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MANUAL AND SERVO ASSISTED, HYBRID SYSTEM FOR POSITION CONTROL IN MACHINE TOOLS

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Abstract. *Nowadays, production are directed for the manufacturing of small lots (10-20 pcs), where the criterion to choose the machine tool is not very clear. In this scene, the present project aims the development of an intermediate machine tool with characteristics intermediate between the universal and the numerical control (CN) machines. The desired machine conjugates the functional advantages of these: high efficiency and flexibility. The machine, thus designed, will have a manual operation (trajectory), and its positioning will be servo-assisted. Here, "to develop" it means: a) to propose a machining strategy; b) to propose a machine architecture that works according to this strategy; c) to develop a prototype and; d) to validate the strategy and the architecture through tests with the prototype. The positioning strategy, is based on a manual positioning, i.e., the operator defines freely the motion of the tool with respect to the work piece. However, a computer monitores constantly the tool position, not permitting the entrance of it inside the area, here called "prohibited region", corresponding to the profile of the part to be machined. Outside that region, the computer enables operator to move the tool as he wants. The prohibited region is supplied directly from a computer aided design system, not needing any kind of computer tools for generating the tool path automatically. Thus, the operator execute the rough machining. The final path, finishing path is executed automatically by the computer, that makes the tool contour the profile of the part, acording to the start-up command given by the operator. In the work, one possible architecture for achieving such strategy is presented. It consists of servo controlled XY table in which, the operator commands the table motion by means a joy-stick. The work also shows results of tests executed in the prototype machine.*

Keywords: *Hybrid control system, Positioning control system, Hybrid machine tool, Servo system*

1. INTRODUCTION

With the predominant globalization in the current world, on the context of the transactions of goods and services, it occurs a constant and increasing necessity of improving the productivity and therefore the competitiveness in the markets. As consequence, it is more and more important to develop new machines or production devices adaptable to the existing machines trying to supply the present limitations and disadvantages. Through this continuous search for improvements in the manufacture processes, a variety of production machines had been developed: from conventional machines until the most refined numerical control (NC) machines and machines of dedicated use.

The development of these technologies does not have, as fundamental target, the elimination of these machines from the productive process (or from the market). Instead, it is preferable to develop machines compatible with specifications of the parts to be produced (form and size of lot mainly), resulting in a more efficient manufacturing (reflected in the cost).

Aiming production of very small lots, up to 10 pieces, this works deals about the development of a production machine, specifically a machine tool, having intermediate characteristics, between a manual or universal machine and a NC machine, i.e., a machine that does not requires programming, as NC machines, and has a productivity higher than a manual machine. Besides advantages from the production economics point of view, the development of such machine is interesting from the social point of view, since it revitalizes the human labor, opening possibilities to the problem of unemployment caused by the high levels of automation observed in recent factories.

2. PRELIMINARY STUDIES

A simple analysis of a machining operation shows that the most time consuming stage of the operation is that of approaching and finishing (Horikawa *et al*. 2007). This suggests that a significant reduction in the machining time, that is, an increase in the machining efficiency, can be achieved increasing the efficiency in these stages, that is, those related to the precision positioning. Based in such consideration, Horikawa *et al*. 2007 proposed and implemented a hybrid positioning system, in which, the operator executes the positioning manually and a servo-system helps operator to execute precise positioning. The proposed system is composed of: a handle driven linear guide with a sliding table, a position sensor, an electromagnetic brake and a control computer. The operator feeds the computer with the desired position, activating the control. Then, the table is moved manually through the handle. During the motion, the sensor monitors the table position and the readings are sent to the control computer. As the table approaches the desired position, the control algorithm in the computer gradually activates the brake, generating a braking force in the handle. The brake is fully activated and the handle locked, when the table reaches to the desired position. The brake is released only if the operator tries to move the table backward. Until reaching the desired position, the servo system does not interfere in the movement and the operator is free for moving the table as he wants. Using such system, there is no necessity of programming, as in NC machines. The operator defines the tool path, moving the table as he wants, and the servo-system helps the operator to avoid trespassing the contour of the work to be machined. Thus, the efficiency of a manual machining is improved, avoiding at the same time, the time-consuming set-up activity of a NC machine. A prototype with motion in a single direction was constructed and the efficiency of the strategy demonstrated by tests.

A bibliographical review was conducted in order to find similar propositions that try in the solution of the inefficiency during the machining, but no work was found. FMC and FMS (see Zhou, 1999) presented for the production of a great variety of small lots, contrast with the proposal of this work, since its boarding is based on the use of machines with high level of automation. In opposition to the Total Automation, the idea of the Balanced Automation (see Camarinha and Afsarmanesh, 1995) traces a balance adjusted between the automation and the use of the human work, proposal more consonant with this work. With respect to the difficulties in the programming of CN machines, there are works referred to the strategies of the automatic generation of tool trajectory, to see for example Ruan and Liou (2005), and Tsuzuki (1999). Works related to position or tool path control in machine tools are directed to the proposition of auxiliary control systems, implemented in existing machines CN, improving its accuracy and obtaining a real time control of the tool path. The use of open architecture in NC machines has received attention in recent years. The architecture of developed control conserve the functionality of machine CNC, as much using the diagnosis and the supervision of the original machine, like its movement systems. One proposal concerning positioning is presented in Hanafi *et al*. (2005). In the work, authors developed a generic external controller to keep the machine under control in real time. A visual servo is executed: by connecting the external controller to the NC controller, reading the machine position and monitoring the position by an external visual sensor. Robert and Shin (1995) developed a controller based on a PC computer, with a lightly different treatment, they conserve the monitoring and security of NC machines, while it is used an external PC to generate the performance signals. To compensate changes in the machining, conserving the accuracy, Shawnky *et al*. (1998) presents the use of an "Offset" of position of the tool to adjust the commanded trajectory. Park, E.C. *et al*. (2003) developed a control strategy for improving the accuracy of the XY table of a NC machine when the velocity reversal occurs. Al-Kindi *et al*. (1993) proposed a solution to the problems associates with the implication of the human part during the manufacture stages, by means of the implementation of an inspection based on computerized vision.

3. BOARDING PROPOSALS

3.1. Proposal for improving the machining efficiency

Diverse alternatives can be cogitated for to make the machining process, specifically with regard to above-mentioned stages of approaching and finishing in a manual machining. Here the proposed servo-system conjugates the architecture of a NC machine and a manual machine (Fig. 1(a)).

In fact, the described machine in the Fig. 1(a) could be understood, in terms of hardware, as being basically a NC machine, that will operate by means of different commands: not through G codes but manually, through the manual pulse generator (MPG).

Operator inserts the reference position in the computer and turns the handle of the MPG in the desired direction. To each fixed angular interval that the handle turns, a pulse is sent to the servomotor that, through the spindle, produces a movement of fixed size (unitary movement) in the table. The table position is monitored continuously through a angular position sensor connected to the servo-motor axis and this position signal is sent to the computer. While the table is distant from the desired position, the computer allows the passage of the pulses, generated in the MPG, to the servomotor and converted into movement of the table. However, when the table position enters in a tolerance band around the desired position, the computer stops to transmit the pulses for the servomotor. Although the operator continues turning the handle of the MPG, the table remains stopped in the desired position. Thus, the positioning is concluded.

Everything occurs as if a barrier exists, inside of which the table cannot advance, although the operator tries. The region beyond the wall will be called "prohibited region".

When operating in a machine with this architecture and this functioning, the desired position is reached easily without the necessity of the operator attention. That is, it eliminates the stages approaching and finishing, thus increasing the positioning speed and, consequently, of the machining.

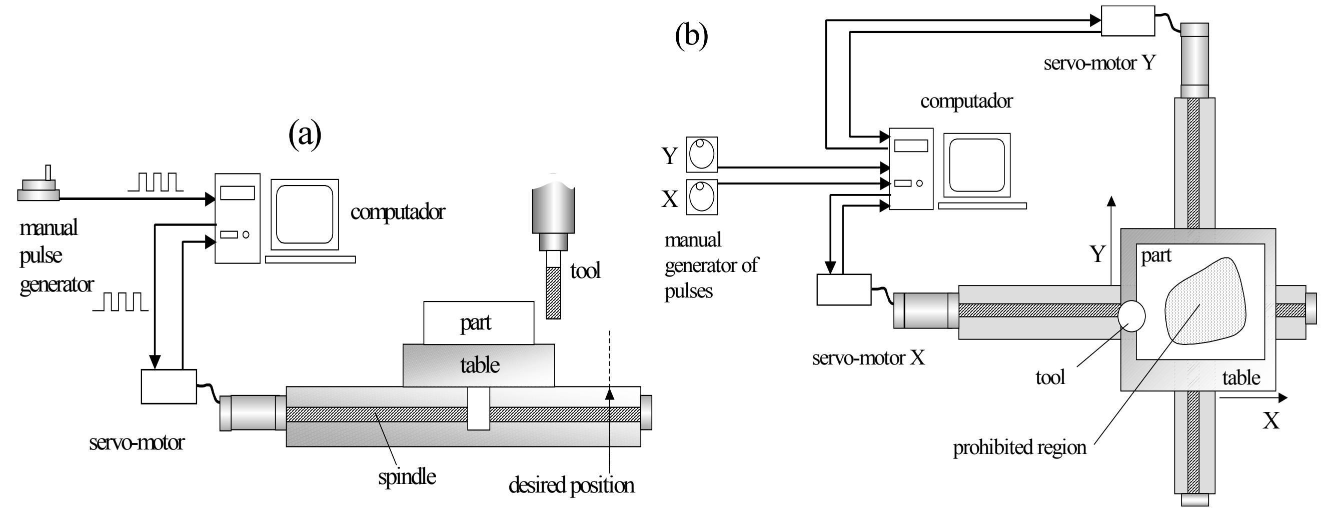

Figure 1. (a) Proposal of servo-controlled hybrid machine, operated manually, (b) Proposal machine for machining in a plane

3.2. The proposal, expanded for bidimensional machining

Arranging two systems in orthogonal directions, as shown in Fig. 1(b), a positioning system in the plan is achieved. In this architecture, the computer monitors the table position in the plan, exerting a control so as to avoid the table to enter in a bi-dimensional "prohibited region". This new prohibited region is nothing more that the contour of the part to be machined, that is introduced to the computer by the operator, prior to the machining.

In a machining with NC machines, files that contain the data concerning geometry and dimension (among others data) of the part, generated by CAD system, must pass through an important activity: the definition of the tool path, so as to obtain the part program in G language. Generally, this task is executed using a computational tool denominated CAM system (see Fig. 2(a)). In the proposed machine of this work, the stage corresponding to the definition of the tool path is eliminated and the CAD data is directly inserted in the control computer, shown in Fig. 2(b), thus defining the prohibited region. Outside the prohibited region, the operator is free to move the tool as he wishes. An experimented operator visualizes the part and defines the tool path to be followed and executes the machining manually.

Thus, the preparation task, such as the programming of a NC machine is eliminated. At the same time, a more agile and precise machining, compared with manual machining, becomes possible. The tool path will not be optimized as in a CAM system, nor the tool life will be optimized as in the NC machines. However these aspects are not so relevant because this work considers only very small lots, up to10 units.

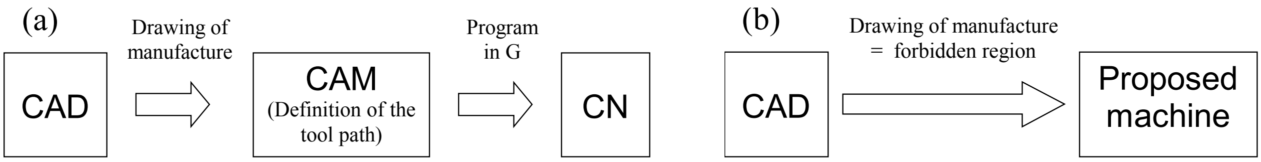

Figure 2. (a) Use of CN machine, (b) Use of the proposed machine

3.3. Movement and direction command instead of position

Until here, the subject was developed and the proposal of the new machine made, assuming that the operator commands the machine movement through handles, simulated for manual pulse generators (MPG). The MPG or the handle of manual machines works as entrances of position command. However, in this new machine, instead of position commands, the servo-system receives motion direction commands. Thus, in Fig. 1(b), instead a MPG, a device for movement and direction commands, for example one joy-stick, is used.

4. DEVELOPMENT OF A PROTOTYPE

A prototype is developed using two commercial NC modules, see Tab. 1 (NSK, Robot Modules, see NSK-1 and NSK-2, 1997), each module having mobility and control in one single direction. These modules, here called X-module and Y-module, are stacked orthogonal as shown in Fig. 3. The tool head is positioned similar, the tool holder and driver system, i.e., the machine head, is implemented by using a commercial bench driller. The frame, that supports all elements, is designed so that the tool head places at the middle of the stroke of both modules. Thus, the prototype is able for a two dimensional positioning (400mm×350mm area) of the tool relative to the work piece. A single controller, capable of executing linear and circular interpolation controls the X and the Y modules. The modules are controlled by a specific language in a very similar way of G codes in usual NC machines. Commands are generated or fed to a computer (PC) and sent to the module controller through serial interface (RS 232C). The computer receives motion and direction commands from the operator through a joystick. According to the direction the joystick lever is inclined, commands for linear motion are sent to the modules controller.

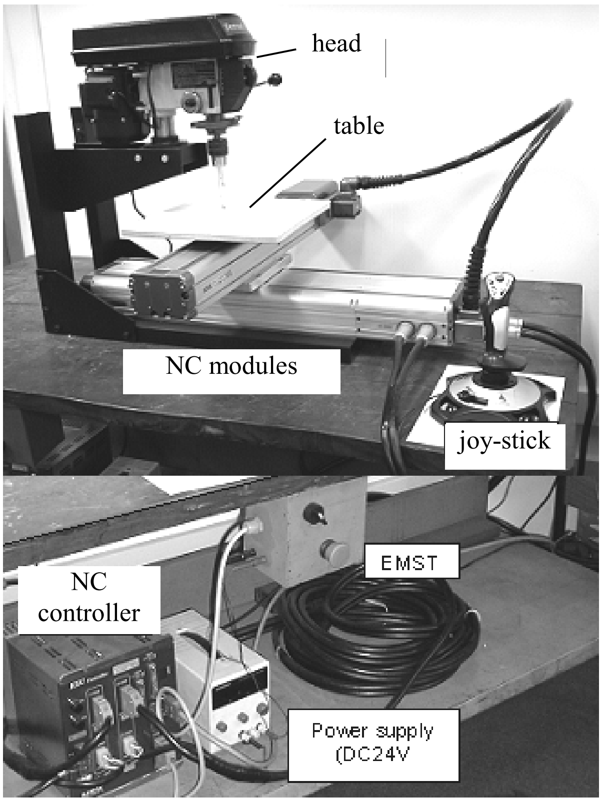

Figure 3. Prototype of the proposed machine

Table 1. Main features of the modules (NSK-1 and NSK-2, 1997)

Feature	X module	Y module
Stroke (mm)	400	350
Maximum speed (mm/s)	1200	1200
Maximum load (Kg)	60	40
Axial thrust (N)	300	300
Position repeatability (mm)	±0.010	±0.010
Motor power (W)	300	300
Ball screw pitch (mm)	20	20

5. DEVELOPMENT OF THE CONTROL ALGORITHM

5.1. Specifications, general description and operation

As explained previously, the idea proposed in this work is to use the concept of "prohibited region" to control the tool position with respect to the part. The prohibited region is defined from the part drawing archive generated by a CAD system. However, this file must be pre-processed so as to extract only information necessary to define the prohibited region.

For example, DXF type archive (file format adopted by Autocad®, Autodesk® Inc., USA) presents in a column the information of the entities that compose the drawing, but of all these, the ones that interest, are the entities of lines and arcs (or circles) that they conform the part profile, the other entities will not be had in account, in addiction, the occult lines, center lines, etc, will have to be carried through in another layer so that they can be hidden at the moment to generate archive DXF. As the main objective in this work is to propose and validate a position control strategy, the problem is simplified to only drawings of parts with polygonal geometries (lines). The developed pre-processing program reads DXF type archive, identifies each pair of points that determines each segment of the polygon. These pairs are arranged in a matrix and sorted according to trajectory of the part profile and related in accordance with the coordinates of the tool. The new matrix of points, so obtained, constitutes the matrix of prohibited points that limit the region where the tool cannot pass.

The machine operates in automatic and manual mode. In the manual mode, the operator moves the table through the joystick, so that the tool moves outside the prohibited region, doing the rough machining. The control algorithm constantly compares the actual position to the distance to the next segment of the part profile. Thus the algorithm limits the motion of the table. After the rough machining, the automatic mode is chosen. In this mode, the operator moves the tool so that it touches the part. Once the tool touches the part, the tool automatically contours the part profile, executing the finishing operation. The control algorithm is implemented in Matlab® (Mathworks Inc., USA) software.

5.2. Invasion check

One of the important problems treated in the tool position control, is the checking of the position of the tool with respect to the part profile, if the tool is inside or outside the profile, i.e., the invasion checking. This problem is treated by computational geometry as the proximity problem (see for example, Pantaleón, 2000).

A simple approach consists of generating a matrix "P_{rp}" using the points that form the part profile. The matrix size is as great, as greater the resolution required in the machining. For each position reached by the tool, the distance of this position to each point of the matrix is calculated. By verifying if these distances are larger than an established value of tolerance (Eq. (1)), the invasion of the tool is checked.

$$|d(\boldsymbol{P_f P}(j))| \le T \qquad (1)$$

Where (see Fig. 4(a)), $\boldsymbol{P}_f$: is the tool position, $\boldsymbol{P}(j)$, the generated point inside of the segment $\boldsymbol{P}(i)\boldsymbol{P}(i+1)$, T, the tolerance and E, the separation between generated points. Therefore, as greater the amount of points that determine each segment of the part profile, greater will be the number of comparisons to be done. This approach, although simple, is less efficient compared to other approach as mentioned forward, offering problems for a real time invasion checking.

A second method for the invasion checking can be derived from the angles sum criterion. In this, given a region delimited for three points ($\boldsymbol{P}_1$, $\boldsymbol{P}_2$, and $\boldsymbol{P}_3$), it is possible to verify if a fourth point ($\boldsymbol{P}_4$) is external of this region through the sum of the angles formed between these four points ($\boldsymbol{P}_4$ with each point $\boldsymbol{P}_1$, $\boldsymbol{P}_2$ and $\boldsymbol{P}_3$). If $\beta + \Phi + \delta < 360°$, $\boldsymbol{P}_4$ is external to the region (Fig. 4b).

Using any of the above mentioned approaches, the position of the point that belongs to the matrix and is the nearest

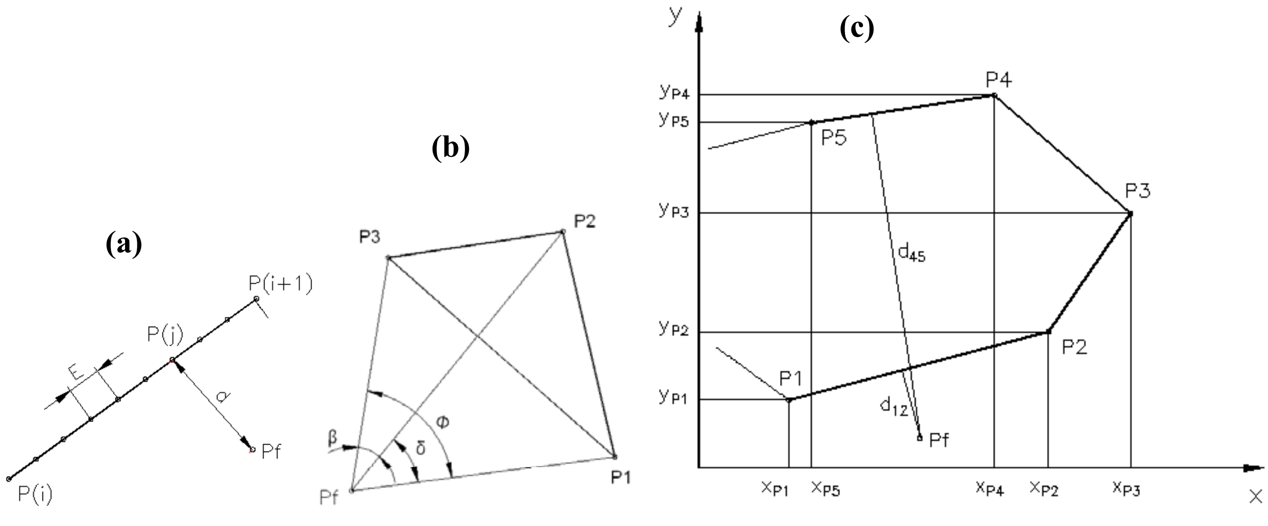

Figure 4. (a) Simple approach, (b) Angles sum criterion, (c) Polygon with classified points and defined intervals

to the tool position ($\boldsymbol{P}_f$ or $\boldsymbol{P}_4$, according to criterion) is still not determined. The proximity problem approach recommends, firstly, sorting the points, then, defining intervals of grouping points and finally, establishing the initial criteria of comparison between points and intervals. Thus the set of points (or segments) is diminished to subgroups where the operation number of comparison obviously will be lesser, becoming the invasion checking more efficient.

Applying this procedure in the polygon of Fig. 4(c), the points were classified maintaining a direction for the route of the profile, ($\boldsymbol{P}_1$, $\boldsymbol{P}_2$,… $\boldsymbol{P}_5$,…). Thus, the intervals for each segment of the polygon (X_{p1}-X_{p2},…, X_{p4}-X_{p5},…, Y_{p1}-Y_{p2},…, Y_{p4}-Y_{p5},…) within which the tool is ($\boldsymbol{P}_f$), thus determining the possible segments near to $\boldsymbol{P}_f$ (segments $\boldsymbol{P}_1\boldsymbol{P}_2$ and $\boldsymbol{P}_4\boldsymbol{P}_5$)

discarding the others, diminishing the unnecessary operation number in invasion check. In the case of this work, it is sufficient with verifying the invasion through segments $\boldsymbol{P}_1\boldsymbol{P}_2$ and $\boldsymbol{P}_4\boldsymbol{P}_5$, by using an third segment defined by a consecutive point ($\boldsymbol{P}_3$) and applying the criterion of the sum of angles.

A third efficient invasion checking is achieved by a method similar to that presented previously. Here, the invasion is verified through the distance from the tool position ($\boldsymbol{P}_f$) to each segment (Fig. 4(c)). As in the previous method, the distance is verified only in the interval of x coordinates where $\boldsymbol{P}_f$ belongs. Using vector geometry, the distance to each segment is determined as follows.

$$d_{12(or\ 45)} = |(\boldsymbol{Pf}\text{-}\boldsymbol{P}_{1(or\ 4)}\ x\ (\boldsymbol{P}_{2(or\ 5)}\text{-}\boldsymbol{P}_{1(or\ 4)}| \,/\, |\boldsymbol{P}_{2(or\ 5)} - \boldsymbol{P}_{1(or\ 4)}| \leq T \qquad (2)$$

This approach adopts the same procedure of that used in the point classification criteria and in the elimination of intervals, but the parameters and the operations are diminished.

This last approach shows to be the most efficient since it eliminates parameters ($\boldsymbol{P}_3$) and calculations (determine distance, instead three angles). Therefore, this is used in the algorithm of invasion checking. The reduction in the operations number in comparison with the simple approach of classification and grouping is described in Pantaleón (2000).

5.3. Definition of the tool path considering the tool diameter

Up to here, the tool diameter was not considered and the tool was considered like a point. But the real problem must consider the tool diameter in the obtaining of the prohibited matrix and the tool path. This is done in the following way.

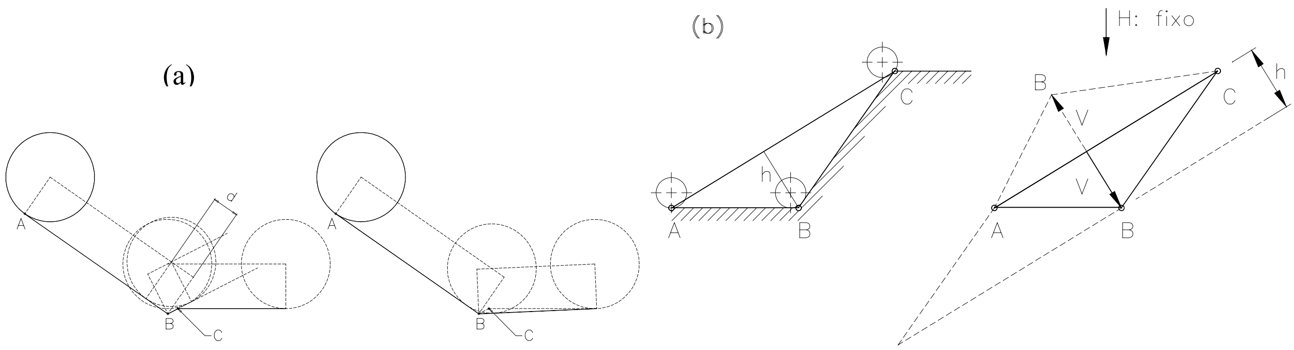

Figure 5. (a) Trajectory with very next point, (b) Perpendicular vector to the segment

Step 1: To filter the "very close" points according to the tool diameter
From the figures 5(a) and 6, is obtained.

$$d = R\ .\ tang\ (\phi/2) \qquad (3)$$

with

$$\phi = arcos\ [(\boldsymbol{V}_{AB}\ .\ \boldsymbol{V}_{BC})/(\,/\boldsymbol{V}_{AB}/.\ /\boldsymbol{V}_{BC}/)] \qquad (4)$$

If $d > |\boldsymbol{V}_{AB}|$, then $\boldsymbol{B}$ is removed, and if $d > |\boldsymbol{V}_{BC}|$, then $\boldsymbol{C}$ is removed.

Step 2: Once the matrix "$\boldsymbol{P}_{rp}$" is filtered, the position of intermediate points is verified, if it is above or below the segment formed by the points between which it is, thus determining the side where it will be the new point of prohibition (and the trajectory) generated by this intermediate point. From Fig. 5(b) it is obtained:

$$\begin{aligned} \boldsymbol{V} &= [\boldsymbol{V}_{AC}\ x\ (\boldsymbol{V}_{AB}\ x\ \boldsymbol{V}_{AC})/ /\ \boldsymbol{V}_{AC}\ x\ (\ \boldsymbol{V}_{AB}\ x\ \boldsymbol{V}_{AC}\ )\ /]\ .\ h \\ &= [(\boldsymbol{C} - \boldsymbol{A})\ x\ [(\boldsymbol{B} - \boldsymbol{A})\ x\ (\boldsymbol{C} - \boldsymbol{A})]/ /(\boldsymbol{C} - \boldsymbol{A})\ x\ [(\boldsymbol{B} - \boldsymbol{A})\ x\ (\boldsymbol{C} - \boldsymbol{A})]\ /]\ .\ h \end{aligned} \qquad (5)$$

If $\boldsymbol{V} \cdot \boldsymbol{H} < 0$, this means that $\boldsymbol{B}$ is below the segment AC and if $\boldsymbol{V} \cdot \boldsymbol{H} > 0$, this means that $\boldsymbol{B}$ is above the segment AC.

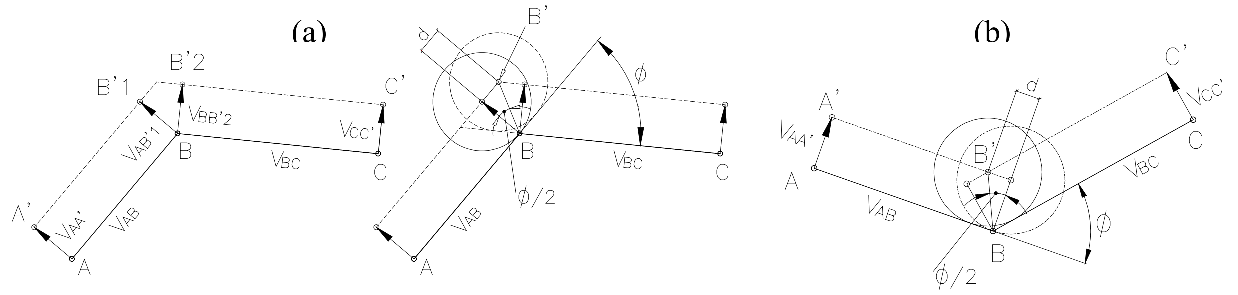

Figure 6. Analysis for (a) ***B*** above of segment *AC*, (b) ***B*** below of segment *AC*

- **If *B* is above *AC*:** in Fig. 6(a) with $\boldsymbol{P}_{pl}$ and $\boldsymbol{P}_{pd}$ the unitary vectors parallel and perpendicular to $\boldsymbol{V}_{AB}$ respectively. Being R, the tool radius.

$$\boldsymbol{V}_{AB} = (\boldsymbol{B}-\boldsymbol{A}) = (x,y) \tag{6}$$

$$\boldsymbol{P}_{pl} = (\boldsymbol{B}-\boldsymbol{A})/|(\boldsymbol{B}-\boldsymbol{A})| = (x,y)/|(\boldsymbol{B}-\boldsymbol{A})| \tag{7}$$

$$\boldsymbol{P}_{pd} = (-y,x)/|(\boldsymbol{B}-\boldsymbol{A})| \tag{8}$$

$$\boldsymbol{V}_{AA'} = (\boldsymbol{A}'-\boldsymbol{A}) = \boldsymbol{P}_{pd} . R = [(-y,x)/|(\boldsymbol{B}-\boldsymbol{A})|].R \tag{9}$$

Then,

$$\boldsymbol{A}' = \boldsymbol{V}_{AA'} + \boldsymbol{A}\ [(-y\ ,\ x)/|(\boldsymbol{B}-\boldsymbol{A})|]\ .\ R + \boldsymbol{A} \tag{10}$$

In the same way, ***C*** would be calculated but is not necessary since the trajectory will be determined from the intermediate points. From point ***B´*** generated and shifted by "*d*", the tool will leave in parallel line to vector $\boldsymbol{V}_{BC}$, where:

$$\boldsymbol{B}' = \boldsymbol{V}_{AA'} + \boldsymbol{B} + d(\boldsymbol{V}_{AB}/|\boldsymbol{V}_{AB}|) \tag{11}$$

- If *B* is below *AC*: In Fig. 6(b), points ***A'*** and ***B'*** are determined by similar analysis.

$$\boldsymbol{A}' = \boldsymbol{V}_{AA'} + \boldsymbol{A} = [(-y\ ,\ x)/|(\boldsymbol{B}-\boldsymbol{A})|]\ .\ R + \boldsymbol{A} \tag{12}$$

$$\boldsymbol{B}' = \boldsymbol{V}_{AA'} + \boldsymbol{B} - d(\boldsymbol{V}_{AB}/|\boldsymbol{V}_{AB}|) \tag{13}$$

Figure 7 shows the flow chart of the algorithm used to control the prototype. This includes the invasion checking.

6. TESTS AND RESULTS

System showed a delay as consequence of limitation in the communication speed between the PC and the NC controller, the time consumed by the computer to making calculation and the mechanical inertia of the devices. A series of tests was done varying the feed speed and the theoretical value of tolerance "*T*" (see 5.2). By this procedure, the percentage of successes (number of cases in which, the prohibited region is not trespassed) and the average of the error (under-cutting, the achieved position is outside the profile and distant for a some amount from the profile) are determined during the rough machining (see Tab. 2 and Tab. 3). So as to simplify the measurement of the obtained path, instead a cutting tool, a pencil was installed in the machine head to plot the trajectory in a paper sheet fixed on the table. In Fig. 8 the irregular paths are the trajectories of rough machining, the path "a" is the trajectory of finishing machining, and the path "b" corresponds to the part profile obtained by finishing procedure.

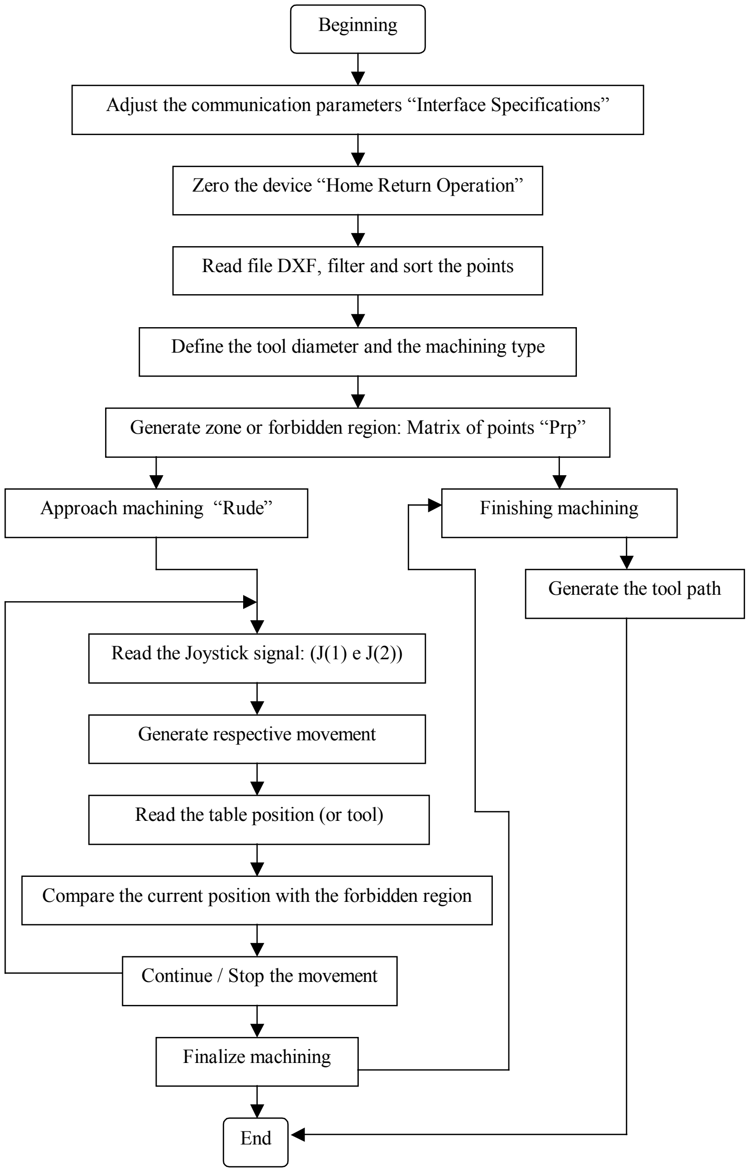

Figure 7. Flow-chart of the control algorithm

Table 2. Results of the machining simulation: (a) external in triangular profile, (b) internal in quadrilateral profile

simulation type	**feed speed "V" (mm/s)**	**Tolerance "T" (mm)**	**No. attempts**	**No. successes**	**Average (mm) under-cutting**	**% successes**
(a)	12	1.0	17	0	-	0.00
(a)	12	2.0	17	3	0.15	17.65
(a)	12	3.0	17	11	0.54	64.70
(a)	12	4.0	18	16	1.25	88.90
(a)	12	5.0	20	20	2.50	100.00
(a)	18	1.0	15	1	0.50	6.70
(a)	18	2.0	19	4	0.25	21.05
(a)	18	3.0	18	14	0.68	77.80
(a)	18	4.0	19	17	1.15	89.50
(a)	18	5.0	20	19	2.63	95.00
(b)	12	4.0	23	22	1.40	95.65
(b)	18	4.0	25	25	1.10	100.00
(b)	12	4.5	28	27	2.00	96.40
(b)	18	4.5	28	28	1.95	100.00
(b)	12	5.0	28	28	2.46	100.00
(b)	18	5.0	28	28	2,48	100.00

Table 3. Results of the simulation of the internal and external machining in irregular profile of 7 sides

Figure of the test	feed speed "V" (mm/s)	Tolerance "T" (mm)	No. attempts	No. successes	Average (mm) under-cutting	% successes
8a	12	4.5	46	44	0.90	95.65
8b	12	4.5	46	43	1.20	93.50

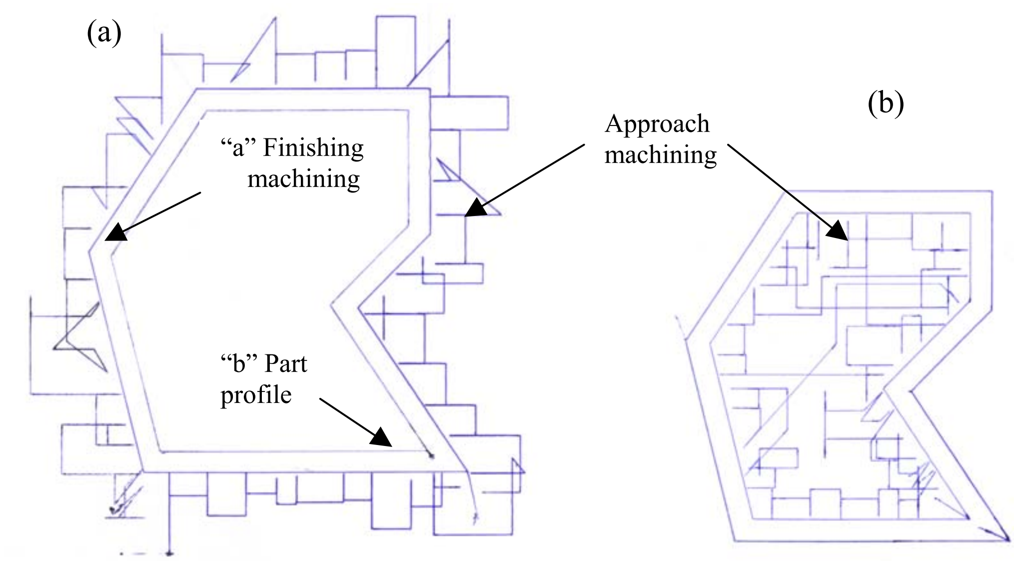

Figure 8. (a) External and (b) internal machining

Results show that, maintaining the feed speed and increasing the value of tolerance, it is possible to achieve a machining with no invasion, obtaining the 100% of successes using values of tolerance (*T*) larger than 4mm. It is observed that the under cutting increases as the value of tolerance is increased. The opposite occurs, i.e., the under cutting diminishes if the tolerance is maintained and the feed speed increased. In the machining tests, an average under cutting of 0.5mm is verified.

7. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORKS

In general terms, the most important objectives intended with the project had been achieved by developing a prototype that served to validate the operation of an architecture designed in agreement with the proposed machining strategy: machining by prohibited regions.

The designed architecture demonstrates the viability of machining parts by limiting the motion of the tool by prohibited regions. It also demonstrates the possibility for starting off a machining directly from a drawing in CAD system, with no need to make a programming using NC machine programming language. The prototype is equipped with two operation modes: the manual operation mode, for rough machining, and the automatic contouring mode, for finishing machining.

In the machining tests, an average under cutting (positioning error) of approximately 0.5mm in obtained. However, such level of accuracy is obtained only by imposing limits to operation condition of the machine, such as the feed speed and the tolerance to control the positioning. One possible way for improving the machining accuracy is to use a double path in the finishing machining. That is, entering an additional drawing with a light over-dimension and making the tool contour the work piece twice. Thus, the final dimension is achieved after the second finishing machining process.

Low machining accuracy, observed in the tests, can be attributed to the time spent since the moment in which a command is sent by the control algorithm to the NC controller, asking for the position, until the moment in which, the stop command is sent after the comparison operations.

This work proposed a new control strategy for machine tools, opening possibilities for development of a machine having characteristics between a manual machine and a NC machine. A prototype of a machine that realizes such control strategy is developed. Despite the machining accuracy achieved in the prototype, of approximately 0.5mm, machining tests demonstrate that the machining strategy by prohibited regions is effective and that the proposed architecture is effective to realize the proposed machining strategy.

Recommendations for future works are focused mainly in the improvement of the precision of the positioning through more efficient control algorithm and improvements in the communication between the algorithm and the NC controller.

8. ACKNOWLEDGEMENTS

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11. RESPONSIBILITY NOTICE