The Possibility of Creating a Low-Cost Laser Engraver CNC Machine Prototype with Platform Arduino

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Abstract: Some of the advantages of CNC machine use are high processing quality and the speed of the final machining of the product. In the paper we present the low cost solution while the goal was to design and implement a 3D model of a CNC machine based on laser engraver that does not contain too many parts (not only because of the price but also because of defectiveness) and to optimize it for easy production use. When implementing, those parts were focused on that are easily accessible for ordinary consumers or they can produce them themselves. Arduino has been used as a microcontroller. The software part was a created GUI that allows direct communication with the laser engraver machine based on the designed 3D model of the processed product, generating and sending a G-code to the machine through the USB port. In the paper we compared the results of laser engraving by our designed engraver CNC machine and the professional solution Akshar Fiber-Pro Laser.

Keywords: laser engraver; CNC machine; Arduino; Prototype; G-Code

1 Introduction

CNC is an abbreviation for Computer Numeric Control. It is based on the automation of machine tools. They operate with program commands uploaded on a memory medium. The introduction of such machines brought a revolution in production processes [1].

Currently there is no need to worry about the precision of the final product because all the CNC machines have been designed to fulfill the specific requirements [2].

The CNC machines have changed in the last 20 years not only from the point of view of output quality but also of total reassignment. By implementing and using various microcontrollers in the field of automated technology, new types of machines have been developed that fix the problem of previous generations. In the methodological part of our submission, we describe our in-house designed prototype of laser engraving machine built on the principle of CNC machine controlled by an Arduino platform. The prototype we designed represents a microcontroller controlled intelligent system for laser machining of various materials up to a thickness of 1cm. Laser machining (or engraving) of material depends on input parameters such as the power output of the laser, laser frequency, wavelength, and the speed and number of (repeated) passes. Our aim within the experimental research was to compare 3 input parameters (laser frequency, speed and number of passes) of our prototype with parameters of a professional solution Akshar Fiber-Pro Laser Engraving Machine. The output parameter is the quality of the machined material in terms of surface roughness and groove depth depending on the set parameters. Experimental results of the professional Akshar Fiber-Pro Laser Engraving Machine solution match the effect of different frequencies (20, 40, 60 kHz), different engraving speeds (100, 200, 300 mm/s), and varying number of passes (10, 15, 20) over a 1.5 mm thick steel plate (304). The Akshar Fiber-Pro Laser Engraving Machine uses a 1060 nm wavelength fiber laser with nominal power output of 20 W. Our proposed solution uses a 405 nm wavelength laser with nominal power output of just 2 W. In the experiment we've focused on the question, whether our prototype can process a product resulting in the same quality as a professional solution, depending on the same input parameters.

In the section Related Work, multiple solutions are presented which do not represent just prototypes but introduce solutions implemented into operation. In the next section Material and Methods we describe the hardware part of designed prototype (mechanical and electronic part). The Section 4 with the name "The preparation of the user's environment and the settings of the engraving process" is focused to the software part (settings of prototype for engraving process). Section Discussion and Results describe realized experiment. The experiment is focussed to identify and evaluation various parameters that has impact adverse effect on the quality of the material being machined.

2 Related Work

Nowadays, precision in processing the output product is an important factor of the CNC machines.

Chen et al. [3] worked on using the Taguichi experimental method in optimizing laser microgravure photo plates that are needed to create the patterns required in the production of small LCDs. In their study they focused on these parameters: focus length, average power of the laser, pulse repetition rate and the engraving speed relative to the engraving width. The results showed that it is possible to create a groove with the width of 18 µm under these parameters: beam expansion ratio of 5x, focal length of 50 mm, laser average power of 0.4 W, pulse repetition rate of 5 kHz and engraving speed of 5000 mm/min.

Genna et al. [4] were researching the influence of the process parameters on the material removal rate (MRR) and on the surface roughness in engraving operation by using C45 carbon steel. They used a 20W laser (Q-Switched) with the wavelength λ = 1070 nm. The parameters studied were pulse frequency, beam speed, and the number of replications of the geometric pattern. The study confirmed that a laser with a wavelength λ = 1070 nm can be used to machine steel, with the MRR parameter and roughness dependent on the input parameters of the machining process.

Agalianos et al. [5] investigated the effect of using laser engraving on the quality of the machined surface. Laser engraving technology removes the material layer by layer and the layer thickness is usually in the range of several microns. The parameters examined were pulse frequency, beam velocity and layer thickness. The surface quality was determined by the surface roughness for each set of parameters. Experimental results on Al7075 showed that surface roughness depends on the frequency and scan speed used. Furthermore, it has been shown that the resulting roughness depends less on the layer thickness. Taking into account all experimental research data, the best surface roughness was achieved using a frequency of 20 kHz, a scanning speed in the range of 600 to 700 mm/s and a layer thickness of 4 and 6 µm. In their research, they used a laser with a wavelength λ = 1064 nm and a power of 100 W (Q-Switched).

Linggarjati & Hedwig [6] designed and created an inexpensive CNC machine equipped with a replaceable laser head. Their CNC machine is flexible in its usage, being able to use CO2 laser and thus to work with different kinds of materials. In a precision machining experiment, they used plywood, acrylic, cardboard and PCBs with a maximum thickness of 5 mm, 3 mm, 5 mm, and 1 mm (in that order). Machining accuracy was around 0.1 mm. They used a 40 W laser as standard.

According to Kasman [7] laser engraving is the most efficient technique for machining hard materials with complex geometry. In his study he investigates the machinability of hard metal produced with powder metallurgy and puts forward and new approach to the laser engraving of P / M metals for Vanadis 10. The required input parameters of the machining process were effective scan speed, frequency, and laser effective power on the surface roughness (Ra) and engraving depth (D). Kasman found that the scan speed has a statistically significant effect on both Ra and D. To minimize Ra, the scan speed should be at a high level (800 mm/s), while in order to maximize D, the scan speed should be at a low-level (200 mm/s).

In the past, CNC machines were suitable for machining metal or non-metal materials using 3 or more axes. The problem of such CNC machines was their high complexity, cost and weight (problems with relocation).

The paper of Yuen & Altintas [8], introduces the methodology of error correction that may occur in the three-axis process. The authors used a geometric error-free ideal forward kinematic model of the nine-axis machine. The model has been designed via the utilization of a homogeneous transformation matrix. The geometric errors of each linear axis, which include positioning, straightness, pitch, roll, and yaw errors, are measured with a laser in a terferometer and fit to quintic polynomial functions in the working volume of the machine.

In her paper Navrátilová [9] has concentrated on the rebalancing within the multi-directional principle of each axis of the laser. When cutting the product, a certain deviation might develop that in the end causes imprecision on the output. To determine this deflection, she used a laser tracer that records the measured data in spherical coordinates. Every deflection is described as signal quality to best signal quality ratio gained from the measurement.

The disadvantage of current industrial CNCs is their high price. The teaching on this type of device is a long-term process and schools do not have enough money to buy them. That is the reason that low-cost solutions are preferred.

To overcome these problems, we designed a prototype of a two-axis CNC laser machine tool that is lightweight and compact in size compared to previous solutions. The only limitation is the size of the material to be processed (up to 1 cm). The materials to be processed can be metal materials but also all non-metal materials such as wood, foam, plastic, rubber, paper. The prototype design was inspired by the following case studies.

The paper of Peixoto & Monteiro (2019) [10], proposed this solution to ensure the technical training in Portugal. As an example of the control unit, they propose the use of Raspberry Pi3 or the platform Arduino. They refer to various works including Antunes et al. [11] that have already been created in UMinhoLabs for technical training of future professionals. According to a paper written by Quatrano et al. [12], on assembling a low-cost CNC machine, a discarded 3D printer was used. This way they lowered the related expenditures. As a control unit Arduino Mega 2560 has been used. The main idea was to build a low-cost CNC machine which can be capable of machining precise various shapes or sizes of the subject. Considering the stepper motor parameters and operating conditions, a need developed for a control system of the actuators using open-loop control laws (the communication takes place in these cases in one direction only: from the controller to the motor). The use of low-cost devices was combined by the use of open source software. The open source software was deployed for creating a tool path from the 3D model. The used 3D model was developed in SolidWorks software as the authors used the CamBam application to create the G-code from the 3D model.

Michael [13], agrees that low-cost devices are nowadays used mostly for teaching to understand the principle of the CNC machine's operation along with testing it. Basically, it was a final project of two students. According to one of the authors, he planned to buy a laser cutter, but soon he realized that this kind of device was too expensive for domestic use. He had decided to build his own CNC machine. His solution represents a proposition and production of a laser cutter with a laser performance of 40 W. The cutter had a space of 1000x600 mm for cutting and it also had a touchscreen for operation. The control unit was made up of Arduino with GRBLShield and a microcomputer Raspberry Pi with a touchscreen connected to it. Thanks to the microcomputer it was a separate device. It means that it does not need a computer to send files to the machine. The cover of the machine was designed in a way that it was not possible to turn on the laser until the cover was shut. These arrangements were important because of the laser's performance (the reflection of the beam is dangerous for the eyes). The total set of the project cost around 1900 €.

Khanna et al. [14] and Desai & Patel [15], proved with their prototypes that it is possible to build a low cost CNC machine. Paper [14] reports on the development of a low-cost CNC system with 6 axes (problem of this solution is low accuracy in pulse repetition rate and engraving speed). The lower cost is achieved by incorporating the Arduino. The authors used G-Code parser where in the G-code is first converted to the canonical code and then interpreted on the microcontroller from a USB key. In their draft, the authors of paper [15] used Arduino 2560 and three unipolar stepper motors for three-axis machining. The axes X and Y were used for two-dimensional interpolation. The axis Z was used to control the deep cut and was not interpolated. As a standard code of part programming the G and M codes were used.

Currently it is possible to come across various architectures, e.g. using the CNC with Cloud Computing. The study by Hui et al. [16] proposed a system that locates its front end in a cloud virtual machine and provides the front end as a service. The application program for interaction with the client can be easily integrated into smartphones or tablets. The cloud communicates with the back end via the Internet or an intranet. Various tasks in real-time are run on the back end, while other tasks are executed on the cloud-enabled front end (not in real-time). The computing ability and intelligence of CNC systems can be, therefore, improved by a switch to the cloud architecture.

3 Material and Methods

In the last five years, various low-cost CNC machines have appeared. They hardly ever reached the high-quality level of professional machines. In this case, they have been used as teaching equipment to prepare future professionals. Some of them had various numbers of axes to process the material. However, it is not always necessary to use a large number of axes for processing. For the model, the axes X and Y have been used. The basic construction of the proposed CNC laser engraving machine (Figure 1) has three axes X, Y, Z. Since the cutting tool was a laser, there was no need to implement the axis Z. This way the construction got simplified and the price was reduced partially. The axis Z might have been needed in the case the depth had been cut.

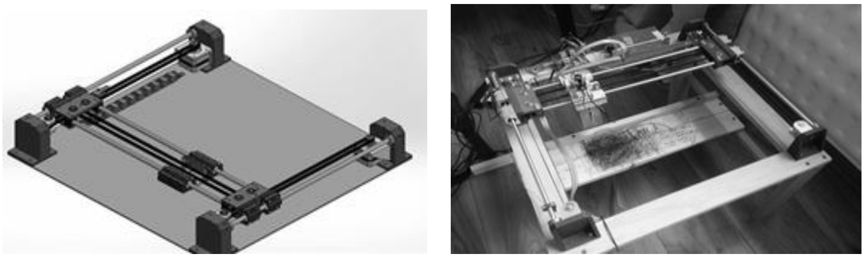


Figure 1
Left - Proposal 3D model of the laser engraving machine, Right – Real CNC laser engraving machine

The 3D model of the machine with the H-bot set is shown in Figure 1 (the name comes from the model's design that has a shape of the letter 'H'). As long as the coordinate recorder is concerned, a similar principle was used so it is a motion in XY space (motion on a plane). The construction of the set was easy because it consisted of two stepper motors – a timing belt and two perpendicularly mounted rails. On the one hand the stepper motors were fixed and in motion they cooperated. The motors are stationary, but these motors work together as they move. The fact that both motors are connected by one belt complicates programming this robot. Movement by one motor causes an oblique movement at a 45° angle. If we rotate both motors at the same time and at the same speed, we get the required linear motion. Depending on which motor is activated, we can realize the move as shown in the Figure 2.

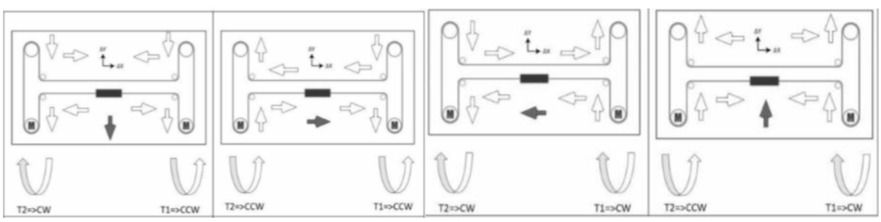


Figure 2
Way of H-bot movement

The size of the machining area was 210x290 mm (A4 format). Some of the parts designed in the 3D model were not possible to buy because they were unique. It was easier to make them. A 3D printer was used for this purpose because it uses plastic that has low weight and is rather firm. The machine had two holders for the axis Y that are identical and were combined from two plastic plates. There were two bearings that held two holders for the guide bars and two belt pulleys interconnected by steel bars with the bearings. The head of the machine consisted of the laser from the plastic plate and of four linear trolleys mounted on the top. The distance between the trolleys had to be the same as the distance between the holders for the bars on the Y-axis. A complete CNC machine is shown in Figure 4. The whole machine was linked up with the belt and both endings were attached to the machining head where the laser diode was found. Table 1 lists the mechanical parts and their price.

Table 1
Part list for mechanical part of the machine

Name	Number of pieces	Total cost (€)
Unsupported bars	4	15
Belt	1 (3m)	2
Pulley	8	4
Ball trolleys	8	15.5
Bearings	12	5.5
Wooden frame	1	12
Connecting material	60	8
3D printed parts	20	80
Sum		**142**

The basic set of the machine was made of mechanical parts that required manual skill. However, when linking all the electronic parts (Figure 3), it was necessary to have basic knowledge from the field of electrical engineering.

To secure the motion, two stepper motors NEMA 17 were used which were mounted during the mechanical building process. To set the starting position of the head, the same principle was used that had been practiced in printing companies for a long time. For this purpose, limit switches were used which reported to the control unit if the machine got into an unauthorized or an error position. The control unit stopped the machine immediately and sent a warning to the program that operates the machine. The CNC model contains four limit switches, two for the axis X and two for the axis Y. From the safety point of view, the limit switches represent the basic security element. The machine head contained the most expensive part – the laser diode. Through testing it turned out that the Blue Laser Diode 200 nW 405 nm was not applicable as intended because of its low performance. After another test and research, it was obvious that there was a need for a laser 1000 mW at least for machining. In the end, the decision was made for a laser with a performance of 2000 mW that works on the wavelength of 405 nm. The laser used on the model contained an active cooling and an aluminum coat that helped with temperature drain.

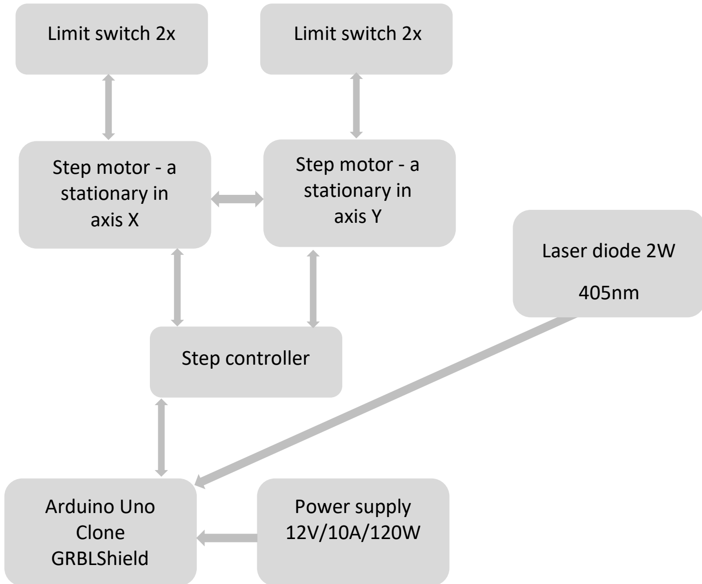


Figure 3
The block scheme of the electronic part

The laser was linked to the control unit (entry 12 V) but the control unit sent from 0 to 5 V to the laser as output. A TTL technology was implemented which based on the entry signal from the control unit changed the 12 V to any value from 0 to 5 V. This meant that the laser's performance was possible to control by the software. For this, pulse width modulation (PWM) was used. This way, the voltage between turning on (5 V) and turning off (0 V) could be simulated by changing the ratio of the time when the entry was turned on (as a duty cycle). Usually, values from 0 to 255 were set that matched with the output signal of 0-5 V.

By analysis of the current state in the Related Work, it can be concluded that it was not primarily necessary to spend large amounts of money on CNC machines if open-source architecture was used. Many constructors prefer this solution, and they often use the existing open-source solution based on Arduino. The use of Arduino in the domestic environment and in the industry brought another development of not only the microcontroller itself but also of various extensions that are possible to connect to the microcontroller. One of these extensions is the GRBLShield. The board was designed to fit into the Arduino UNO's board. Depending on the model, it was possible to control the four-step motors with the board. Each motor controller could be replaced separately and rather quickly. The stepper motors could be linked quickly without soldering. The use of pins made it possible pins to attach the limit switches and the PWM port to which the laser was attached. It was necessary to bring the voltage of 12-36 V to the board. It enabled the user to set micro stepping for each controller. A power supply of 12 V was used that supports a maximum of 10 A power. Table 2 lists the electronic parts and their price.

Table 1
Part list for electronic parts of the machine

Name	Number of pieces	Total cost (€)
Stepper motor Nema 17	2	22.5
Limit switches	4	2
Arduino Uno clone	1	5
GRBLShield V3	1	10
A4988 Step controller	4	2.5
12V 10A 120W PSU	1	9
Blue Laser Diode 2W	1	43
Sum		**94**

4 The Preparation of the User's Environment and the Settings of the Engraving Process

New educational methods such as e-learning and “edutainment” may have emerged as a result of digital development. Edutainment is based on the idea of disseminating information to students in an entertaining audio-visual environment provided by multimedia equipment. This approach is based on conclusions that have been drawn from the latest findings of education science. It is a fact that the effectiveness of traditional teaching methods supported by the use of electronic devices is increased when placed within an entertaining framework (especially with regard to oral presentations). The interest of students may be continuously maintained by stimulating presentations in which information transfer is aided by animations or visuals utilized at given points in a lesson, facilitating emotional identification, active participation, and, later, the retrieval of information from the memory [17], [18], [19].

An awareness of new ICT (Information and Communications Technology) trends and their constructive applications are essential in modern teaching and learning.

To program the Arduino boards, Arduino IDE was used by which the program was compiled and uploaded to the board. The result of the compilation was a hex file where all the programmed instructions were uploaded. The smooth operation of the stepper motors and thus the whole machine was ensured by a software called G-code interpreter. The essence of the program was simple. On entry, it obtained the coordinates in a form of a text which was then translated into motion. The text was set in a standardized form and was called G-code. Since the programming of the interpreter was a demanding task for only one programmer, a group of programmers published their long-time work on the interpreter as an open-source providing free access to everyone. To make the machine work, programs needed to be installed that facilitated the drawing of the picture that was set to be engraved. Then, a G-code had to be generated that was intelligible for the CNC machine. Finally, the program was installed that connected to the machine, set the zero point and loaded the G-code file. Considering the open-source solutions, those programs were chosen that were free of charge: Ubuntu (Distribution of OS Linux), to which the programs Inkscape and UGS (Universal G-code Sender) were installed. To use UGS, it was necessary to install Java Virtual Machine as well. UGS was an intuitive program with a native support for the work with the GRBL software.

Before setting the precision of the machine, it was necessary to understand how the stepper motors worked. The stepper motor was a synchronous rotating machine, connected by a direct current pulse. The magnetic field was generated by gradual linking of each pole pair. The rotor vibrated during lower speed, moved among the stable positions in a certain angle. This is called step motion. The stepper motors were characterized by high mechanical resistance and a long lifetime without maintenance. Some of the disadvantages were a so-called step loss that occurred after exceeding the limit load and a tendency to mechanical deceleration that might have led to instability in the motion. Both negative features could be possibly avoided by selecting the right stepper motor and controller in regard to the torque characteristics of the drive. The stepper motors controller was a special electronic circuit generating pulses in a certain order and length. The pulses were made through the power section in an exact order of each rotor boring. The frequency, the order and the length of the pulses from the control circuit controlled the number, the direction of the rotation and the torque of the machine. The stepper motor NEMA 17 used in the machine had a step size of 1.8°. If 360° is divided by 1.8°, it meant 200 steps per motor rev. The increase in the number of steps could be achieved by using a step controller with the support of micro-stepping. According to the settings, it was possible to reduce the step of the motor to 1/2, 1/4, 1/8, 1/16 of the original motor step. In the case when all three jumpers were added, the number of the steps increased by 16 times meaning from 200 steps to 3200 using the same motor. By increasing the number of steps, the machine was more precise and it was possible to get rid of the undesired vibrations that might have appeared in the slower motion of the motor. With the help of the program, the inner settings could be changed which would be saved in the memory of the Arduino board. After the successful link on Arduino, the information about the GRBL version and with the command $$, all the settings were shown that had been saved in EEPROM. The values changed in the following way $x=val where x was a particular setting that was needed to be changed and val was a new value, for example $100=120 changed the number of the steps to millimeters for the axis X to 120. To begin with the cutting of the product, Extensions>Generate Laser Gcode>J Tech Laser Tool had been selected from the extension offer and a G-code was generated. With the help of the program UGS, the G-code was loaded into the machine. If needed, values for X and Y it was advisable to recalculate. This initial setting was necessary to perform because the picture drawn in Inkscape might have had different resolution while the parameters were needed to adapt to G-code.

In the experiment, we focused on the comparison of the resulting parameters of laser machining of stainless steel material using a professional solution and a prototype designed by us. The experiments were performed on an Akshar Fiber-Pro Laser Engraving Machine which operates with a 5% deviation in the machining process. This laser engraving machine uses 1060 nm wavelength fiber laser with nominal power output of 20 W. The prototype we designed (Figure 1) uses a laser with a wavelength of 405 nm with a nominal power output of 2 W.

As a material to be processed (engraving process) we used a stainless steel (304) plate from the company Ocelex with a thickness of 1.5 mm. The maximum engraving depth (groove depth) was set to 0.9 mm. The chemical composition of SS 304 is in the website http://ocelex.sk/old/pages/213.htm. The input parameters of the experiment were Frequency: 20, 40, 60 kHz, Engraving speed: 100, 200, 300 mm/s and Number of pass: 10, 15, 20. The observed output parameters of the experiment were surface roughness and groove depth (µm). The results of the experiment are listed in the Discussion and Results section. The surface roughness parameter was measured with the MarSurf PS10 Elcometer 7062. The groove depth parameter was measured with the Universal PIG Elcometer 121/4.

5 Discussion and Results

The aim in the present is to identify the sources of vibration under various operating conditions so as to minimize the adverse effect on the quality of the material being machined, stop vibration from occurring and slow down the rapid wear of the cutting tools [20], [21], [22].

Table 3 shows the measurements of Surface roughness and Groove depth for the professional Akshar equipment and the Prototype.

Table 3

Measured input and output parameters in the machining process

No.	**Frequency (kHz)**	**Engraving Speed (mm/s)**	**No. of pass**	**Variance of groove depth (µm) Akshar**	**Variance of groove depth (µm) Prototype**	**Surface roughness (µm) Akshar**	**Surface roughness (µm) Prototype**
1	20	100	10	61.852	59.349	2.562	2.314
2	20	100	15	61.992	59.456	2.848	2.524
3	20	100	20	62.018	59.711	2.831	2.519

4	20	200	10	61.124	60.236	1.423	1.269
5	20	200	15	61.356	60.255	1.678	1.381
6	20	200	20	61.547	60.308	1.236	1.332
7	20	300	10	63.475	61.403	1.582	1.269
8	20	300	15	63.684	61.496	1.547	1.281
9	20	300	20	63.324	61.502	1.00	1.369
10	40	100	10	71.751	61.655	1.256	1.186
11	40	100	15	71.792	61.699	0.985	0.884
12	40	100	20	71.801	61.704	0.954	0.864
13	40	200	10	71.568	62.406	0.993	0.837
14	40	200	15	71.583	62.463	1.214	0.974
15	40	200	20	71.607	62.488	1.201	0.942
16	40	300	10	72.429	65.571	1.035	0.937
17	40	300	15	72.471	65.589	1.126	0.917
18	40	300	20	72.783	65.635	1.287	0.906
19	60	100	10	83.578	71.127	0.487	0.368
20	60	100	15	94.367	71.218	0.469	0.344
21	60	100	20	98.741	71.283	0.471	0.339
22	60	200	10	96.586	71.714	0.712	0.671
23	60	200	15	96.627	80.789	0.697	0.585
24	60	200	20	96.685	80.795	0.736	0.634
25	60	300	10	95.814	80.963	0.461	0.356
26	60	300	15	95.829	80.985	0.831	0.614
27	60	300	20	95.895	80.992	0.814	0.609

The aim of our experiment was to engrave an image with the inscription (Figure 4) at various input parameters on a stainless steel plate.

Figure 4

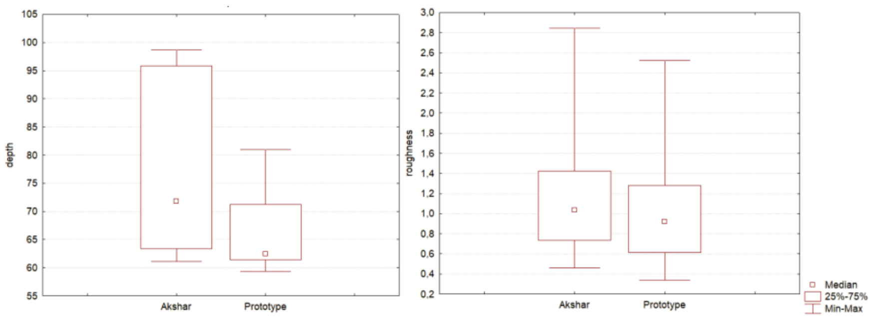
Example of engraving image on stainless steel plate

The aim was to cut to a depth of 900 µm (0.9 mm). Therefore, a new variable, the Variance of Groove depth (µm) was created for both devices in Table 5 to reflect the deviation from the expected depth of cut. The aim is to verify that the cut accuracy with Prototype is better than with Akshar. We therefore need to verify that there is a statistically significant difference between the deviations. Therefore, we are verifying the H0 hypothesis: *The distribution of the Variance of groove depth variable in both groups (Akshar, Prototype) is identical.* We test the hypothesis at the 5% significance level of the Mann-Whitney U test, which works with serial numbers (Table 4, Figure 5a).

Table 4

Mann-Whitney U test for variable Variance of groove depth and Surface roughness (µm)

Variable	Rank Sum Akshar	Rank Sum Prototype	U	Z	p-value	Valid N Akshar	Valid N Prototype
Variance of groove depth	918	567	189	3.036	0.002	27	27
Surface roughness	810	675	297	1,168	0,242	27	27



(a) (b)

Figure 5

Mann-Whitney U test for variable Variance of groove depth (a) and Surface roughness (b) (µm)

The test verifies whether the difference in the order of the two groups / variables is statistically significant or only random. Based on the results of the Mann-Whitney U test and the extracted p-value, which is less than 0.05, we reject the H0 hypothesis at 5% in terms of significance. This means that there is a statistically significant difference between the values of Variance of groove depth (µm) Akshar and Variance of groove depth (µm) Prototype. Based on the fact that the Rank Sum Prototype (567) from Table 4 is lower than the Rank Sum Akshar (918) and the analysis showed that there is a statistically significant difference between these variables, we can say that the Variance of groove depth of our Prototype is statistically significantly lower compared to Akshar. This is also evident from the box plots in Figure 5a. This confirms that the prototype we have created has a smaller variation in the depth of cut compared to a commercially available device (Akshar) and has a higher accuracy in this regard. Similarly, we have verified whether there was a statistically significant difference between the Surface roughness values after using the Akshar and the Prototype. The H0 hypothesis was verified (Table 4, Figure 5b) here: *The distribution of the Surface roughness variable in both groups (Akshar, Prototype) is identical.*

In case, we reject the hypothesis, it would mean that the measured values are not identical and therefore statistically significantly different. On the basis of the p-value of the Mann-Whitney U test, we do not reject the H0 hypothesis. This means there is no statistically significant difference in surface roughness when using Akshar and our Prototype.

Based on our measurements, we further verified whether the values of the variables Variance of groove depth and Surface roughness were affected by changing Frequency, Engraving Speed and No. of passes. In terms of the number of measurements, we used a non-parametric alternative to the analysis of single sort variance, namely Kruskal-Wallis ANOVA [23]. We verified it at a 5% confidence level. Verification results for H0 hypothesis: *The medians of Variance of groove depth variable are the same for all Frequency settings as* shown in Table 5 below.

Table 5

Kruskal-Wallis ANOVA for variable Frequency in relation to Variance of groove depth

Frequency	Valid N	Rank Sum
20	18	198.0000
40	18	501.0000
60	18	786.0000
		p-value ≈ 0.000

We reject the H0 hypothesis, which means that the Frequency setting has a statistically significant effect on Variance of groove depth.

Verification results for H0 hypothesis: *The median values of the Surface roughness variable are the same for all Frequency settings* as shown in Table 6 below.

Table 6

Kruskal-Wallis ANOVA for variable Frequency in relation to Surface roughness

Frequency	Valid N	Rank Sum
20	18	814.0000
40	18	500.0000
60	18	171.0000
		p-value ≈ 0.000

We reject the H0 hypothesis, which means that Frequency has a statistically significant effect on Surface roughness.

Using the same method, we verified whether the results in Variance of groove and Surface roughness differ statistically significantly at different Engraving Speeds as well as different No. of passes. Kruskal-Wallis ANOVA (Table 7, Table 8) was also used here. In none of these four combinations did the analysis confirm statistically significant differences between the measured values.

Table 7
Kruskal-Wallis ANOVA for variable Engraving Speed in relation to Variance of groove depth and Surface roughness

Engraving Speed	Valid N	Rank Sum (Variance of groove depth)	Rank Sum (Surface roughness)
100	18	441.0000	500.0000
200	18	471.0000	494.5000
300	18	573.0000	490.5000
		p-value = 0.341	p-value = 0.995

Table 8
Kruskal-Wallis ANOVA for variable No. of passes in relation to Variance of groove depth and Surface roughness

No. of passes	Valid N	Rank Sum (Variance of groove depth)	Rank Sum (Surface roughness)
10	18	471.0000	484.0000
15	18	495.0000	504.0000
20	18	519.0000	497.0000
		p-value = 0.879	p-value = 0.977

Based on the comparison of the commercial Akshar equipment and our constructed prototype we've found that at the 900 μm (0.9 mm) cutting depth setting, the deviation between the specified depth and the actual cutting depth was statistically significantly lower when using our constructed prototype. This means that the equipment we've created is paradoxically more accurate in this respect. The results also suggest that at higher Frequency, surface roughness decreases and Variance of groove depth increases, both by a statistically significant degree. Other uploaded input parameters have no statistically significant effect on these values. The measured results can be explained by our use of a different wavelength and lower power laser. At the same time, we've concluded that at a lower frequency and low number of passes the Surface roughness increases. Our proposed solution is not intended for commercial purposes but serves as a teaching aid for students. When testing the prototype, we were able to successfully cut various types of material to a depth of 1.5 cm (rubber, wood, veneer, plastic). However, we do not recommend using the designed prototype as a cutting or machine tool, as the laser power is only sufficient to carry out the engraving process.

Conclusion

The aim of the paper was to show the possibility of creating a low-cost laser engraver CNC machine prototype that was able to engrave into a 210x290 mm surface. The machine itself had a low consumption and worked with high precision thanks to the precise control of stepper motors. Compared to other CNC devices, the expenses to create it were not that high (Akshar Fiber-Pro Laser Engraving Machine with 20 W laser, price starting at 1900 € compared to the 236 € price of the prototype). It was made of easily accessible parts so there was no problem of getting spare parts. Although it meets the parameters of industrial machines, we would not recommend it for commercial use. However, it would do very well in educational institutions. It was designed to be simple and could be moved easily everywhere. The automated programming of the device can be learned in a fast and easy way by using the appropriate methodology. [22] In the control unit Arduino, an open-source software was used. As part of the project, Inkscape was used to create the content and then a plugin to generate a G-code. Universal G-code Sender facilitated manual operation of the machine, its visualization and G-code loading. As planned and recommended refinement, two lasers with lower performance could be used showing perpendicular lines. The zero point of the machine was then found where these lines crossed. The team managed to build the low cost prototype of the laser engraving machine (total 236 €) and to operate it without bigger complications.

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