LOW COST MACHINES SHAPING THE FUTURE OF TECHNOLOGICAL SOCIETIES

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Abstract. *The way of life of technological societies is supported by the availability of a large set of goods, either products or services. They are produced somewhere in the planet and made ready to the end users worldwide. International trade is made increasingly easier because larger ships, trains, planes and trucks keep being built, and transportation paths are expanding more and more to reach distant places. Part of the tasks to be carried out demand a lot of skilled manual work to be done, such is the case in manufacturing, where skilled professionals are needed. Several technical tasks (and related learning activities) are rejected by the youngsters because they are difficult and unattractive. On the other hand, teaching systems find it difficult to support technical apprenticeship because of the need of expensive equipment (and usually obsolete after a very short period). Besides, the system frequently directs the promising students to less technical courses, and casts the unsuccessful to alternative technical programs that are expensive, always carrying the brand of forming second class professions, although presenting high employment rates. It is well known that training improves performance. Although the amount of training needed to achieve a certain level of performance varies with the individual and personal characteristics, some training is always desirable. As plain manufacture is frequently not appellative enough for youngsters, building a CNC machine increases the inherent pleasure of manufacturing one's models, may offer a sound environment for learning the laws of mechanics and technology, to trigger and sustain the interest over these subjects, so contributing to attract students for learning and training technical skills. To manufacture one's own machine-tool is a source of creativeness and a passionate hobby. Beginning with CAD modeling of machine components and ending with actual making of the machine itself, skils can be effectively transmitted to the new generation. Stimulating the students curiosity, a set of low cost machine tools is under construction to access a project envisaging the dissemination of modeling and manufacturing interest and knowledge to the elementary and secondary level in the vicinity, expecting to increase attraction of youngsters for Mechanics, Electronics and Manufacture, and so guaranteeing a sustainable income of new skilled generation. This paper explains the motivation and the technical background in the origin of a Low Cost Manufacturing Laboratory. Its refinement and functional operative condition will enable replication in an educational or professional training scenario, where Numerical Computer Machines require expensive inoperative lead times and costly learning skills.*

Keywords*: CAD/CAM; Teaching\learning; Mechanical Technology; Numerical Control; Modeling*

1. INTRODUCTION

Taking a look to any field of activity of technological societies one easily identifies professions requiring manipulation skills that must be trained. Someone must be able to do manufacturing difficult jobs, either trough direct handling requiring physical strength, or maneuvering some sort of apparatus with mechanical help. Naturally this kind of jobs demand experience, and experience demands training.

Time and materials are consumed in every job acquiring experience. As experienced generations get old, new generations need to be trained in order to get the skills needed to get the tasks done. An increasing percentage of the children and teenagers are kept out of the professional world not only because their work no longer is needed to help support their family, but also because longer learning periods are needed to achieve the level of knowledge required to integrate productive activities. During learning time most of them are attracted by “white collar” professions, and when finishing school they have no actual skills to join the available professions, often demanding physical competences they haven’t acquired “Monteiro *et al.* (2007)”. Furthermore, there are also “white collar” professions often needing to qualify their professionals with new developed physical techniques, for example in surgery or in investigation activities.

Figure 1shows two manufacturing situations where skilled professionals are needed.

The continuous development towards and increasing better life quality tends to produce:

- Fast technological change;
- Longer periods of apprenticeship;
- Attraction for softer, unrisky, high profit professions;
- Market and professions niche involving specialized workforce.

Along the production chain of any product, there are tasks to be accomplished where some kind of skilled manipulation is needed. Both a computer and a car are assemblies of some dozens of components that undergo a lot of

transformations from the raw material to the delivery to the end user. Taking a look over manufacture or maintenance, we conclude some essential activities arise that are not particularly attractive for youngsters as potential professions:

- Industrial base metal works - casting, welding, machining, wrought products, ironworks – needed to obtain the raw material of the component or the component itself (see Figure 2);
- Assembling and finishing machines and equipment or spare parts, needed to produce the final shapes or to verify component's accuracy;
- Manufacture and operation handling equipment for the items above;
- Assembling and mounting metallic structures: factories, containers, stores;
- Operating machines and equipment for generate and deliver the energy needed to their operation;
- Operating machines, equipments and material for their maintenance;
- Tools and fixtures making.

Figure 1. Conventional manufacturing operations in a lathe (left) and a in a milling machine (right); Skilled professionals are needed to handle the machines, and risk is all time present.

Craft skills always were despised. From ancient Greeks where free men hardly did anything except govern the city, leaving actual work to the slaves, to societies organized in cast systems that still exist where craftsman belong to the lower levels, the negative connotation of hand work is seen, even in western societies, where "white collar" professions are preferred.

Besides, continuous investments in research and investigation of technological issues to keep up to date, societies must also invest in tools capable to improve and simplify training for their production processes so reducing the time and costs associated with personal skills acquisition "Gomes, *J., (2008)"*.

Figure 2. Casting metals: a profession that is not particularly attractive for young people.

This paper presents, in the next section, the adequacy of machine tools to constitute the main object for teaching engineering courses; then in section 3 the importance of Machine Tools for the sustainability of developed societies is discussed. In section 4 the pedagogic interest to convey scientific and technological knowledge through Low Cost Machine Tools is shown; in section 5 the work, being done in this field the Mechanical Department of the University of Minho (UMinho), is presented along with the perspectives for future work; as a final point remarks are presented, in section 6.

2. MACHINE TOOLS, THE PERFECT ENGINEERING LEARNING OBJECT

Nowadays, a machine tool is a sophisticated system that includes a command, data acquisition and treatment, measuring devices, automatic load and unload of parts and tools, that carries failure diagnosis, etc. In order to grant the high reliability that manufacturer's claim their machines offer, a modern production system demands well prepared human resources. Then, a productive system, where the machine tool is just an element, imposes the continuous supply of skilled people to fulfill the demand from the manufacturing industries, their suppliers and the maintenance teams.

Designing, building or operating machine-tools incorporate immense scientific and technical knowledge, from physics to mathematics, from materials to heat transfer. After the introduction of numerical control in the fifties of the XX century, also electronics and computer science must be considered by any developed society aiming to master machine tools science, manufacture or operation "Pruvot (1993)".

The machine-tool became a perfect object of study from an engineering school point of view: a machine tool integrates support structures that must be dimensioned, where direct application of materials resistance may be explored and where numerical methods can be applied in elastoplastic dimensioning. Also hydraulics, fluid and heat flow may be studied using machine tools as application field, when considering lubrication, some power systems, and the phenomena around swarf formation.

Computer science suffered a formidable evolution in the recent years: the personal computer (PC) became accessible to everybody, and all of the companies, even the smallest, have computers that allow not only scientific calculation, but support software to easy and foster the entire set of activities that a company may be involved into. CAD software appeared and spread, and professional powerful PC supported versions become available (like ProEngineer, Inventor, Solid Works, or CATIA), incorporating an increasing number of engineering applications (CAE), better adapted to the machine design function in general, and machine design in particular.

Machine-tools are an excellent learning support. All the learning methods of all the disciplines of an engineer's profession (beginning with CAD) can be exercised on them. They collect the whole industrial and scientific knowledge spectrum, from the conception to the commercialization, trough investigation, development, production and management. They constitute the man/machine interaction perfect example, better than in any other machine or technique "Pruvot (1993)".

They present however the serious inconvenience of not being very attractive. A machine-tool is rarely perceived as spectacular when operating. Most machines make no any movements to motivate the non expert, with the exception of robots, and these only because of some anthropomorphic features they present.

A machine is not particularly good-looking, not only for its shape or color, but because it is first designed to be functional. A good machine passes almost unnoticed (see Figure 3). It should not be noisy nor generate vibrations, and protect as much as possible the operator from risk.. On the opposite, an airplane, a boat, a rocket and even a simple car are, attractive machines, partly after the excitement they provide to the user.

Lathe

Milling machine

Robot

Figure 3. Machine tools are not particularly attractive.

In short, to choose the machine-tool as base support for technical and scientific education will just be possible if the school, the university or the country understand the particular interest in it. Of course, the risk of boring the students must be considered when choosing the machine-tools as the main theme to motivate attracting students to technology or engineering fields. An indirect and possible method to increase the appeal of machine-tools as a subject may be through the demonstration of the advantage its development brings as a resourceful tool to build more attractive machines, like aircraft, boat or car models (see Figure 4).

To promote machine tools usefulness in the creation of attractive goods, like art artifacts, is possible by using the modern technologies supported by CAD (Computer Aided Design). As a consequence, it results the early introduction of CAD disciplines, opening other domains to CAD, and hence to give a further considerable step simultaneously in

direction to the computer aided teaching and learning, to technical and industrial subjects, currently difficult to find in secondary level syllabus, at least in Portugal “Pinto (2007)”.

Figure 4. A plane or a car are examples of useful machines in which attractiveness is an important variable in design.

2.1. Computer Numerical Controlled Machines

Modern computer numerical controlled (CNC) machine were born with the development of electronics and computer science, which allowed the table and the spindle movements (the axes) of conventional machine tools adequately motorized to be controlled from a computer.

Figure 5. Modern CNC machines accept numerical instructions to control its moving elements;
A NC machining center (left), and a lathe (middle);
Top right- lathe’s protection door opened showing the tools and the part;
Bottom right – blank material and tool, ready to the operation start.

This technology was pioneer in the molds industry to command high precision machining centers. The high cost of the first computers made unfeasible their use in machines of medium or low cost. The high cost of this kind of machine-tools was directly related with the level of dimensional precision achieved and with the price of the software to operate the equipment.

Nowadays the cost of machining is a portion of the cost of the equipment that must be recovered in each component produced. Initially the costs of a CPU were proportional to the costs of the machine tools, making CNC technology prohibitive for small and medium companies, but the advance in computer science and electronics technology brought today’s cost of a powerful CPU and of the control mechanisms to command a CNC machine tool, to ridiculous values.

3. POLITICAL AND ECONOMOCAL IMPORTANCE OF MACHINE TOOLS

Machine-tool industry is a strategic industry only comparable in political importance with aerospace and armament industries (Pruvot, 1993). European machine-tools, until the end of the Second World War (1939-1945), dominated the world market. A dozen of years later, that no longer happened. Soon the Japanese showed that they knew how to do equivalent, or even better machines than the Europeans, and at much better prices. Certainly they began by simply copying, but by turning more scientific and less “intuitive”, shortly they managed to achieve general recognition for the quality of their products

In Portugal the machine tools industry failed the electronic evolution of the domain during the eighties (with some exceptions like ADIRA, a builder of metal sheet forming equipment). Serial machine tools builders became vendors of

foreigner builders, from Western Europe (firstly from Germany), USA or Far-Eastern countries like Japan, Korea and Taiwan, and nowadays risk to add R. P. of China to the list.

The modernizing effort of Portuguese industry became heavily dependent on equipment made elsewhere, so becoming unable of following its own competitive strategic producing policy. The companies, failing to master the entire cycle of the machine tools development, became unable to design, modify and improve their equipment "AIM-CEP, (2009)". The installation of high technology factories in the territory is frequently and mostly an expression of the availability of man (and brain) power to satisfy the convenience of foreign multinational companies to find a place to enlarge their production capability. If needed, the downsizing of the operation is always an option to which decision nationals may have little contribution, as the recent drawbacks from international crises are proving.

4. LOW COST MACHINE-TOOLS

Nowadays machine tools technology is used in several branches of the industry like electronics, automobile, molds, modeling, etc (see Figure 6). The technological development of electronics and of computer science made the cost of the hardware unimportant in face with the cost of the mechanical components of the machine tool. CNC technology is now used not only in machine tools of great precision but in most of the types of machines as bench milling, rapid prototyping machines, printers, plotters, measuring and digitalizing machines and so on. The cost decrease of computers, interfaces and programs made possible that any neophyte can build his own CNC machine tool, with greater or smaller precision to fulfill his needs. Parallel forums of discussion of problems tied to the construction, assembly and programming of this type of CNC machine tools are available and accessible in NET.

Further, companies appeared building low cost CNC hardware and software to control machine tools. This philosophy, although recent, is deeply rooted in the area of modeling, in particular in ludic modeling, mainly in countries like France, Italy, Spain, UK and USA "Azevedo P., (2007)".

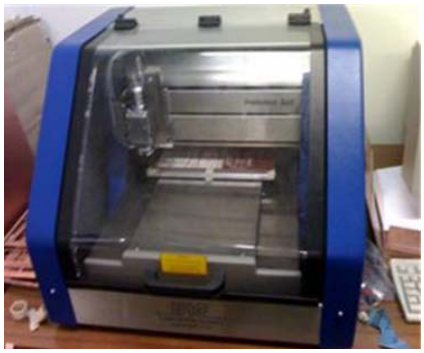

Figure 6. Example of a low cost CNC milling machine, used for milling PCBs

4.1. Low cost CNC hardware

Low cost CNC hardware use technology identical to the one used in the construction of the hardware of the common printers, that nowadays are spread everywhere. This hardware type controls step motors that power systems of coordinated axes controlled by a CPU, this being commanded by software that controls the hardware. The difference between this hardware type and the one that commands conventional CNC machines, is due to the type of motors that each one of these hardware types can control. The hardware used in conventional CNC machines usually controls servomotors (Figure 7), because this kind of motors allow very superior power ranges than those found in any type of step motor (Figure 8)

Figure 7. Servomotor.

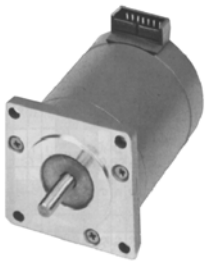

Figure 8. Step motor.

The direct consequences of operating machine tools powered by step motors are then the decrease of the feeding speeds, decrease of the overall machine strength, decrease of the dimensional achievable accuracy, and limitations in the range of materials that can be machined, but also a decrease of the costs of the machine tool, decrease of the costs of the hardware and software to control the motors is expected.

The development of low cost CNC machine tools done in the last years, induced the emergence of several companies offering a wide CNC hardware range to command step motors, now being easy to find available cards to control simultaneously up to 5 step motors (5 axes).

An examples of a popular CNC cards are is the CNC hardware (Figure 9) that controls step motors operating in the tension range from 12 to 40 V and supporting 4 A of maximum current intensity "Fouga, (2001)". Also some manufacturers of this kind of hardware make available information on the printed circuit board design, the list of the components used and the techniques to do the card assembly, as well as the images of their printed circuits maps. (5). In possession of the available information virtually anyone is able to build his own CNC machine tool.

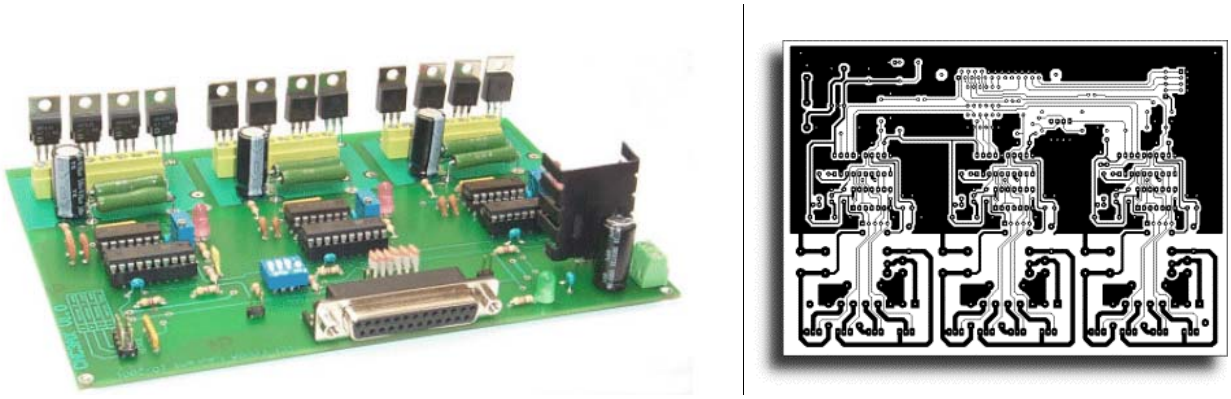

Figure 9. CNC3AX board and the printed circuit map – controls up to 3 step motors (FEOGA).

4.2. **Low cost** CNC soft**ware**

An enormous diversity of low cost CNC software exists to control machine tools powered by step motors. For each hardware there are several compatible softwares, from the more economical and limited to the costliest and completes. For each actual case one must study the needs and limitations of the machine tool to make a coherent choice of the software to acquire. For example the CNC3AX hardware is compatible with several types of low cost software, like CNFRAISE, KELLYCAM, CNCPRO, WINPCNC, DESKNC and IproCAM CFAO (Figure 10). The choice of the software must consider the actual objectives to achieve, from the machine to control (a CNC lathe, a CNC milling machine, …), the design, and actual impression of printed electronic circuits, creation of 3D relief shapes in parts starting from a 2D images, creation and simulation of cutting paths for parts machining from a CAD file or reading a hand written G-code text file "Azevedo P., (2007)".

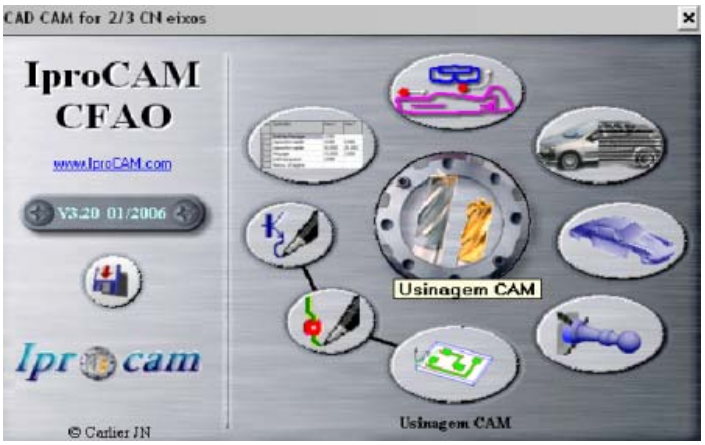

Figure 10. An example of a low cost Software, NINOS 3.2 from IPROCAM.

4.3. Pedagogic Interest of Low Cost Machine Tools in CNC

Above has been stated that the machine-tool has high scientific and technical interest. From the machining process arise problems of fundamental physics, metallurgy, non lineal automation phenomena, etc.

So a machine-tool is a complex unit where one or more processes take place, with structural elements, fixed or moving, such as frames, sliding, spindles and shafts that turn in bearings, and a command. Therefore a machine-tool is truly a "system" and should be studied as such. Several domains deserve careful attention, and there is always space to innovation. It is enough to consider that creation and invention is frequently driven from solutions to particular engineering problems: welding using friction, the cutting hard metals by electro erosion, part construction by layer manufacturing and so on.

The availability of very cheap electromechanical equipment like modern printers or other electronic appliances that frequently are replaced for it does not pay to get them repaired is a source of components that usually end in scrap, although perfectly functional and then reusable. Besides, the intrinsic interest of machine studying and building, reclaiming components from non functioning equipment, not only contributes to keep the cost low, but also allows the student to learn equipment functions, maintenance and design, and turns him aware of recycling possibilities.

5. WORK IN COURSE AT UMINHO

Low cost CNC machines study and development are subjects that from some time now have been given attention. First a small machine was bought with the objective of learning the main aspects of its working principles, its main functions and more important, to check its limitations and study improvement possibilities. Besides the expected limitations imposed by its small dimensions, the major limitations of the machine result from:

- The dedicated proprietary software controlling the machine is not enough similar to professional versions used in industrial CNC machines, so limiting actual numerical control competences acquisition;
- The equipment seems to be an upgrade of a small plotter to which a Z-axis was added, but access to workspace is severely restricted by solutions more adequate for the previous bi-dimensional functionality;
- Part holding took not much attention from the designer, and so is mostly left to the users' imagination.

The list of non satisfying characteristics found is not complete, but of course the objective of this paper is not to establish the machine capability.

The UMinho students were challenged to study and develop and built alternative solutions to solve not only the limitations found in this particular machine, but also to design entirely new machine tools.

At the moment, the low cost machines under development include a lathe and a milling machine, and under consideration are a hot wire polystyrene cutting machine and a measuring machine and a rapid prototyping machine.

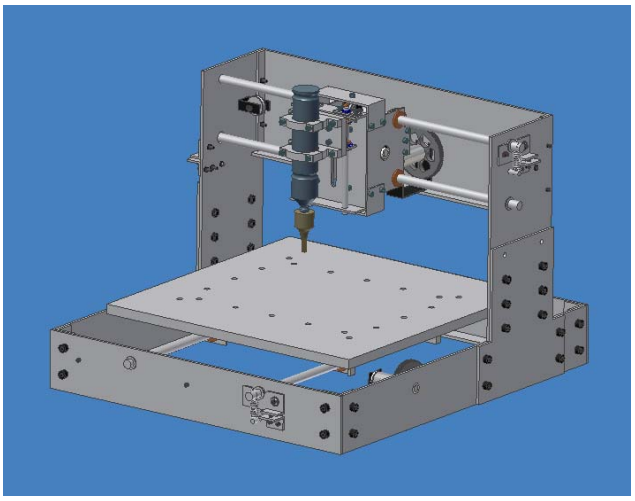

Figure 11. 3D CAD model of the CNC milling machine under development at the UMinho.

This work intends to serve as to make of a "do it yourself" manual with building solutions, to spread trough the secondary level in order to catch the attention and interest of young people to technology, manufacturing and engineering. The work may be seen as a roadmap for the selection and manufacture of components, its assembly and set up of the control hardware to be supported in a PC.

Most of the elements to include in the new machines will be reclaimed from common printers, desk photocopiers and other equipment alike. Some components of the machines that need to be specifically designed or modified will

built using he department Lab facilities, including CAD/CAM and conventional machine tools. Electronic hardware will range from low cost CNC control cards already acquired, to solutions designed and built by the students themselves. Solutions for driving and control software will follow the same pattern.

6. CONCLUSION

The construction of small low cost CNC machines may be fascinating. To materialize an idea is the objective of many industrial activities, and it carries in itself a non despicable part of the reward to match the time and money invested. Actually building a design made for scholar purposes is then an incentive to be considered. This project aims not only to build machines, but draws a larger objective of spreading technology, engineering, opportunities and challenges to youngsters so shaping the future of the society that is expected to keep developing with sustainability.

During the project, electronics knowledge, computer science, programming CAD/CAM, acquisition of competences in CNC, the manufacture, constitution and construction of machine tools CNC are acquired, objectives adjacent to the project and already initially foreseen. The same can be said about the NC software to run the board, so covering the learning of application software making. As final product of such a project, CAD skills, machining skills, soldering, dimensioning and choosing components, reclaiming and valorizing components are also results that must be emphasized.

Technologies keep developing, and new professionals must be trained in order to replace the previous generations.

This has highlighted the motivation and the technical background in the origin of a project to assist basic technology teaching and learning. In this area, authors are convinced that spreading low cost CNC machines will play a major role in the forthcoming professional teaching and actual industrial expertise workforce reconversion.

Also, a new branch for machine constructing industry is emerging: the possibility of constructing “low cost machines” not only for education purposes, but also for specific activities for some small and specif companies.

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