal materials regarding to the higher energy in a beam pulse.

Fiber laser generates laser beam by amplifying seed laser in specially designed glass fibers, which are supplied with energy via pump diodes. It is a newer type of laser system, replacing the diode pumped solid state crystal. It can produce small focal diameter, and intensity up to 100 times higher than CO_2 laser at same emitted average power. It offers great advantages like excellent beam quality, freedom from alignment, easy thermal management, and robust operation [12] . It can be used in metal marking, engraving and high contracts plastic marking. However, it utilizes expensive pump diodes and must be replaced after 8000-15000 laser hours.

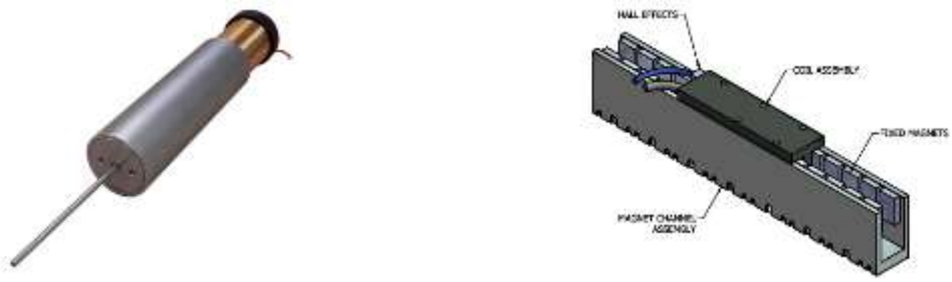
Diode laser is a type of semiconductor or injection laser. It is similar to an ordinary LED, yet it generates a beam of high intensity light. The light is emitted through population of inversion electrons when voltage is applied across its p-n junction. The p-n junction of diode laser has polished ends, thus the emitted photons reflect back and forth and creates more electron-hole pairs [13]. The generated photons are in phase with the previous photons. The most common wavelengths for high power diode lasers are 809nm and 911nm. A single semiconductor laser can produce a beam power up to a few 100mW. To increase the beam power, 100-200 diodes are arranged in parallel but not in phase into an array and then several arrays are combined into a stack [2]. This type of laser produced has a large output dimensions and therefore has a poor beam quality.

The ability to cut most materials by laser types in ascending order is diode laser, CO_2 laser, Nd:YAG laser and fiber laser. The costing for the laser types increase in similar fashion. Nd:YAG laser and fiber laser although have high cutting ability due to production of good beam quality at high power output, the costs are incredibly high which is not affordable by individuals. Besides, the pumping diode system is huge in size, making the laser cutting machine large, heavy and not portable. CO_2 laser and diode laser are quite commonly used in desktop laser cutting machines. The main drawbacks of CO_2 laser are (i) the tubes are fragile, (ii) vibration to the machine may induce misalignment of lenses and mirror position; and (iii) safety issues arise when users have contact with the flying optics pathway. Diode lasers are more compact in size, cheaper, easier for maintenance; and have longer lifetimes compared to CO_2 laser.

2.3.2 MECHANICAL SYSTEM

To provide linear motion for the laser to move along X, Y and Z directions, there are varieties of motor actuators that can be selected for this purpose. Firstly, linear motors (See Figure 2.1) such as linear voice coil motor or linear induction motor are able to create linear motion. Besides, rotary motors such as stepper motors or servo motor (See Figure 2.2) are also capable producing linear motion with complementary components like screw drive, recirculating linear slides or belt driven system (See Figure 2.3). These motor actuators come in different cost and have different performance characteristics in terms of accuracy, precision and speed.

Linear voice coil motor consists of a magnetic housing and a coil. The direction of the motor can be controlled by the polarity of the applied voltage. The force generated is proportional to the current flows through the motor coil. Linear voice coil motor has the advantage of producing accurate positioning less than one micron without any commutation or position sensor. Nevertheless, the linear voice coil motor has its setbacks like limitation of stroke distance, low force generation and high cost. On the other hand, linear induction motor is constructed by unwrapping the stator of a conventional induction motor to lay out flat and the rotor moves past it in a straight line. Although it cannot achieve high accuracy like voice coil, it provides repeatability less than 1 micron, faster acceleration, high velocity, high force generation, smooth and no cogging movement, and a wide range of stroke distance [14]. Linear motor drives are commonly applied in high-precision or ultra-precision machines [15].



(a) (b)

Figure 2.1: Linear Voice Coil Motor (a) and Linear Induction Motor (b)

Servomotor is a type of rotary motor which controls angular or linear position, velocity and acceleration precisely. It is made up of a motor coupled to a sensor using position feedback. Servomotor uses 4-12 poles; therefore it needs encoder to keep track of the position. Closed loop mechanism is prerequisite for servomotor as it reads the difference between the encoder and the programmed position; subsequently adjust the magnitude of current to move. The speed of servomotor is proportional to the input current. Servomotor usually has better precision, resolution, higher speed and acceleration yet at the expense of greater price. On the other hand, stepper motor, another type of rotary motor, converts electrical pulses into discrete mechanical movements of shaft. The speed of the rotation is dependable on the frequency of input pulses [16] while the length of rotation is related to the number of input pulses applied. Stepper motor commonly uses 50 to 100 pole brushless motors; hence it does not require encoders as it can accurately move between many poles. Stepper motor works in an open loop mechanism [17].

(a) (b)

Figure 2.2: Stepper Motor (a) and Servomotor (b)

To drive rotary motion to linear motion, screw drive is one of the options. There are lead screws, ball screws and roller screws. Screw drive is capable of producing high axial thrust, as wells as provides good accuracy and repeatability. It has low system inertia and predictable service life. Some limitations of power screw drives are shorter length than belt drives, running speed limited by critical speed values at which is near the system natural vibration frequency, and shorter duty cycle compared to belt drives. Power screw drive can achieve higher resolution. The smaller the pitch size of the lead screw (minimum 1mm pitch), the higher the resolution can be provided. Backlash can be avoided by preloaded nut and friction can be reduced [18]

Moreover, linear slides such as cross-roller guide, recirculating ball slides, rolling bearing slides are also able to convert rotary motion into linear motion. It is compact, lightweight, and provides unlimited range of motion. However, it is the least stiff and has the largest friction one among the three. Recirculating ball slides are more expensive, but have less friction and are stiffer than rolling bearing slides. Cross-roller guides have limited range of motion, but enjoy the highest stiffness and robustness among three different slides, and have the same level of friction as recirculating ball slides.

(a)

(b)

(c)

Figure 2.3: Lead Screw (a), Linear Slides (b) and Timing Belt System (c)

Timing belt drives work by meshing with the corresponding grooves on the pulleys, thus prevent any relative motion between the belt and pulleys. Timing belt drives are highly efficient, accurate in movement [19], easy to operate, long service life and east to maintain. There are few moving parts and low component wear. It is suitable for long stroke application requiring high linear velocity and acceleration. However, it has lower accuracy, lower repeatability and less load-carrying capacity. It is sensitive to impact loads, prone to gradual elongation during operation and hence require periodic tensioning.

In addition, there are two types of frame design, which are close frame design and open frame design that are shown in Figure 2.4. Close frame design has a more rigid structure, ensure prolonged usage by preventing the invasion of dust and external damage; and able to ventilate toxic gases produced by laser cutting process. However it comes with greater complexity in design and higher cost. On the other hand, open frame design has more simplicity, low cost and provides easy access to workspace.

(a) (b)

Figure 2.4: Closed Frame Design (a) and Open Frame Design (b)

2.3.3 ELECTRONIC SYSTEM

Some CNC applications including laser cutters have changed from a proprietary hardware to open source hardware system like Arduino, Beaglebone and Raspberry Pi due to the declination of cost [20]. An Arduino is a microcontroller board which is similar to a simple computer that can run one programme one at a time repetitively. Raspberry Pi is a general purpose computer, operating with Linux operating system. It runs multiple programs simultaneously. It is more complicated to use compared to an Arduino. BeagleBone is a powerful Linux computer that is capable for many projects. A detail comparison between them is shown in Table 2.2.

Table 1.2: Comparison between Arduino, Raspberry Pi and BeagleBone

Name	Arduino Uno	Raspberry Pi	BeagleBone
Model Tested	R3	Model B	Rev A5
Price	$29.95	$35	$89
Size	2.95"x2.10"	3.37"x2.125"	3.4"x2.1"
Processor	ATMega 328	ARM11	ARM Cortex-A8
Clock Speed	16MHz	700MHz	700MHz
RAM	2KB	256MB	256MB
Flash	32KB	(SD Card)	4GB(microSD)
EEPROM	1KB		
Input Voltage	7-12v	5v	5v
Min Power	42mA (.3W)	700mA (3.5W)	170mA (.85W)
Digital GPIO	14	8	66
Analog Input	6 10-bit	N/A	7 12-bit
PWM	6		8
TWI/I2C	2	1	2
SPI	1	1	1
UART	1	1	5
Dev IDE	Arduino Tool	IDLE, Scratch, Squeak/Linux	Python, Scratch, Squeak, Cloud9/Linux
Ethernet	N/A	10/100	10/100
USB Master	N/A	2 USB 2.0	1 USB 2.0
Video Out	N/A	HDMI, Composite	N/A
Audio Output	N/A	HDMI, Analog	Analog

Referring to Table 2.2, the main difference between them is in terms of clock speed. Arduino is about 40 times slower than the other two and has less RAM. Raspberry Pi and BeagleBone require SD card and microSD card respectively to store memory. It is able store multiple configurations and setups on different cards. Therefore, the operating system can be easily changed by swapping different cards.

Raspberry Pi and BeagleBone both include Ethernet interfaces and USB, hence they can be connected to networks and wireless modules easily. Although Arduino supports plug-in peripherals called “shields” that enables it to connect to Ethernet, but the access to the networking functions is fairly limited. Raspberry Pi is well known for its graphical user interface as it has an HDMI output. It is suitable for low cost web browsing device.

Both Arduino and BeagleBonne have analog to digital interfaces that can easily connect components to output varying voltages. Arduino uses the least power as well as work with a wide range of input voltages. The cost for Arduino is the cheapest, followed by Raspberry Pi then followed by BeagleBone [21].

2.3.4 SOFTWARE SYSTEM

In laser cutting, image in scalable vector graphics (SVG) format is usually used compared to drawing interchange format (DXF) format due to its better performance. SVG format is basically an XML-based vector image format for 2D image graphics, which is standardized by the World Wide Web Consortium (W3C) since year 1999. Being as XML files, SVG images can be created and edited with any text editor as well as with drawing software. Differing from raster images that are described of a bit pattern using x and y coordinates, vector images are defined by fixed shapes using mathematical statements [22]. Therefore, scaling of the vector image does not deform or alter the shape. The top eight most popular laser cutting software in generating SVG image include Adobe Illustrator, Inkscape, SketchUp, SolidWorks, AutoCAD, On Shape, SolveSpace and Solid Edge 2D. After converting into SVG format, the vector image was then converted into a series of G-code commands that could be read by the machine using CAM software. G-code, which is uploaded to the machine, generally tells the machine about the features like the tool path, cutting speed, feed rate, number of steps, direction of movement etc.

CHAPTER THREE

METHODOLOGY

Phase 1: Review Phase

- Formulated the problem statement and objective
- Researched on similar existing products and analysed their pros and cons
- Studied on the laser cutting system

Phase 2: Design Phase

- Proposed a design solution
- Illustrated the design in CAD model
- Performed necessary calculations in choosing specifications of standard parts
- Performed stress and strain analysis on the design

Phase 3: Realization Phase

- Fabricated the parts
- Assemblied all the components together
- Set up the software
- Estimated the financial cost
- Ran the laser cutting machine and tested the output

3.1 PROPOSED DESIGN

After weighing the pros and cons, 5.5W blue purple light diode laser as shown in Figure 3.1 was selected as the cutting and engraving agent for this design. Diode laser was chosen due to its compact size, light-weight and good cutting ability empowered by the high power supply at 5.5W. Although CO_2 laser can be operated at 40W, most of the laser beam is unfocused and thus much energy is wasted. Blue violet light emitted at 445nm has short wavelength which can be absorbed by most materials, and thus enable the laser to cut and engrave a variety of materials. Smaller spot size is also produced from light of short wavelength. Moreover, diode laser come in much lower price compared to CO_2 laser.

Figure 3.1: 5.5W Blue Purple Light Diode Laser

To provide a strong rigid support, aluminium profiles were used to build up structural frame of this design. Aluminium profile has attributes like light weight, durable, low cost, and easy to assemble. The mechanical parts could be easily connected to each other through the use of bolts and slot nuts. An open frame structure was proposed so as to enable the user have a greater access to the workspace. Besides, open frame structure promoted the laser cutting machine to come in a smaller size which enhanced its portability. An open frame structure also allowed future changes to the design, for instance changing laser head to CNC spindle or to 3D extruder head.

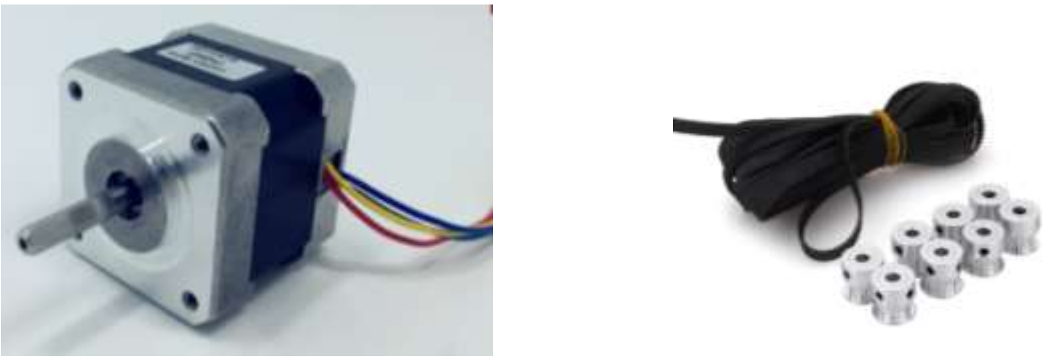
(a) (b)

Figure 3.2: Aluminium Gusset (a) and Aluminium Profile (b)

In order to provide the linear motion, slider assembly was designated for this purpose. It basically used bearings to slide on the groove on the aluminium profile. Besides, bearings were necessary to support the weight of load. A slider assembly consisted of three bearings whereby two bearings were on one side while one bearing was on the other side, in which all of them were being connected together by a plate holder. This configuration of bearings was to eliminate the moment force generated during movement. The bearings were covered with nylon plastic to reduce the friction encountered (See Figure 3.3).

Figure 3.3: Nylon Wheel with 625zz Bearing

Timing belt system driven by stepper motors was implemented to move the slider assembly. This system configuration offered simplicity and accuracy at a low cost. The mechanical setup for this system was relatively easy as there were less connecting parts. Timing belts are cost effective when travelling over a greater distance. Besides, stepper motors operate in open loop and does not require any feedback device to achieve the required accuracy. In specific, Nema 17 stepper motor, GT2 timing belts and GT2 pulleys were used in the design. To further cut down the cost, two stepper motors instead of three stepper motors are used to control xy motion in a mechanism called H-bot mechanism.



(a) (b)

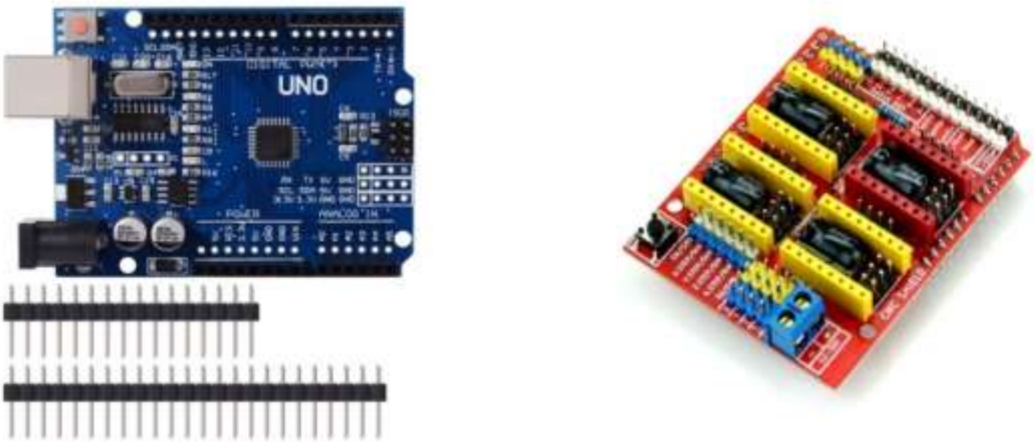
Figure 3.4: Nema 17 42x26mm Stepper Motor (a) and
GT2 Timing Belt and Pulley (b)

Polulu A4988, a micro-stepping drive designed for smooth and quiet operation was chosen to drive the NEMA 17 stepper motor. This motor driver was a current amplifier that transformed a low-current control signal to a higher current signal that could drive a motor. Moreover, when the motor driver received the control signal from the microcontroller board to the terminals PULSE and DIR, it would generate the corresponding digital pulse signals for stepper motor to control the rotation of the motor. **[23]**

Figure 3.5: Polulu A4988 Microstepping Driver

In this design, Arduino Uno had been selected as the microcontroller board due to its simplicity to program, low cost, easy user interface, low power consumption and easy to operate [23]. It can interface with varieties of sensors and effectors without external circuit.

Moreover, Arduino uses the low level programming language like C++. Arduino Uno could be easily powered up through the USB cable connected to the computer. Furthermore, Arduino CNC shield provided an easy platform to connect all the parts together. It could be powered by a 12V DC voltage adapter which was also used to supply voltage to the laser module. From the Arduino CNC shield, each stepper motor consumed 5V respectively. As Arduino CNC shield was powered through an external source, the Arduino Uno was less likely to burn out due to high voltage consumption.



(a) (b)

Figure 3.6: Arduino Uno (a) and Arduino CNC Shield (b)

To lower down the total cost, any image that was intended to cut or engrave could be converted into a vector in SVG format by open source software like Inkscape, OnShape, Solid Edge 2D etc. The vector could then opened in Universal G code Sender software which transformed the vector into a series of G code commands in the form of serialized text strings to Arduino through the serial interface on predefined baudrate 115200. For Arduino to understand G-codes, the GRBL driver needed to be first uploaded into Arduino library. GRBL is written in C language and supports most platforms based on ATMega328p [24]. Nevertheless, due to the H-bot mechanism, ordinary G code interpreter was not able to perform the tasks desired. For instance, turning one stepper motor would result in a 45° motion. To provide a vertical and horizontal motion, two stepper motors must be activated simultaneously. Therefore, a special version of GRBL was uploaded into Arduino.

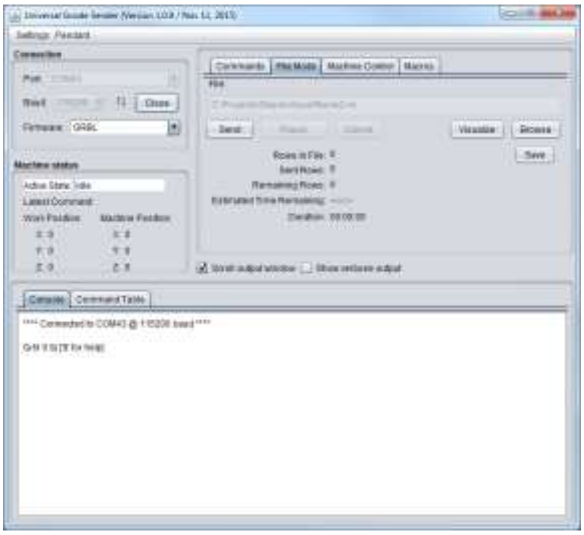


Figure 3.7: Universal G-Code Sender Interface

3.2 CAD MODEL

The proposed design was illustrated in CAD model through SOLIDWORK 2016 software. The proposed design had a physical dimension of 350 x 410 mm. It had a weight of around 1.7kg. Light-weight, small sized and simple structure of this design enabled to user to carry it anywhere. The working space for this proposed design had area slightly larger than that of an A5 paper, which is equivalent to190 x 170 mm. This working area is suitable for most small applications.

Figure 3.8: CAD Model of the Proposed Design