Holonic machine controller for Adaptive Non-linear Control in 5-axis Machining

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Abstract :

This paper describes an ongoing research and development of a theoretical foundations and new type NC controller that is capable to generate the toolpath autonomously and the full functionality of the machine control unit (MCU) of a five axis milling machine for a chosen tool geometry and open in comparison to present NC technology. The input to the controller is a feature-based part descriptions. The new NC controller is intended to autonomously generate machining NC sequences that are stepwise downloaded and executed by the original NC controller, using the **LSV/2** communication protocol. The protocol is conceived as a device-driver. And, the new controller is more flexible: a measuring probe provides the controller with up-to-date data during the machining process. Based on those data the controller is able to take into account up-to-date process data. The feature-based NC controller is capable to select autonomously tools and cutting conditions. This would improve the surface finish and the machine efficiency.

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1. Objective of the research

The overall objective is to develop the required theoretical foundations and control algorithms for this adaptive non-linear 5-axis interpolation. It is proposed to work in two phase:

Phase I:

Theoretical development of the models and graphical simulation

- develop the theoretical foundations and control algorithms for this adaptive nonlinear five-axis interpolation.
- determine the real tool path.
- analysis of the cutter inclination.
- parameters influencing the surface roughness.

Phase II:

Implementation of the algorithms on a 5-axis machine

- develop the communication system under the LSV/2 protocal
- remote control base on the adaptive control under the algorithm foundations

2. Introduction

Todays 5-axis milling machines can only linearly interpolate in 5 axis simultaneously. The 5 axis CL - files generated by todays CAD/CAM systems provide only an approximate piecewise linear (or piecewise circular) toolpath. The 5 axis postprocessor must linearise the toolpath in between two succesive CL - points to approximate the toolpath.
When a reorientation of the tool axis is requested, it is necessary to translate the centers of rotation while simultaneously rotating one or both of the rotary axes. If these translational and rotational slide moves are contained in one instruction on the CNC control equal proportions of the linear and rotary moves occur in equal time increments and result in the physical end of the tool moving in some curved path relative to the workpiece. The problem of non-linearity occurs when there is simultaneous change in all the 5-axis . The problem is illustrated in fig. 1, the tool moves from position P_1 to position P_2 without changing its orientation at P'_2, and from P'_2 rotate about the cutter center to position P_2. This case, there is no over cutting of the workpiece. The translation and rotation of the tool was performed in two separate motions. However, if both the translation and the rotation of the tool were to be performed simultaneously, the resulting path will overcut the workpiece. It is the responsibility of the postprocessor to correct for this deviation from the linear path as outputted into the CLDATA. In practice, current postprocessors simply ensure that the tool end remains within a specifiable tolerance band of the desired path.It does not follow that non-linear paths traced by the tool end always require linearisation. When the curvature of the tool end path approximates to that of the required machining surface, it should be possible for the postprocessor to incorporate a number of linear cuts into a single output block. This would improve the surface finish and the machine efficiency.

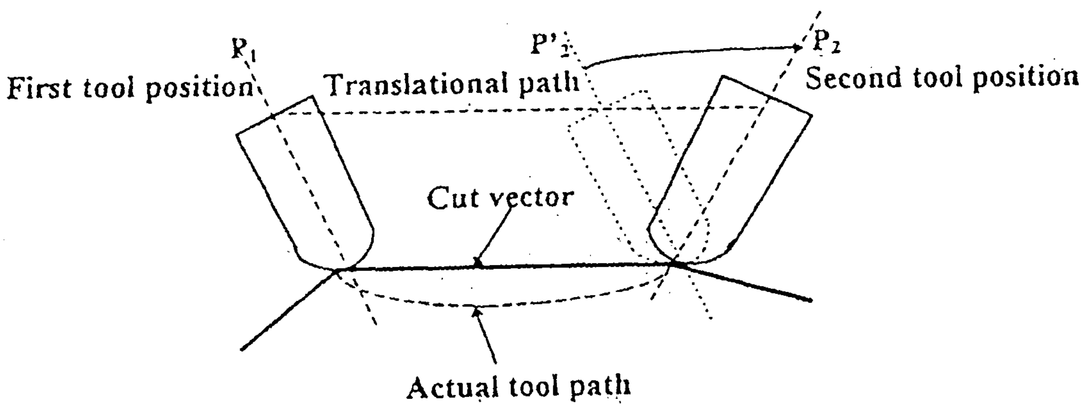


Fig. 1: Non-linearity in 5-axis machining

3. Conceptual design approach

Many literature, They were concentrated the new algorithm solve the problem of non-linear control in 5-axis machine and we can seperated in 3 processs:

First process, we are machining the a raw blank workpiece base on the CAD/CAM system in CL file and NC program under environment of the PC adative controller or **Holonic machine controller** with **LSV/2 protocal** until the final shape.

Second process, after machining process can measuring the workpiece by the touch-probe system on the MAHO 600E five-axis machine

Third process, after measuring by the probe system of the machine can know the error of cutting condition then get information of the workpiece after machining by the PC computer or remote center system compare to the machine surface of CAD/CAM. So that, we can calculated non-linear algorithm and give the CL file, NC program to machine again.This would improve the surface finish and the machine efficiency.

This research and development can make a new type NC controller that is capale to generate the toolpath autonomously for a chosen tool geometry. Input to the controller is a feature-based workpiece descriptions. The new NC controler is more flexible: a measuring probe provides the controller with up-to-date data during the machining process. Based on those data the controller is able to take into account up-to-date process data. The feature-based NC controller is capable to select autonomously tools and cutting conditions.

Holonic manufacturing systems is a paradiagm developed in the framework of the intelligent manufacturing system (IMS) program. In compliance with IMS goals, the HMS project for adaptive control aims at a better understanding of the requirements for future generation manufacturing systems and at ways to build systems satisfying there requirements. Below, the concept of "*holonic systems*" is decribed by Valckenaers et.al. (1994) to clarify some terminology used in this manuscript.

Historical backgroung

Some 25 year ago, Authur Koestler (1967) proposed the word "*holon*". It is a combination from the Greek word holos (whole) and the suffix *on* which, as in proton or neutron, suggests a particle or part.

Two observation impelled Koestler to propose the word holon. The first comes from Simon (1990), a Nobel prize winner, and is based on his 'parable of the two watchmakers'. From this parable, Simon concludes that complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not ; the resulting complex systems in the former case will be hierarchical.

The second observation, made by Koestler while analysing hierarchies and stable intermediate forms in living organisms and social organisation, is that --although it is easy to identify sub-wholes or parts--'*wholes*' and '*parts*' in an absolute sense do not exist anywhere. This made Koestler propose the word holon to describe the hybrid nature of sub-wholes/parts in real-life systems; holons simultaneously are self-contained wholes to their subordinated parts, and dependent parts when seen from the inverse direction.

Koestle also establishes the link between holons and the watchmakers' parable from professor Simon. He points out that the sub-wholes/holons are autonomouse self-reliant units, which have a degree of independence and handle contingencies without asking higher authorities for instructions. Simultaneously, holons are subject to control from (multiple) higher authorities. The first property ensures that holons are stable forms, which survive disturbances. The latter property signifies that they are intermediate forms, which provide the proper functionality for the bigger whole.

Finally, Koestler defines a holarchy as a hierarchy of self-regulating holons which function (a) as autonomous wholes in supra-ordination to their parts, (b) as dependent parts in sub-ordination to controls on higher levels, (c) in co-ordination with their local environment.

Holonic concept

Figure 2 shows the distinct steps that are executed to machine a workpiece. Notice that the touch and trigger probe actions are included and control the program's behaviour.

The distinct steps, to be executed are:

- recognise the workpiece blank and location,
- declare the workpiece origin,
- execute an operation,
- measure the quality or accuracy through sensors, and
- decide on the subsequent execution steps to be taken, based on the acquired sensor information.

The NC controller processes all the enumerated tasks one by one. Each subtask can inturn be decomposed in other subtasks until primitive functions are reached. The controller delegates the subtasks to respective autonomous submodules, mediates if conflicts occur, and sequences the subtasks in the right order. Such a co-operative hierarchy of distributed autonomouse sub-functions is called a ***holonic system.***

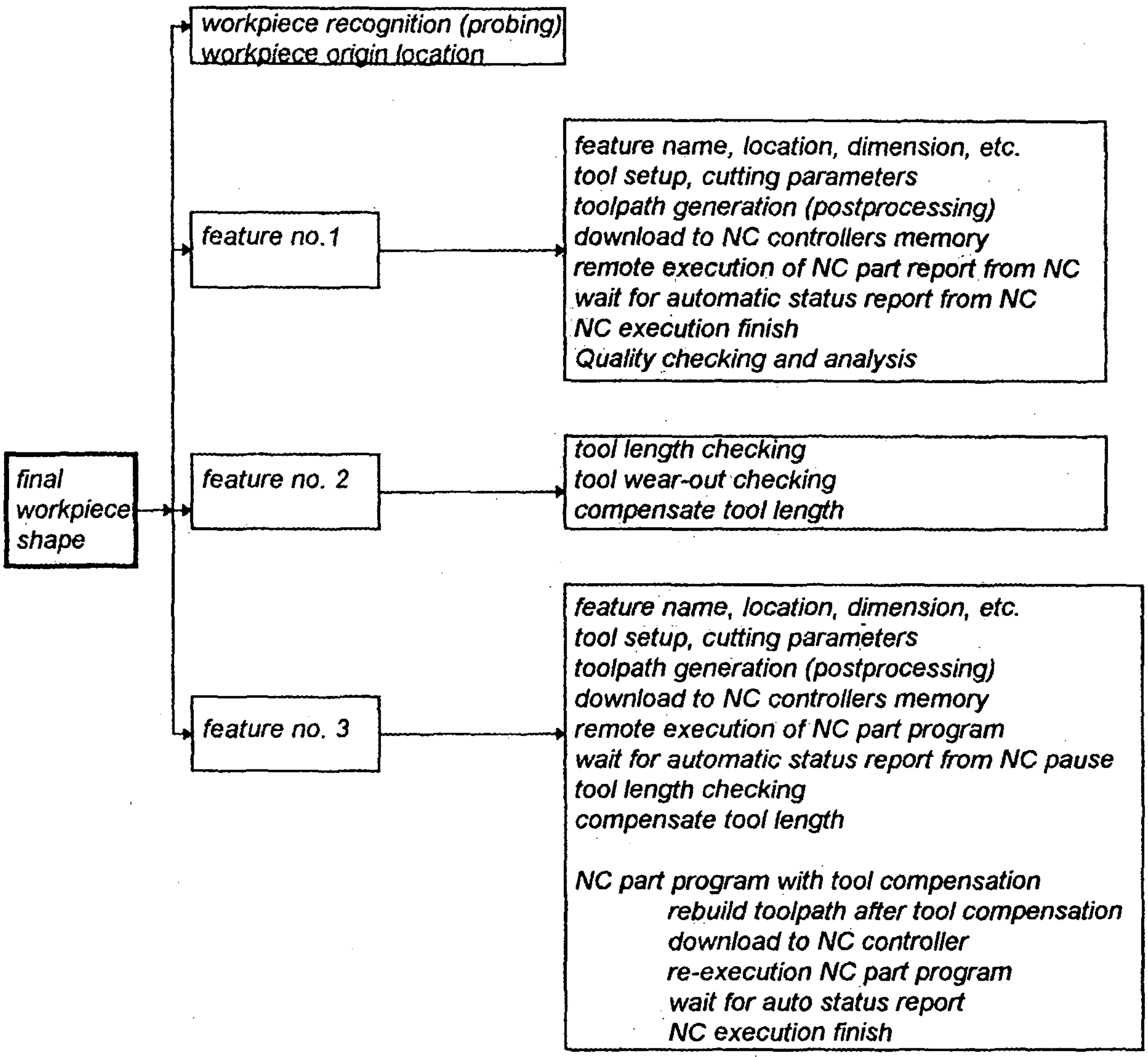


Fig. 2: Holonic concept of machining planning

4. Procedure of the research

This section describes the various design aspects and physical implementation of a phototype theoretical foundations and control algorithms for adaptive non-linear control in 5-axis machining and a touch trigger measuring probe, that will serve as a sensor.

4.1 Test-bed configuration

The test-bed is a MAHO 600E machine tool with Philips CNC432 controller. The machine tool is a knee type milling machine with horizontal spindle, 24 tool magazine capacity, and simultaneously

controlled movement on its axes; 3 translation; X, Y, Z, and 2 rotary; A, B (see figure 8) that capable to machine complex surfaces.
To implement the holonic controller without drastic changes to the original NC controller, a PC has been connected to the original NC controller and a communication protocol software has been developed.

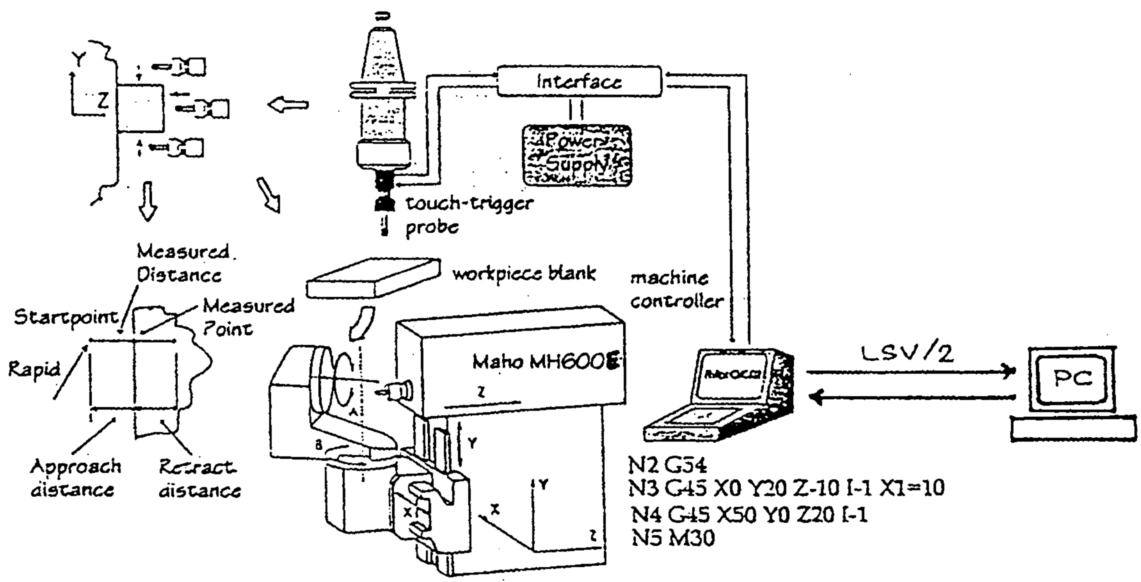


Fig. 3: Touch-trigger probe integration

4.2 Communication protocol overview

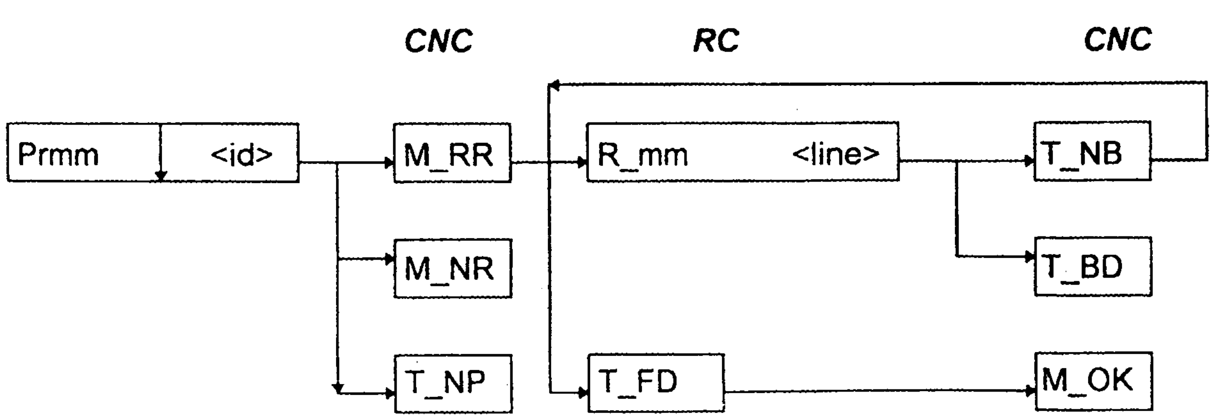


Fig. 4: Reading NC program from NC static RAM memory

RC = remote control (PC) *RR = ready to receive*

PR	= *program file receive*	*NR*	= *bad number*
mm	= *memory model of user program,*	*NP*	= *not possible*
<id>	= *user program<id> number*	*NB*	= *next block*
*M_*	= *misc. command*	*BD*	= *break down*
*T_*	= *transfer control*	*FD*	= *end of transfer*
*R_*	= *receive data*	*OK*	= *function OK*

The original machine tool controller supports a communication protocol, call ***LSV/2***. This communication protocol has functions to perform **file management, monitoring,** and **control.** The ***LSV/2*** functions are available in 2 mode, namely, a **local** and **remote** mode. The 'remote' mode gives more function access flexibility compare to the 'local' one.

A protocol function is composed of various sequences of meta-control. A meta-control code consists of 4 (four) ASCII characters. Each meta-control code performs among other the progress of transaction, error messages, etc. Figure 5 shows an example of a meta-control transaction to perform reading operation of the part program, with identification<id>, located in the NC static RAM memory which initiated from a remote platform (a PC).

Before meta-controls are exchanged, serial communication is performd, e.g. through acknowledgement (ACK) or not-acknowledgement (NAK).

4.3 Diagnostic by sensor based task control

One important characteristic in a control algorithms for adaptive non-linear control in 5-axis machining is the notion of *self-diagnostics* and *self-repair*. This behaviour will also be introduced in the holonic NC controller though sensor based task control actions. Two modes of diagnostics can be implemented : (1) off-line sensing tasks that are performed between two machining tasks, and (2) in-process sensing and on-line control correctionss. The first type of diagnostics will be implemented though a touch-trigger probe. The second type through temperature sensors, accelerometers, and dynamometers.

For a first prototype implemention, we have chosen to focus on the first diagnostic tasks. we have developed an interface between a standard gauging probe and the philips CNC controller (see figure 3). We also developed a device-driver which allows to communicate gauging tasks and measuring results between the machine controller and a PC. This device-driver was first implemented in DOS but has now been ported to the windows 16-bit environment.

This gauging device-driver is used as a self-diagnostic tool to improve the autonomy of the NC controller. For instance, The feature dimensions could be checked after roughing to get an estimate of the tool-length after a certain amount of wear. This compensated tool length can then be used to perform a more accurate finishing process.

Machining operations are performed based on the feature information. A machining operation may contain several tasks taht will be executed. And, a task consists of a list of device-driver commands that may contain several **LSV/2** protocol functions. A device-driver task is described as an event on the application module. Each event correspond to a C++ object-oriented method. The application has been programmed as an event-d driven or message-based execution to be able to use the advantages of using windows platform.

A research prototype of the system planner that will be developed in the frame of this study will incorporate following tasks (see figure 5)

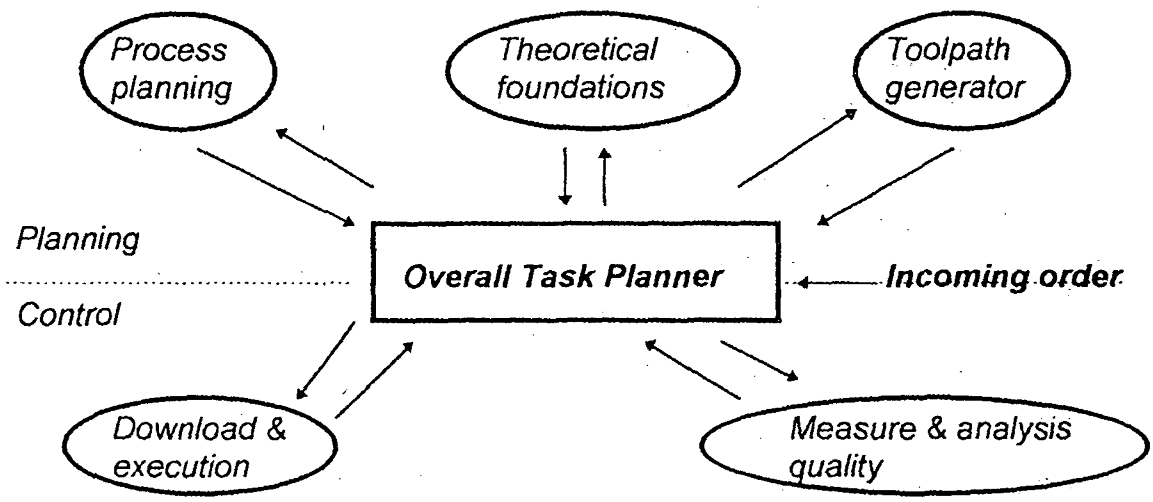


Fig. 5: Task planner of the prototype NC controller

- determine the required operation steps for one manufacturing feature,
- select appropriate and available tools for each manufacturing step,
- calculate cutting parameters,
- find an optimum sequence of manufacturing steps with respect to manufacturing cost and global scheduling criteria (expressed by priorities), and select the theoretical foundation and control algorithm
- a toolpath generator (block by block) and formatter,
- an overall task planner in a multitasking environment (only tasks executed by one controller),
- download and execute routines, and
- obtain sensor information

The described developments will be started when the functions of the ***LSV/2*** protocol and ***tuoch-probe measuring*** have been implemented and tested.

5. Current state of development

Before issuing the sophisticated development decribed in paragraph 3, the presented research has started the downstream communication protocol on a PC under DOS environment. This module consists of routines to communicate through asynchronouse serial line RS232C and a routine to implement ***LSV/2*** protocol to exchang data. Figure 6 displays the PC and MAHO 600E mchine configuration. The message exchange is sequential. The PC or NC controller can take an initiation to begin data exchange. Each sent protocol command shoud be answered prior to exchanging the message. This flow is shown in figure 7. A concise protocol handshaking diagram.

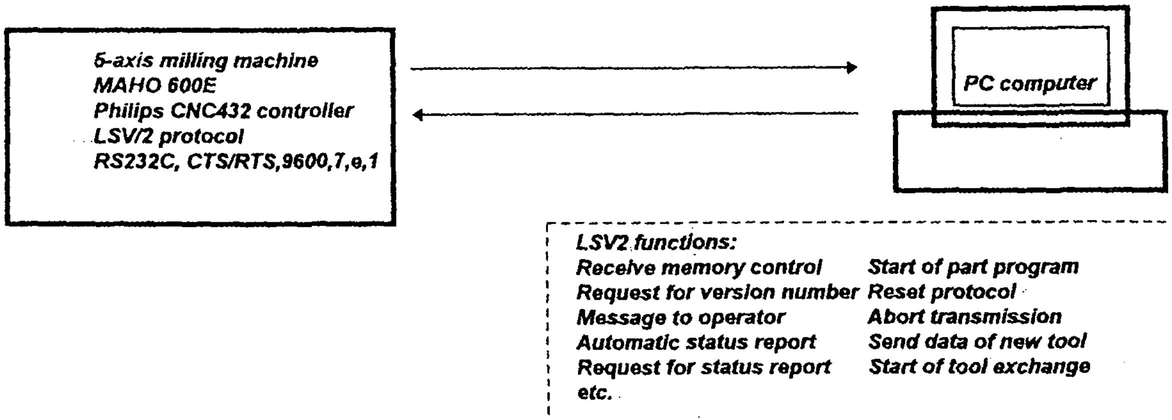
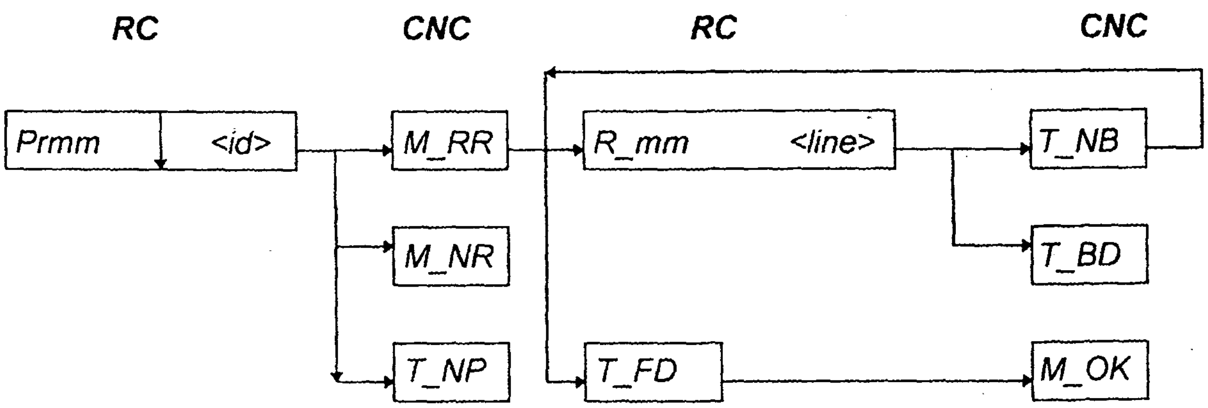


Fig. 6: Asynchronouse link PC-MAHO machine



RC	ENQ
CNC	DLE 0
RC	DLE STX PR PM 9012 DLE ETX BCC
CNC	DLE 1
RC	EOT
CNC	ENQ
RC	DLE 0
CNC	DLE STX M_RR DLE ETX BCC
RC	DLE 1
CNC	EOT
RC	ENQ
CNC	DLE 0
RC	DLE STX R_PM 9012 LF N1 DLE ETX BCC
CNC	DLE 1
RC	EOT
CNC	ENQ
RC	DLE 0
CNC	DLE STX T_NB DLE ETX BCC
....	
CNC	DLE STX M_ OK DLE ETX BCC
RC	DLE 1
CNC	EOT

Fig. 7: Protocol handshaking transmitter diagram

Decription of software developments

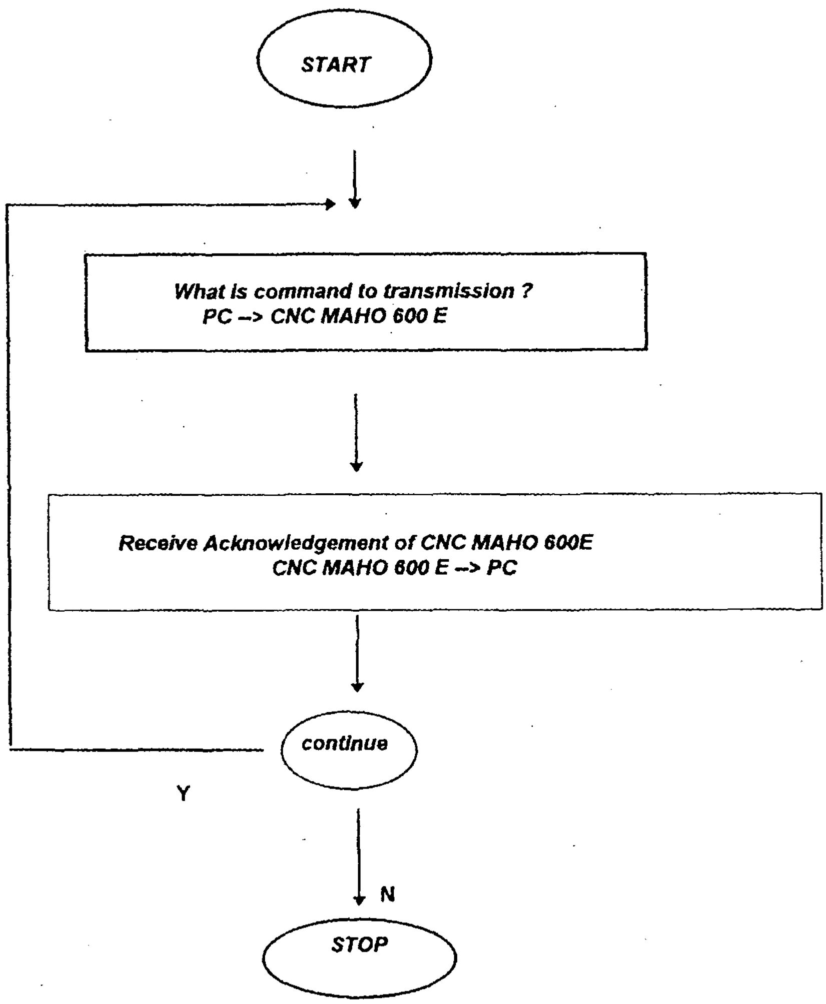


Fig. 8: Flowchart structure of software development in C program

Description of measuring on the maho 600E machine
we are installated the touch-probe (TS120) on the spindle head of the machine then make the NC program at list belows:

N17002	*;Program number*
N10 G17 T1 M6	*;The scanner is clamped*
N20 D207 M19	*;Positioning definition of scanner for horizontal*
N30 G46 I1 J1 M26	*;The measuring cycle is carried out and the computed scanner radius is stored under T1*
N40 Z200 M30	*;Withdrawal of tool and end of program*

The programe is the calibration of the scanner

5. Conclusion and future work

The implementation of LSV/2 protocol is used to transmit any information from a PC to the original NC MAHO 600E machine and vice-versa. The PC controller software modules are developed bottom-up. Those modules are:

- downstream communication,
- workpiece recognition,
- quality inspection,
- optimization and theoretical foundations selected,
- toolpath generator and formatter,
- machining operation strategy, and
- feature-based input.

Due to this, the NC controller may communicate and negotiate with external world in a more easy way. The task execution is event-driven or message-based. The application waits for event notification, then accesses appropriate C++ method to perform the task.
The sensing touch trigger probe is currently begin developed and will execute task to recognise the workpiece dimensions and location, to inspect the accuracy of machinning and to perform quality analysis. Parallel to this work, a software is developed to analyse the touch and trigger probe coordinatedata collection.

In the next phase, the planning overall tasks and theoretical foundations, controller algorithms.
First task, we will be develop the treoretical foundation and algorithm of the 5-axis milling machine follow on my research proposal phase I of required research environment and we can assigned in two steps, as follows

Reference

1. **Erzi Agson Gani, Dr. Lauwers B. and Dehaes J.** (1994), "An investigation of the surface charateristics in 5 axis milling with thoroid cutters", Pacific conference on Manufacturing, Conference Proceddings, Dec., Jakata, p.53-60.

2. **Lo C.C. and Lin J.F.**(1994), "Error compensation for repetitive machining", Pacific conference on Manufacturing, Conference Proceddings, Dec., Jakata, p.121-128.

3. **Nguyen van Chung** (1995), "Influence of the tool path on workpiece accuracy in five axis machine", Master thesis, Industrial system engineering divicsion, SAT, Asian Institute of Technology.

4. **Kruth, J.P., J. Detand and P. Indra Tanaya** (1994), "A Prototype NC Controller Driven by Feature-Based Part Description", Pacific conference on Manufacturing, Conference Proceddings, Dec., Jakata, p. 535-544.

5. **Kruth, J.P., J. Detand and P. Indra Tanaya** (1995), "Holonic machine controller", Co-operation in manufacturing: CIM at work, Eindhoven, Aug., Nethelands.

4. **Vissenberg, C.J.M.** (1990), Specification data communication, Phillips machine tools control CNC M700 900315

5. **Baughman, J.A.** (1970), "Multi-axis machining with APT", Numerical control users handbook, In:W.H.P. Leslie(ed.), McGraw-Hill, London, p.217-298.