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Simulation of Parallel Robots

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Abstract Article describe new method of simulation of parallel robots. Since currently there are only few efficient and universal tools for modeling, interpretation and kinematic simulation such one has been was developed and implemented. A new procedure allows the formalize able calculation of the direct transformation as well as the Inverse transformation and is based on mathematical modeling which has proved itself have delivered optimal performance in the area of the industrial robots.

Keywords: *parallel robots, simulation, kinematic of hexa robot, singularities of parallel robots*

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1. Introduction

Conventional machine tools have a linear "performance window" which means that wherever the workpiece is located compared to the TCP, the stiffness of the machine tool is the same. From the public, as well as from the manufacturers, especially thanks to the development in the field of computer technology, interest in parallel mechanisms has been interested. The team was able to use sufficiently powerful control systems that would manage the parallel kinematics of the structure successfully. The initial enthusiasm was mainly due to the expected high stiffness of these machines. With time and increasing knowledge of practical deployment, it has been found that even if the stiffness is higher than the user nature kinematics, it is not as high as expected. At the same time, it was becoming increasingly clear that parallel mechanisms would certainly not push the serial mechanisms out of their dominant position, which seemed to have contributed to the fact that a number of manufacturers were limiting their activities in this area. Despite this unfavorable fact, a number of prototypes and experimental machines were produced. A PKM has its highest stiffness in general when the legs are as short as possible and at equal length. This means that in order to optimize a NC (Numerically Controlled) program for a PKM, the forces should be reduced the further away from the maximum stiffness area as the TCP gets. A conventional software to generate off line programs such as IGRIP or RobCad take no consideration to this during simulation and assume a perfect machine. The model presented in this thesis integrates the different phenomenas such as deformation due to heat and external forces which occur during machining with a PKMT (Parallel Kinematic Machine Tool). By continuously monitoring the simulation of the CL-data code it is possible to detect if the PKMT is performing within tolerances. It is also possible to reduce the machining time of the workpiece if the machine is not utilized to its maximum [1,2,3]

2. The Concept of Active Simulation

Conventional off-line programs and simulation tools rarely consider dynamic effects in the machine tool, and up until now most machine tools have been of conventional type. Conventional machine tools have a constant performance window which means that the performance of the machine is not depending upon the location of the workpiece. The new PKMs are quite the opposite, their performance is unlinear compared to where the workpiece is located in the machine's coordinate system. The machine's stiffness will vary depending upon the struts length and angles. This means that a NC-program can work properly if the part is located in a certain place in the coordinate system, but not at all on another location. Machining a big workpiece that covers a great deal of the machine's workspace could result in a product that is within tolerances in the middle but outside in the outer sides due to uneven performance. Figure 1 shows how the deflection varies during a fictive action along the x-axis. The lines are, from the top left, deformation in the x, y, z axis of the machine respectively. It is easily seen that the stiffness of the machine decreases the further away from the center of the machine the TCP gets. The fictive machine has the same dimensions as a conventional PKM. Given the machine characteristics during different operation conditions, it is possible to optimize the NC program for a certain machine tool, in parallel kinematic machine tools. By taking all of the features of the machine into account it is possible to get an accurate model of the machine. The calculations of these models will result in the real accuracy of the machine during load. One of the main objectives to achieve this has been to develop fast code for all the modules. These were able to perform the calculations at a rate of 30 times per second corresponding to the frequency which ENVISION calls on the models. Hence, some of the models are simplified due to the gain in process speed. [4]

The model presented covers many areas within machine technology and manufacturing engineering. Thus the model is generalized and simplified in many areas. The model is mostly focused on the speed and proves that relations between the performance of the machine and the mechanical configuration can be established. There are a lot of existing programs that solves the same problems as the modules but they are in general designed to solve a single task, such as ADAMS, ANSYS and ProMechanica. It would be an immense work to interconnect those programs with each other and still get some speed in the model. [5]

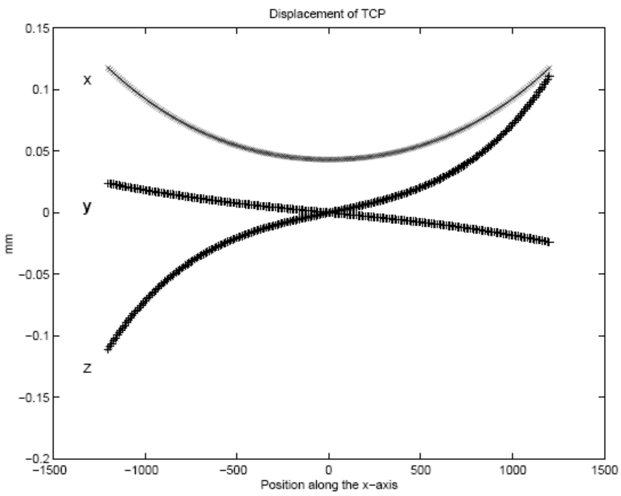

Figure 1. Deflection from TCP along x-axis

The information flow in Active Simulation can shortly be described as follows (see Figure 2 as an aid in the explanation). The information flows from the ISO-code coated from the CL-DATA and from this information is the forces and speed that is affecting the machine calculated. By calculating all major external and internal loads the deformations and hence the TCP offset (TCPrl= Real TCP value) can be calculated. This sequence is done for each point the machine travels through and if the error due to improper moving data then the model suggests a change in moving data. [6,7]

3. Description of the General Flow Model

The "cans" are data and the "squares" processes or functions. Figure 3 describes the flow of data in the model described in this document. Because the machine's mechanical performance is considered in the model the modification of the code will be "tailor made" for that unique machine. Due to the mass of the parts below the 4'th axis the acceleration is taken into account, the contribute from the last two axis can generate a force which is higher than the feeding force acting on the tool [8,9]

A CAD/CAM operator creates a drawing (1) of the desired product. The CAM module within the program generates a ALDATA (Actor Location Data) file (2) which contains all the necessary data for generating a NC-program. The post processor (3) creates one file with tag points (4) and one with the acting data (5). The tag points file is used for ENVISION (6) that generates the trajectories for the virtual PKM. The other file is used for calculating the forces on the TCP, the forces are calculated by an ANN (Artificial Neural Network). This is decisive for the performance of the complete model since this is the only external disturbance which is acting on the PKM.

ENVISION provides the joint values and the TCP values (8) for the calculation modules that calculates the Heat in structure (9), Geometric errors (10), FEM Joint deformation (11), Struct. deform (17) and the Dynamic Forces (18). The two first are only depending upon the data received from ENVISION, but the third is depending upon both the Force and the data provided from ENVISION. The dynamic forces are added to the static forces. These three functions calculates the difference in joint values due to external and internal influences. [10,11]

These are later added to the old joint values and new joint values (14) are calculated. A new TCP is calculated (13) from the new joint values and the TCPn (TCPn=nominal value of TCP) and TCPrl (TCPrl=real value of TCP) are compared and the difference between them is the actual performance of the machine. If the difference in TCP (ΔTCP) (15) is bigger than the set tolerance the acting data (16) file will be adjusted so that the ΔTCP is within tolerances. [3,7,8]

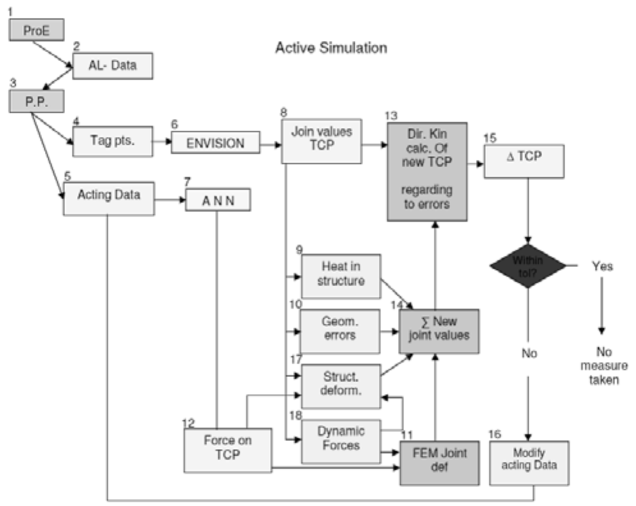

Figure 2. Principal description of the active simulation model

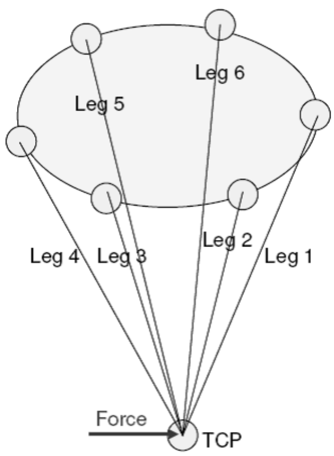

Figure 3. Principal description of the FEM model

3.1. Description of Active Simulation Modules

The first three modules are based on existing software, the first is ProEngineer, a commercially available CAD (Computer Aided Design)/CAM program. The available second module is a Post processor, WinPost [66] is a commercial, general post processing system. WinPost can generate code both for ENVISION and conventional ISO-code for the Hexa robot. ENVISION is also a commercially available software.

ENVISION is exporting the information using a protocol called LLTI (Low Level Telerobotics Interface) to communicate with the modules that calculates the deformations and deflections. LLTI uses standard socket communication to exchange information with other computer processes. [12,13]

FEM module:

The FEM module is a simplified structure of the Hexa robot which consists of six fictive legs which meet in a single point, the TCP see Figure 3. The boundaries are that the top connection points on the circle are fixed and the lowest point is flexible due to the deformations. The center beam is not subjected to any deformation because it is not fixed in the top connection point. The only deformation is the one that occurs in the prismatic joints. Depending upon the length of the six legs and the orientation and magnitude of the force there can be an infinite number of configurations of deformation. By calculating the deformation of the legs a new TCP can be calculated, hence also new fictive leg lengths. The difference between the old and new leg lengths are added to the leg length given by ENVISION. [3]

Thermal deformation

Due to friction in gears, heat is developed and transmitted in the strut which increases in length. This problem can be solved in three ways, the first is to use a measuring device which can measure the correct length of the strut independent of the temperature. [3]

The second way is to measure the temperature of the struts during operation and adjust the control system due to the temperature.

The third way is to measure the distance traveled and the speed of the struts to do an estimation of the temperature and develop a mathematical model which describes it. This is the most interesting method because it can be used separately from the physical machine for the simulation purpose. The expression determines the length of the legs as function of the ambient temperature, the total traveled length of the legs and at which speed they have traveled. Thus the temperature hence the real length of the legs can be obtained from the ISO-code or ALDATA.

Geometric Errors

The kinematic model of the machine is designed for a perfectly manufactured machine, it takes no consideration to variations in positions of the different connection points of the physical machine. Consequently the kinematic model is representing another machine than the real one. By changing the connection points in the kinematic model it is possible to calculate the errors of the machine due to this cause, given the nominal tolerance of the manufacturer. It should be noted that geometric errors can to a large extent be compensated by a calibration.

Singularities

Depending upon the structure of the PKMT and trajectories, singularities can occur on various places i the work volume. As in the case of the Hexa robot a reorient action of the tool occurs every time the length axis of the tool crosses the machine origin. If this happens during a acting operation, the machine stops because the 4'th axis can not do a 180 turn as quick as the control system wants. [3]

There are two ways of treating singularities, singularity is not represented in Figure 2 due to this. The first method is to integrate the singularity check as a module just shown as 9, 10 and 11 in Figure 2. This is not a problem free approach either. Because if a singularity is detected in the end of a simulation sequence, the whole sequence has to be rerun due to the change in results because of the repositioned workpiece.

The second method is to integrate the singularity check into the post processor, this could be an easy way to generate singularity free code for the simulation program. But it could also cause problems because the singularity free code may not be the optimal code for the acting sequence. For example, in order to get a singularity free code the post processor can suggest a position of the workpiece which may not fit the performance of the machine. The best way is to start the post processing with the workpieces positioned in the center of the machine table. If a singularity would occur the work piece should then be moved out of the center position. By striving to have the workpiece as close to the center of machine table as possible the stiffness of the machine can be maximized. [3]

This model describes the development tools made using Matlab platform, a workspace boundary finder and a simulator for the Hexa robot, both used in this work. These tools are useful for understanding how the Hexa robot works and for the synthesis and optimization of the robot architecture [11,14].

4. Results

This model describes the development tools made using Matlab platform, a workspace boundary finder and a simulator for the Hexa robot, both used in this work. These tools are useful for understanding how the Hexa robot works and for the synthesis and optimization of the robot architecture.

4.1. Geometry and Workspace Definition Tool

From this window it is possible to access the simulation tool and also to run the workspace finder algorithm. The first step is to define the Hexa machine geometry along with all key points. An image of the desired machine is shown as well. The desired constraints (the minimum acceptable distance between limbs and angular limitation of the joints) also serve as inputs for the workspace finder algorithm. Figure 4. [8,15]

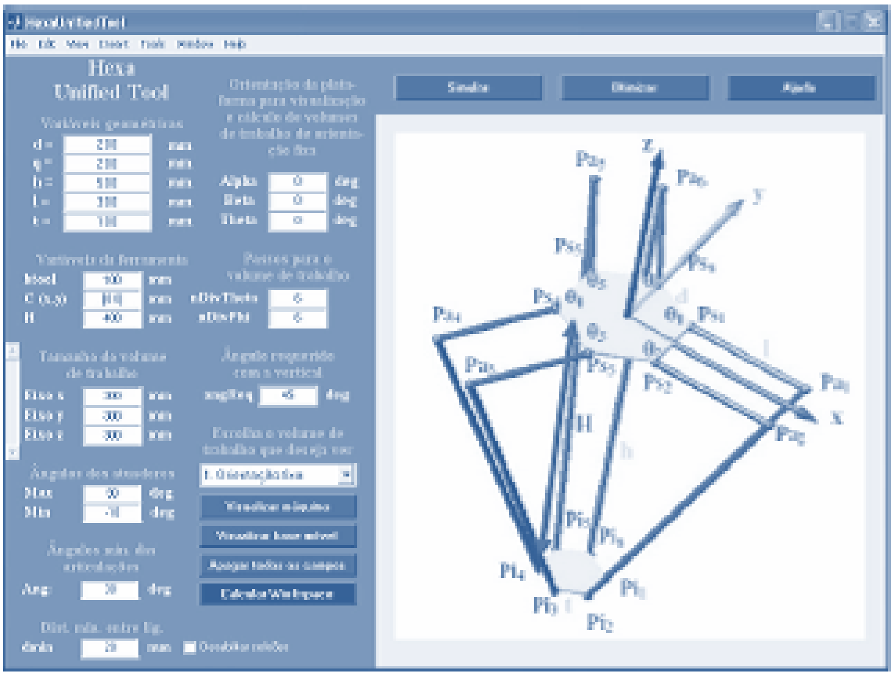

Figure 4. Main window of the Hexa tool for matlab

4.2. Geometry and Workspace Definition Tool

The developed simulator is useful to identify Hexa's workspace limitations in terms of certain common tasks that the machine has to perform while in operation. Some of the simulator features shown in Fig. 5. As shown in this figure, the tool is capable of simulating several types of movements of the Hexa machine, such as linear and circular interpolations, in any chosen plane, and platform orientation changes in any direction using any point as center and while moving. It is also possible to use linear interpolations from the coordinate system o-xyz, instead of the O-XYZ. As outputs, the tool calculates in real time the actuators position and the roll-pitch-yaw angles.

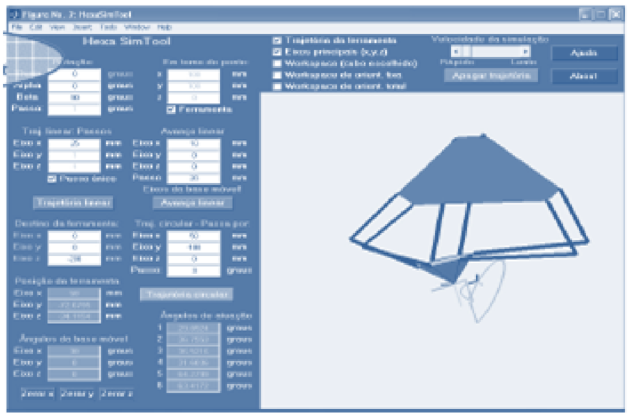

Figure 5. Main window of the Hexa tool for matlab

For the next results, the fixed orientation angles of (0°, 0°, 0°) and the required angle for the total orientation equal to 45° are used. It was also imposed angular restrictions of (100°, -20°] for the actuated joints (maximum and minimum angles, 30° of minimum angle for the others and a minimum distance between limbs of 20 mm. Hexa robot's dimensions are: 100 mm for the distance between each one of the three pairs of the actuated joint centers; 100 mm for the side of the moving platform (hexagonal shape); 100 mm for the tool height; 250 mm of actuated rods length; 500 mm of passive rods length; and 300 mm for the distance from the center of the fixed base to one of the actuated joints center lines. [3]

5. Conclusion

The presented inverse kinematic model proves to be a simple way to solve this particular issue in parallel robotics and can be used in other types of architectures. The model is fast and is applied in real time simulations through the simulation tool. The workspace algorithm suggested in this work is also suitable for implementation and can be combined with the simulation algorithms, providing an even more advanced tool.

The developed tools are the first steps of a deeper study in parallel architecture robots. Also by proving that the tools developed so far are correct, we are moving toward our ultimate goal that is the synthesis and optimization of a Hexa machine, possibly followed by a prototype construction.

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