Manually Interchangeable Heads of Homemade Computer Numerical Control (CNC) Machine

Jimmy Linggarjati and Rinda Hedwig
Computer Engineering Department, Bina Nusantara University, Jakarta, Indonesia

***Abstract*—The aim of this research is to design and produce a low cost Computer Numerical Control (CNC) machine which is equipped with interchangeable head for many applications especially for small-medium creative industry. The CNC machine has good flexibility where its head can be changed manually and easily between pen (impact-engraver) mounted and CO_2 laser mounted. The choice will depend on the application that is chosen by the user. The software that is used is basically from open source software and its precision is "what you see is what you get" (WYSIWYG). Some creative applications are successfully performed as shown in this paper, and its lower-production cost is favorable for small-medium industry. By the year 2014, this machine will be produced in a mass production and will be marketable in Indonesia.**

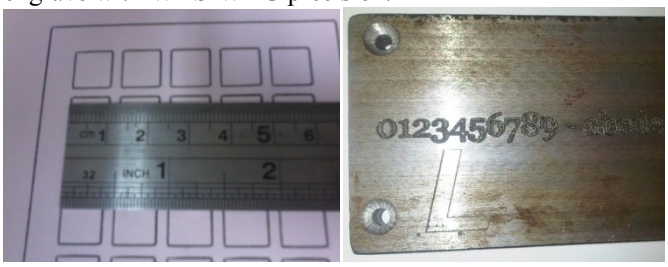
***Index Terms*—CNC machine, interchangeable head, pen head, impact-engraver, CO_2 laser head, creative industry applications**

I. INTRODUCTION

Since the first CNC patent was published in 1995[1], many industries start to use this machine for many applications especially for shaping process which is performed on a work piece. This patent is also referenced by more than 100 patents that produce similar machine but for special purposes. When it was first developed, specialized hardware including application specific integrated circuits were required for any practical machines. With the performance of modern Personal Computers (PCs), it is entirely practical to use a standard PC to make a useful machine. In fact the majority of commercial controllers are now simply ruggedized PC architectures which include some form of isolated high speed digital inputs and outputs[2].

A laser-based CNC machine from China that is sold in Indonesia has price range from US$10,000 up to US$15,000 depending on the dimension and purposes. Nevertheless, usually this typical CNC machine is only for one mounting device since each application will need one head either for cutting or welding as well as for drilling or engraving. We studied that one company in India offered different kind of machine for different applications such as laser cutting, laser marking, laser engraver, laser 3D subsurface, and laser welding machine. It means that no single CNC machine can do the several tasks simultaneously.

Understanding the needs for lower cost CNC machine as well as multi purposes function to be used in small-medium enterprise in Indonesia, we did a small research about these needs, especially for creative industry. It took one year to complete this homemade CNC machine construction with tool path feedback control[3], which is equipped with one servo motors and two stepper motors. Since the first design was for writing purpose, an inked-pen head was mounted and the machine was functioned as if it was a plotter. The drawing result on a paperboard can be seen in figure 1(a). Having succeeded with the first step, we then mounted an impact-engraver head and used it for metal which was successful as well and the result can be seen in figure 1(b). Since the machine was developed in Computer Engineering Laboratory at Bina Nusantara University, the main purpose of this machine was for Printed Circuit Board (PCB) drawing, drilling or technical drawing. In year 2012, we got a research grant that supported the continuum of this research which enhanced the CNC machine design by manually mounting it with CO_2 laser head. Actually CO_2 laser can be used to cut metal target[4], however the energy of the laser for this machine is only 40Watt, and the application merely only for paper, plastic, wood, and acrylic but it could cut, mark, and engrave with WYSIWYG precision.



(a) (b)

Fig. 1 Engraving result on (a) paperboard target using inked-pen with rectangle 10x10mm^2 and (b) metal target, i.e. iron, using impact-engraver-pen.

II. DESIGN AND EXPERIMENTAL SETUP

The homemade CNC machine's dimension is 800mm x 700mm x 1200mm as shown in figure 2 and the block diagram can be seen in figure 3 with its working area's dimension is 500mm x 450mm. It has three axes (X, Y, and Z) with two racks to put the CPU inside. Most of previous CNC machine is using table moving [5,6], while for this design the table is not

This work is partially supported by "Hibah Bersaing KOPERTIS Wilayah III" under Grant number 102/DRIC/IV/2012.

J. Linggarjati and R. Hedwig are with the Computer Engineering Department, Bina Nusantara University, Jakarta, Indonesia (phone: +6221-534-5830 ext. 2144; e-mail: jimmyl@binus.edu and rinda@binus.edu, respectively).

moving to the axes (X and Y), instead the two axes are driven by a DC servo motors (TAMAgawa 200W) and a stepper motor (VEXTA ASM 66A – 1.7A – 100W), respectively, which in turn drive two precision ball-bearing screws, in order to provide highly accurate movements. The end-tool, which holds the pen, is placed along the Z axis. It is also driven by a stepper motor (VEXTA ASD 13AA – 0.9A), equipped also with a precision ball-bearing screw. Nevertheless, during the CO_2 laser operation the Z axis was fixed, since the focus length of the laser is determined only by the focus-lens.

Fig. 2 Manually interchangeable cutting head of homemade CNC.

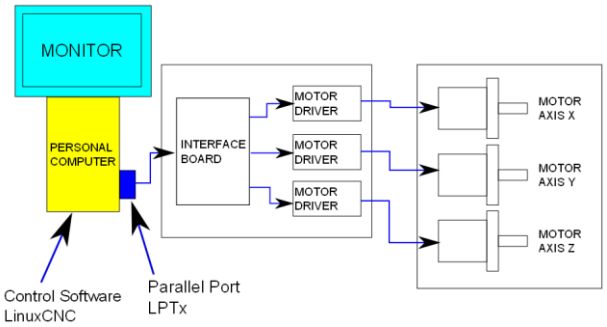


Fig. 3 Block diagram of the CNC system.

Four (4) wheels are attached to the four-legs of the CNC machine so that we can move the position of the entire system smoothly from one place to another. There is a 20Watt water circulation pump for water cooling system during CO_2 laser operation, as well as vacuum filtration system with its energy consumption as high as 750Watt. The total power consumption for CO_2 laser operation can vary up to 1500Watt. This energy consumption can vary depends on the technology that we choose. We can reduce the energy consumption by changing the cathode ray tube (CRT) to liquid crystal display (LCD) monitor. During the pen head operation, the vacuum filtration system and the water circulation pump are not used. The operating system that is used to control is based on Linux Ubuntu 10.04 with open source program such as Linux CNC[7-10] and Inkscape[11].

A comprehensive study[12] was done in order to select appropriate laser for building a low-cost CNC machine and we finally chose CO_2 laser for its lower cost per watt along with good beam quality as well as its wide range of average output power ranging from a few watts up to over 60kW. The CO_2 laser that is used is a continuum type with wavelength of 10.6μm (power 40Watt; triggering voltage 20kV; current 16-18mA; length 700mm; ∅ 50mm; water cooling system; lifetime 1500-1800 hours). The setup of this system can be seen in figure 4 where three sets of 20mm gold plated mirror and a 18mm ZnSe lens (f = 50.88mm) are attached to the tools of X, Y and Z axes. Figure 5 shows the Z axis which mounted with impact-engraver pen, and "mirror-lens" for CO_2 laser. For reminder, the Z axis was fixed during "mirror-lens" mounting and the distance between working area and the lens are accordingly to the lens focal length, i.e. 50.88mm.

The materials that were used for this experiment are plywood, acrylic, and cardboard, PCB with maximum 5mm, 3mm, 5mm, and 1mm thickness, respectively. The total production cost that is needed to construct the whole system was US$6,250 (US$1 equal to 9,600 rupiahs).

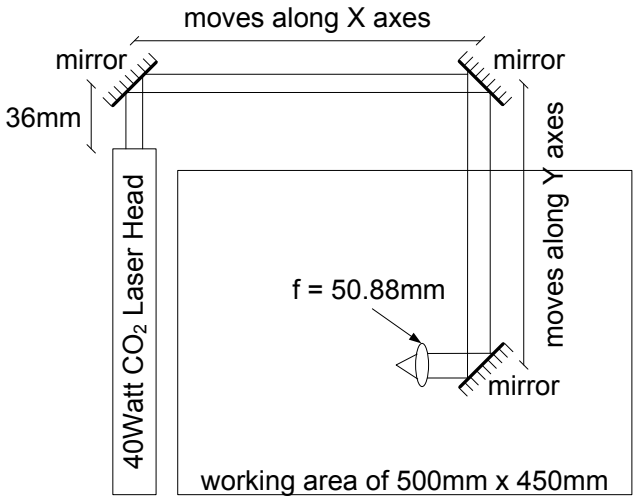


Fig. 4 Setup of CO_2 laser based system.

III. Applications and Discussion

At the beginning, the whole system was dedicated for PCB production where a piece of paper was set on the working area and the drawing was done accurately with an inked-pen – only used as a prove test that the precision of this machine is enough for PCB engraving application. Later on the PCB was drilled by the use of automated hand drill that was controlled with computer. For further application, a CO_2 laser head was mounted in the CNC and functioned to cut cardboard, plywood, and acrylic. The alignment for laser mounted head was no easy at the beginning, we were using HeNe laser as guidance along with a white thin string. The alignment took several days before finally we fixed the position of the mirrors and lens. Once this alignment had successfully done, the manual interchange among pen head, spindle head, and laser

head was easy. We just replaced the Z axis manually and once we changed the head back to laser, we just had to do minor adjustment with the guidance of laser beam on the paper. Several results are shown in figure 6, such as the traditional shadow puppet made of plywood, the picture engraved on acrylic, and the 3D object made of plastic board.

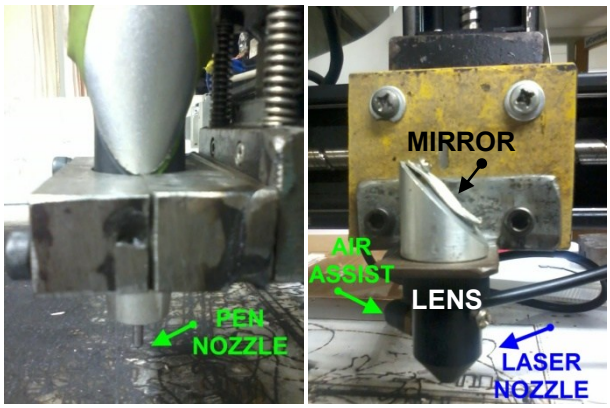


Fig. 5 The head was mounted along the Z axis. From left to right: impact-engraver-pen and mirror-lens.

(a) (b)

(c)

Fig. 6 Some results produced by the use of CO_2 laser based CNC machine, they are (a) traditional shadow puppet made of plywood, (b) cat's picture engraved on the acrylic, and (c) 3D object made of plastic board.

The accuracy of material produced compared to what was displayed in the monitor was precisely the same and with 100% reproducibility as shown in figure 1a (using inked-pen) and figure 7 (using laser-cut). The time consumption needed for each process was depended on the size of the object and its thickness. The thicker the object, the slower the laser will move. The time consumption for 350mm x 250mm plywood shadow puppet with lots of detailed, will take around 2 hours. As for the engraved cat picture on the 105mm x 130mm acrylic and the 3D dragon object made of plastic board will take 3 hours and 1 hour, respectively.

When we tried to draw an electronic circuit on the PCB by using the CO_2 laser, we had to apply paint stripping technique[13-15]. It has been studied previously that the threshold of copper for the plasma generation in TEA CO_2 laser was considerably high because of its high reflectivity (more than 95%) at around 10.6μm[16]. The process of paint stripping as shown in figure 8 is explained as follows, the paint on top of PCB will absorb the CO_2 laser ablation since PCB (made of copper) reflects most of the laser energy leaving a clean stripped surface. Due to most metal's high reflection factor, metallic surfaces are suitable for laser cleaning. Typically, the substrate is not mechanically or thermally stressed or stained by the CO_2 laser stripping process. The process converts the stripped paint to particles and vapor which are automatically removed by a vacuum filtration system.

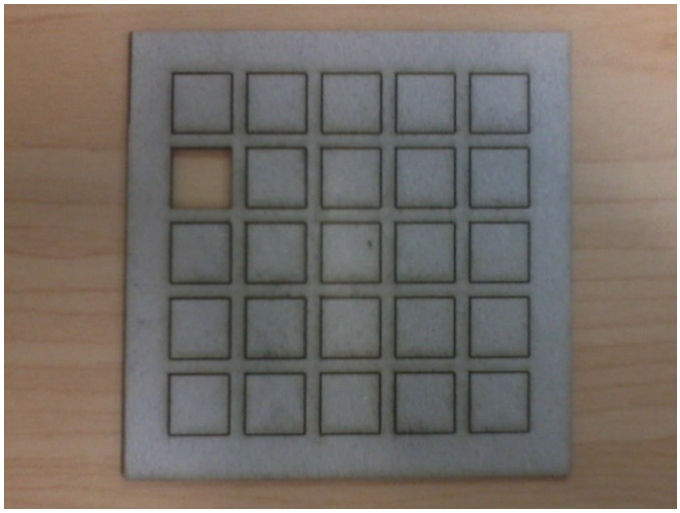


Fig. 7 Reproducibility and accuracy of 10x10mm^2 squares using laser cut. We got WYSIWYG result.

We tried to apply several kinds of paints in order to get the most effective PCB that would be successfully etched. Even though the paint stripping process finally was successful, we failed to get a good etched-PCB during the etching process for several times until we found that varnish is the most effective paint to be layered on top of PCB before paint stripping process as shown in figure 9. Nevertheless, we did not realize that when the CO_2 laser attacked the opened surface of the PCB (the paint already removed from the surface on the first bombardment) for the second time, the laser beam was

reflected back to the laser head and it removed the reflective layer of the back mirror of the laser head. It happened since we programmed the laser to do paint stripping twice for thick path and once for thin path. Therefore, the laser head was failed to produce 40Watt energy but produce two separated beams instead, with a very low energy that could not even cut a 5mm plastic board.

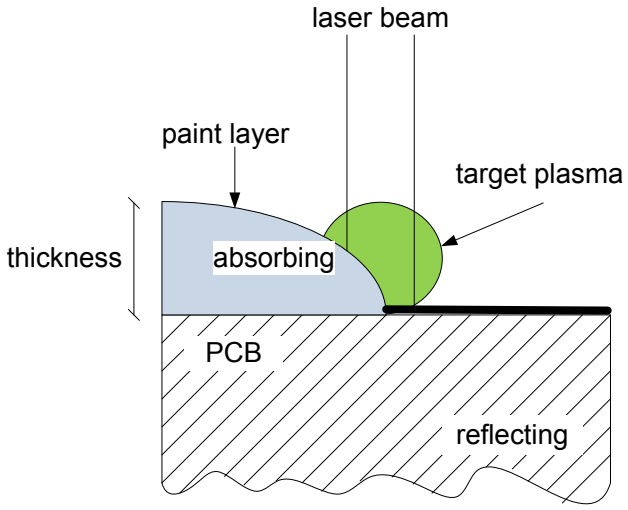


Fig. 8 Laser stripping process.

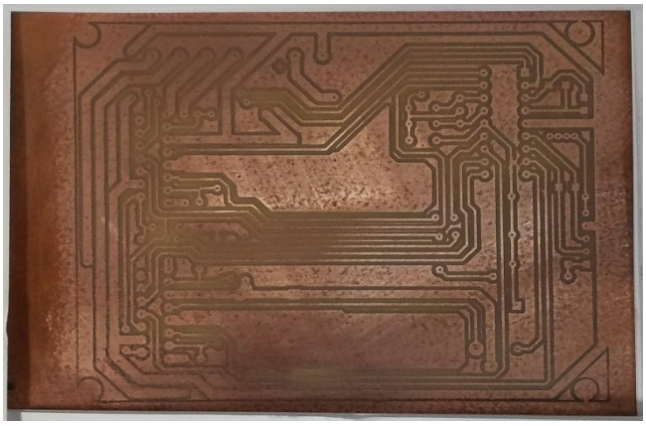


Fig 9 Example of the etched PCB after paint stripping process.

This result also proved that when the distances of laser pathway closer to the laser head, the laser beam reflection would come back to its path and attack the laser head. This is also due to copper's high reflectivity for laser wavelength at 10.6μm. Therefore we need to put anti back reflection tool just in front of the laser head.

This machine had been demonstrated to other Departments (such as Architecture Department) and they showed their interest to utilize this CNC machine for any design purposes. In the mid of December 2012, we already offered this machine to a small homemade CNC industry which also showed his great interest in the machine. The further collaboration will be discussed in order to make this machine marketable in 2014. However, we still want to do further development research in 3D cutting or sculpturing or engraving on the woods.

IV. Conclusion

Building a home-made CNC machine with a low cost budget gives advantage for small-medium industry, especially when this CNC machine can be manually interchanged with 3 different kinds of tools according to its needs. This CNC machine can be attached with pen head, spindle head, and laser head for different purposes but the most useful part happened when we attach with laser head. The open source program also support this machine to perform with 100% reproducibility and WYSIWYG accuracy.

References

[1] M.R. Wright, D.E. Platts, D.B. French, G. Traicoff, M.A. Dupont, and G.A. Head,"CNC Control System Patents," US patent 545393, Sep 26, 1995.

[2] McKilliam G., "CNC Overview White Paper," Industrial Automation Series Ltd., Oct 2012.

[3] Gong Zhiming, Huang Sheng, ZengHao**and** Chen Xiaoqi, "CNC Laser Marking on Freeform Surfaces without Prior Geometrical Information," in *Proc. 2002 IEEE/RSJ Intl. Conf. Intelligent Robots and Systems*, Lausanne - Switzerland, 2002, pp. 1862-1867.

[4] J. Wang, "An Experimental Analysis and Optimisation of the CO_2 Laser Cutting Process for Metallic Coated Sheet Steels," Int. J. Adv. Manuf. Technol., vol. 16, pp. 334-340, 2000.

[5] A. Hace, K. Jezernik, B. Curk, and M. Terbuc, "Robust Motion Control of XY Table for Laser Cutting Machine," in *Proc. 24th Annu. Conf. IEEE Industrial Electronics Society*, vol. 2, 31 Aug-4 Sept 1998, pp. 1097-1102.

[6] Cao Shukun, Zhang Heng, ZeXiangbo, Yang Qiujuan, and Ai Changsheng, "Software and Hardware Platform Design for Open-CNC System," in *IEEE Int. Symposium on Knowledge Acquisition and Modeling Workshop*, 21-22 Dec 2008, pp. 139-142.

[7] Wang Changlei, Cao Shukun, Zhang Qianqian, Sui Zhiming, and Yang Shangwei, "Design of Five-Axis CNC Based on Linux," in *Int. Conf. Computer Science and Network Technology*, vol. 2, pp. 1336-1339, 24-26 Dec 2011

[8] Huang Hai-peng, Chi Guan-xin, and Wang Zhen-long, "Development of a CNC System for Multi-Axis EDM Based on RT-Linux," in *World Cong. Software Engineering*, vol. 3, pp. 211-216, 19-21 May 2009.

[9] Wang Zi-niu, Li Song, and Wang Yan, "Researching of Real-Time Version and Testing Its Performance of CNC System Based on RT-Linux," in *Int. Conf. Networking and Digital Society*, vol. 2, pp. 174-177, 30-31 May 2009.

[10] TianrongGao, Dong Yu, DongfengYue, and Yi Hu, "Design and Implementation of Communication Platform in CNC System," in *Int. Conf. Mechatronics and Embedded Systems and Applications*, pp. 355-360, 15-17 July 2010.

[11] D. Spinellis, "Drawing Tools," IEEE Software, vol. 25, issue , pp. 12-13, May-June 2009.

[12] A.J. DeMaria, and T.V. Hennessey, Jr., "The CO_2 Laser: The Workhorse of the Laser Material Processing Industry," *SPIE Professional Magazine*, submitted for publication.

[13] R.J. Ranalli, "Laser-Based System and Method for Stripping Coatings from Substrates," US patent: 5662762, Sep 2, 1997.

[14] G. Schweizer, and L. Werner, "Industrial 2-kW TEA CO_2 Laser for Paint Stripping of Aircraft," in *Proc. 10th Int. Sym. Gas Flow and Chemical Lasers*, vol. 2502, pp. 57-818, March 31, 1995.

[15] Sp.G. Pantelakis, Th.B. Kermanidis, and G.N. Haidemenopoulos, "Mechanical Behavior of 2024 Al Alloy Specimen Subjected to Paint Stripping by Laser Radiation and Plasma Etching," Theo. and Appl. Fracture Mech., vol. 25, issue 2, pp. 139-146, Sept-Oct 1996.

[16] MM. Suliyanti, R. Hedwig, H. Kurniawan, and K. Kagawa, "The Role of Sub-Target in the Transversely Excited Atmospheric Pressure CO_2 Laser-Induced Shock-Wave Plasma," Jpn. J. Appl. Phys., vol. 37, pp. 6628-6632, 1998.