Micro-robots used in control of automatic drilling operations

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Abstract: - A micro-assembly station based on a micro-robot, under an optical microscope, is one of the typical styles to practical application of the task of assembling simple micro parts, even if they are still almost at the start phase. The performance of the micro-robotic system has the potential to have an important role in such applications with reference to the transportation, handling and storage of micro objects. For that, has developed an automated system consisting of multiple drilling micro-robots. In this paper is presented a concept of control for automated micro-drilling, "cluster" type, in which several miniature robots, piezoelectric trained, are used to transport the piece of work to hold and to permit the micro-borer introduction. This type may provide some advantages having in view the accuracy and flexibility of micro fabrication.

Key-Words: - Micro-robot, Actuator, Micro-controller, Drill, CCD Camera, DC motor, Dynamic Modeling.

1 Introduction

For modern portable consumer product applications, development of production facilities for assembly and production of miniature components are a great interest because one of the major orientations in the industry is to manufacture smaller products at low prices. In fact, with the increasing of this miniaturization, it is known that it will be more difficult for conventional sized mechanisms to manipulate and assemble the small pieces of work, as they will hit the mechanical limits of accuracy due to manufacturing errors, friction and thermal expansion, as high energy consumption during operation.

Even if will be possible the improvement of machine performance, then it will be higher costs for maintenance [Donaldson et al., 1986]. As an alternative solution to this problem, miniature robots which are equipped with micro-sensors, manipulator and tools may have an effective role in such a small scale production system with greater flexibility and reduced cost.

A micro-assembly station based on a micro-robot, under an optical microscope, is one of the typical styles to practical application of the task of assembling simple micro parts, even if they are still almost at the start phase. On the other hand, practice production application, such as a micro-drilling operation, using conventional machine tools, is based on a combination of mechanisms for both spatial positioning tool and for the sample, relative to standardized mechanical cutting on different axes [4].

In this paper is presented a concept of control for automated micro-drilling, "cluster" type, in which several miniature robots, piezoelectric trained, are used to transport the piece of work to hold and to permit the micro-borer introduction.

Here, the micro-robots, which are formed from a pair of piezoelectric elements for smooth motion and some electromagnets for fixing on a mounting surface, are developed for a resolution of movement and positioning of sub-micron level [6].

This arrangement can also allow the robot to move not only in the horizontal plane, but also on vertical walls or even on ceilings. Moreover, a micro-borer with reducer, a micro motor shafts and support for a particular sample are fixed on each moving mechanism.

In the main experiment, automatic special task, to give more small holes under the supervision of the camera CCD, based on a feedback system, will be discussed to investigate the performance and feasibility.

The general task of automatic generation of the control tests for various object areas, allowing the creation of the single formalization based automatic test control systems. The control of models and adequacy of their realization always was regarded as an actual problem, because checking of the adequacy of the model realization is an informal, difficult, multi-factorial task. Testing control is usually used to ascertain the adequacy. On the background of continually increasing the dimension of such problems, to make control more effective it becomes necessary to make testing control process automated. It is necessary to work out the principles of constructing the automated testing control systems and testing control methods for various object area formal models and adequacy of there concrete realizations. To organize the automated testing control it is needed to have tests with high completeness and efficiency [3].

For related auto parts industry, modularization and weight reduction of chassis subassembly are one of the main goals in order to achieve fuel efficiency and lower production cost. Additionally, auto makers also require that the part manufacturers to provide a subassembly unit defined by modularization [8].

A computational method for solving the dynamic equations of motion of manipulator-robots, using the integration methods can be made. The proposed algorithm is conceived using Mathematica software (for example) software, which allows the integration of differential system equations by his functions, assuring in this way the result correctness and a high computational speed.

The software may be used for the 2-D or 3-D robots manipulators, which contain an open kinematics chain with rotation and translation joints.

The software allows also for the calculation of the time variation curves of the degrees of freedom, having as initial data the values of joints generalized forces, the mass and inertia of the robot links, the inertia of the actuators and the initial conditions for joints coordinates and speeds

After the establishing of dynamic equations, the dynamic simulation of micro-robots represents the integration of the differential equation system, considering like inputs loads and actuator torques vector from manipulator joints. The dynamic simulation problem represents the direct dynamic model design having like solution the manipulator behavior [5].

2. Dynamic modeling of some industrial robots

The dynamic modeling of robots [11,13] represents the determination of the dynamic equations, which is the first information necessary for robots control [3,6]. These equations are useful for computational simulation of the robots motion and for the evaluation of kinematical structure of robots [3]. In the dynamic formulation of manipulators the following methods are used: Lagrange-Euler, Newton-Euler, D'Alembert. In [11,13] reference books there are discussed only plan manipulators with 2 degree of freedom. For the manipulators with more than 2 degrees of freedom (DOF), a very laborious calculation is necessary. The Lagrange-Euler method is relatively simple and systematically. As a rule, the dynamic for a device of electronic control and the frictions of gearing are not considering. Thus there is obtained a 2nd degree equation system. For the robots with 6 degree of freedom, the dynamic equations are nonlinear and very laborious. Generally, each term of the inertial force and gravitational force depend of the instantaneous position of the kinematical links; the terms moment and force depend on the velocity and the position of kinematical links. The dynamic equations are obtained by the Lagrange-Euler method for the non-conservatives systems. If the non-dimensional method is used, the dynamic formulation is more efficient. The new method of kinematics and dynamics modelling use the homogenous matrix and the Lagrangean formulation [6].

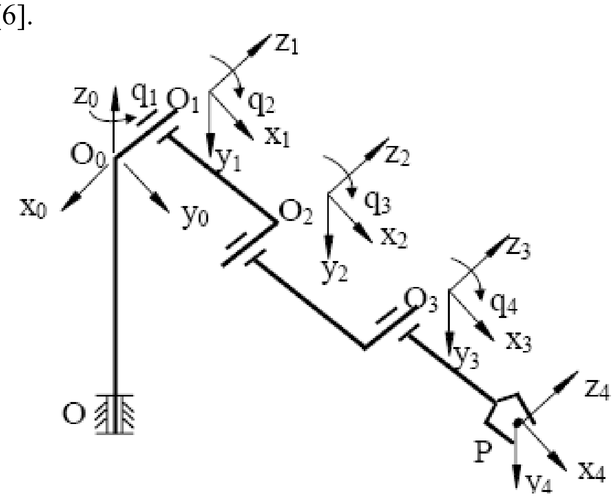

Fig. 1 The 4R spatial manipulator

The D-H method was used buy many researchers for the study of kinematics and dynamics of manipulator robots. It forms the basis for the following programs GESIMA (GEometric SImulation of the MAnipulator), SPHEMA (SPHEres Manipulator), IKIREM (Inverse KInematics REdundant Manipulator) which solves the inverse kinematics for a redundant manipulator by utilizing the optimum simulation of the system manipulator – obstacle [5].

Also based on the D-H method the SUMT program was developed [6] which computes the penalty function method for inverse kinematics. The upper mentioned programs where developed using Fortran programming language because this language also allowed the graphical representation of the robots position based on calculated solutions and through the communication with other commercial programs which contain subroutines for graphical communication. The program proposed in this paper is similar to the upper mentioned ones, except it's development in the Mathematica programming language, thus because the paper aims to establish the dynamic equations and the Mathematica already contains specific functions for this purpose.

The proposed algorithm and program for the dynamics calculation of the manipulator-robots has input and output data [6].

The input data are: D-H parameters; the coordinates of mass center for each kinematical link; the inertial couples axial and centrifugal of each kinematical link; the inertial motor (actuator) couple for each joint; the vector of gravitational acceleration.

The output data are: the geometric - kinematical model; the effective inertial force or couple of each joint;

the inertia of coupling between the joints i and j; the centrifugal force of link i due to speed of joint j; the Coriolis force of the joint i due to the speeds of joint j and k; the gravitational loads of each joint; the manipulator – robots dynamic equations.

The notations used in computational program are [5]:

$m[i]$ - the mass of i kinematical link;

g - the gravitational acceleration vector, with respect to the fixed-reference system;

$q[i][t]$ - the generalized coordinate of kinematical link as function of time;

$Q[i][t]$ - the generalized force of joint i corresponding the independent parameter $q[i][t]$.

It is consider, as example, a planar manipulator 3R (Fig. 2) actuating in the vertical plan [6].

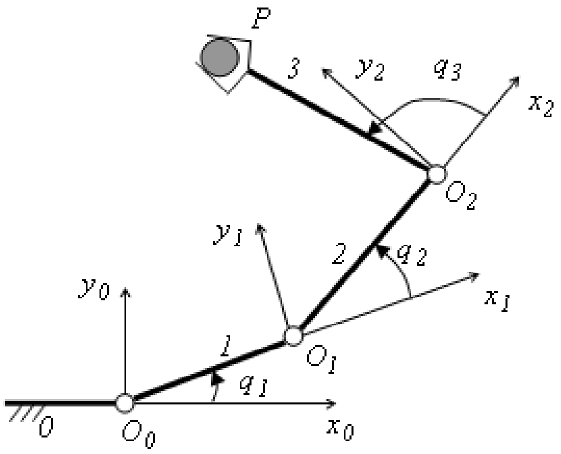

Fig. 2 Trimobil planar manipulator 3R

In order to solve a specified application, an industrial robot should be installed so that the application is found into the work field. Taking into consideration only this condition, the problem has infinity of solutions.

The optimum position of an industrial robot in respect to the given application is a very important problem, which can not be solved without a complete analysis of the robot working, from the kinematics and kinetic-static point of view.

The optimum position of the robot frame in respect to the given application is determined so that [7]:

- the robot productive rate must be maximum, i.e. the time of a duty cycle must be minimum;
- the energy consumption for a duty cycle must be minimum;
- the maximum power consumed during a duty cycle must be minimum;
- the maximum driving force or moment from the driving system, measured during a duty cycle, must be minimum.

3 Robotized Technological Process

Here, it is presented a possibility, proposed for establishing the sequence of the operations for the technological process. The most important, from the technologic engineer point of view are the information that is related to manipulation and orientation of the work piece. That information must be related to workspace of the robot and the workspace of the machine tools [7].

Robotic arm are commonly used in industries. In many field applications where technical support is required, man-handling is either dangerous or is not possible. In such situations three or more arm manipulators are commonly used [9].

Some robots are used to inspect dangerous areas or/and to remove and to destroy explosive devices. These robots can be used to make some corridors through mined battle fields, manipulation and neutralization of the intact ammunition, inspection of the vehicles, trains, airplanes and buildings [9].

For these robots a good functional activity is to determinate the dimensions of the work space and kinematics of the robotic arm.

About the numerical simulation model it can say without fear of error, there are a variety of such models. The problem ourselves now is to find a model or a class of simulation models, which we call the standard models in the sense that all others are reducible to them. Experience has shown that the most common simulation models are differential model for continuous systems, and finite difference model (discrete time), for discrete systems.

All other methods may be reduced by appropriate changes in the two models [9].

This class of systems is well represented by differential model as a set of nonlinear differential equations with given initial conditions and sub-optimality intervals for state variables.

Each of these equations is actually a vector equation describing the evolution status sub-vector xi (i = 1,2, ..., n) from state-space. This model is [9]:

$$x_i(t) = A_i x_i(t) + B_i u_i(t) + f_i(x_i, a_i) + v_i(x);$$

$$x_i(0) = x_{i0},\ i=1, 2, \ldots, n;$$

$$v_i(x) = \sum_{j=1, j+1}^{n} g_{ij}(x_j),$$

where:

A_i and B_i is the matrix of state and control respectively, of appropriate size;

f_i – vector functions describing non-linearity subsystem I;

v_i – the interactions between subsystem I and other n-1 subsystems;

$x_i(0)$ – initial condition;

α – parameters modeled sub-process.

Adding some intervals of sub-optimality one obtain:

$$x_{i1} = \overline{x_i} - \Delta x_i \le x_i \le \overline{x_i} + \Delta x_i = x_{i2}$$

($\overline{x_i}$ - being the average amount of inpatient regime and Δx_i is the uncertainty over the state x_i)

The control variables u_i are those who are under restrictions:

$$u_{i1} \le u_i \le u_{i2},\ i=1, 2, \ldots, m.$$

If the subsystem is linear, the state equation is written as:

$$x_i(t) = A_i x_i(t) + B_i u_i(t) + \sum_{j=1, j\ne i}^{n} A_{ij} x_j(t);$$
$$x_i(0) = x_{i0}.$$

Applying to the equation of Laplace transformation one obtains:

$$s[Y_i(s) - x_i(0)] = A_i Y_i(s) + B_i F_i(s) + \sum_{j=1, j\ne i}^{n} A_{ij} Y_i(s)$$

and finally:

$$Y_i(s) = (sI - A_i)^{-1}[s x_i(0) I + B_i F_i(s) + \sum_{j=1, j\ne i}^{n} A_{ij} Y_i(s)],$$

where:

$$Y_i(s) = L\{x_i(t)\};\ Y_i(s) = L\{x_j(t)\};\ F_i(s) = L\{u_i(t)\}.$$

3.1 Kinematics analysis of industrial robot mechanisms

In order to determine the above mentioned objective functions it is necessary both the kinematics analysis and the kinetic-statics analysis of the robot mechanisms. It is assumed that the dimensions and masses of the component elements of the industrial robot and of the manipulated object are known. Also, it is considered a variation function for the independent variables with respect to the time. Generally, the dependence with the time of an independent variable (generalized coordinate) may have any form. The choice of the optimum function for certain goal is made in concordance with the motion type, maximum and minimum values of the relative speeds and accelerations and with the continuity conditions from the acceleration diagrams [6]. One of the functions, $s = s(t)$, is make from three sectors, namely accelerated motion sector, uniform motion sector and decelerated motion sector (fig. 1). The acceleration and deceleration are constants. This function has the advantage that, for a certain value of the maximum speed, the acceleration and deceleration values are the smallest [7].

The acceleration time t_a and the deceleration time t_d are calculated in terms of the maximum acceleration $\ddot{s}_{\max}$ and maximum deceleration $\ddot{s}_{\min}$, respectively.

Obviously, the statement

$\ddot{s}_{\max} t_a + \ddot{s}_{\min} t_d = 0$ must be true.

If $\ddot{s}_{\max} = -\ddot{s}_{\min}$, then

$$t_a = t_d = 0.5(T + \sqrt{T^2 - 4h/\ddot{s}_{\max}})$$

where h is the length of the relative displacement of the contiguous elements of the prismatic active kinematics pair;

T is the total time of the displacement;

$\ddot{s}_{\max} > 4h/T^2$

In a similar manner, the acceleration and deceleration times is calculated in the event that the active kinematics pair is a revolute one, in terms of the relative rotation angle magnitude and the maximum angular acceleration [7].

In the inverse kinematics analysis of a mechanism are established the variables of the driving kinematics pairs in terms of the position of a point of a element or as function of the position of a coordinate axes system assigned of this element.

The problem has solutions only if the freedom degree of robot [7].

3.2 Kinematic instability in hybrid control through Railbert and Craig method

This depends on the kinematic structure, the reports of the steps of various joints and the robot configuration foot. In addition, by adding more depreciation or speed steps, system instability persists. Modified control by resolved acceleration or operational space method is stable because the inertia matrix is also included, cancelling the destabilizing effects of the inverse Jacobian. If dynamic modelling is accurate, the robot motion is completely decoupled from the top in Cartesian coordinates. Even if the dynamic modelling has a 50% error, simulations have shown that resolved acceleration is still stable [13].

3.3 Fuzzy multi-stage method using control by resolved acceleration of walking robots.

In figure 3 is presented the control system architecture by dynamic models through fuzzy multi-stage method where it had been chosen as compliant control method, the control method through resolved acceleration.

Controller tasks were defined, as a decision rule and the fuzzy variables used in decision-making. The deviation values detected by the sensor values were quantified in a number of points corresponding to elements of the discourse universe, and then values were assigned as membership levels in some fuzzy subsets. Relations between inputs, for example deviations measured, or outputs, as the example of speeds, and the membership level were defined in accordance with the experiments and the demands of the task. Fuzzy values were chosen as follows: NM - negative big, NM - negative medium, Nm - negative small, ZOzero, Pm-positive small, PM - positive medium, PM - positive big [13].

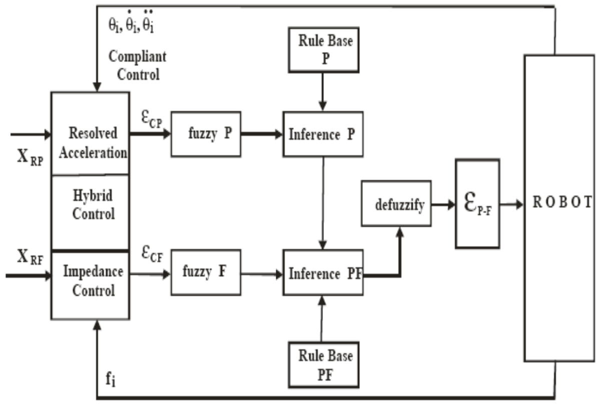

Fig. 3 Control system architecture through resolved acceleration using multi-stage fuzzy

4 Drilling operation by multiple micro-robots

It is known that the characteristics of the robots, in general, are utilized to give a flexibility to the system and, therefore, the complexity of the robotic model is increasing slower with the number of degrees of freedom, compared with the general type of some manipulators [7].

In Figure 4, is illustrated an overview on a micro-drilling system, being in development, based on micro-robots. Each of the small robots, used in this system has a pair of electromagnets and piezoelectric elements to move precisely as an "inchworm", and is specialized to handle one or two specific operations [16].

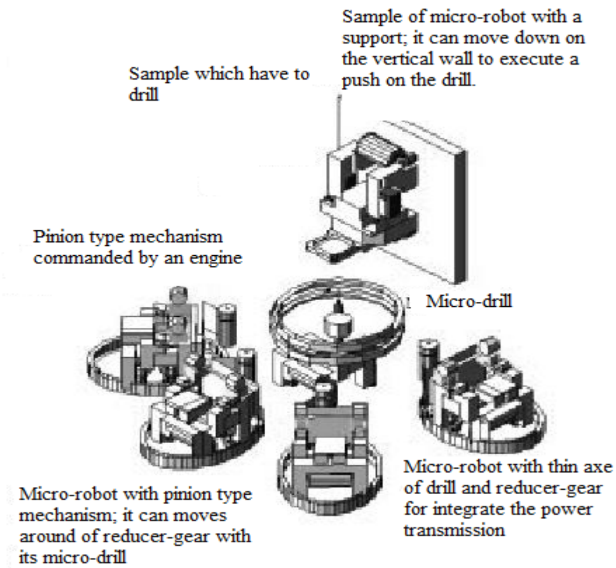

Fig. 4 The assembly of a micro-drilling system based on micro-robots

This mechanism can provide fine mobility with step by step microscopic motion and stable clamping on such a surface during operation, even on vertical walls and ceiling, all over on the vast working space, even if the target area is limited to ferromagnetic surfaces. In an input voltage of 100 V on piezoelectric element, the typically step is about 10 microns, so it can move at a speed of 1.5 mm / s when is activated a frequency of 150 Hz [Aoyama *et al.,* 1993].

Also, the different pitch of each piezoelectric element can command the direction of motion. However, the electricity and the robot control signal are transmitted by wire, because of high voltage sent to the piezo-element and high amperage sent to the electromagnet, this should be improved in a future by advanced technology.

In such robotic systems is essential to incorporate visual monitoring tools, such as CCD camera, and computer resources to control them, but this system is very complicated. Therefore, it is developed a simple navigation system, of acoustic type, for example. To achieve the proper task of drilling have been developed three types of micro-robots [6].

One of them is equipped with a thin drill, with the gearbox on axis; the others have the shafts mechanisms commanded by D. C. micro-engines. The little part that will be holed is going to be held by the micro-robot who can move even on the vertical walls. After that, the product positions and the drill characteristics are fairly fixed, the micro-robots with engines can approach by the robot with drills for drilling. Then the robot from vertical wall can carry the piece down to the drill and carefully push for a hole from start to finish.

4.1 Centralized and distributed control systems

It is well known that always the control of several robotic systems have one of the biggest problems because it contains many points of difficulty and complexity of robots command; planning and programming, operations allocation, communications, and problems of other areas [5].

In order to get the operation required, a part of the control system is taken into account from the beginning, so that the system can be partially centralized and partially distributed. It is expected that the combination of centralized and the distributed architecture can provide effective solution to the multi-robot systems.

In Figure 5 are shown some robots which are organized having in view the control system.

To avoid the complication or increasing of the price system, a monitoring CCD camera is mounted at an angle of 45 ° on a framework, the purpose of that is to monitoring the robots in horizontally and vertically plans.

The image of the camera from the robots with the drill machine from horizontal plan and the vertical plane model, can be extracted and the coordinates x - y can be passed to a central computer using image processing tools in real time that are able to reach a the resolution of 5000 x 5000 with a refresh rate of up to 60 Hz.

Because this framework can cause image distortion the numerical compensation is taken into account to obtain details of individual geometric positions of the two robots. Thus, total accuracy is expressed in an area of 0.1 mm to 400 x 400 mm^2. However it is essential to implement advanced systems to measure spatial positions [5].

On the other hand, the robots with D.C. micro-engines are not driven by visual systems, but with micro-gears drilling machines helping, using acoustic signal being on the base of routing system of robots.

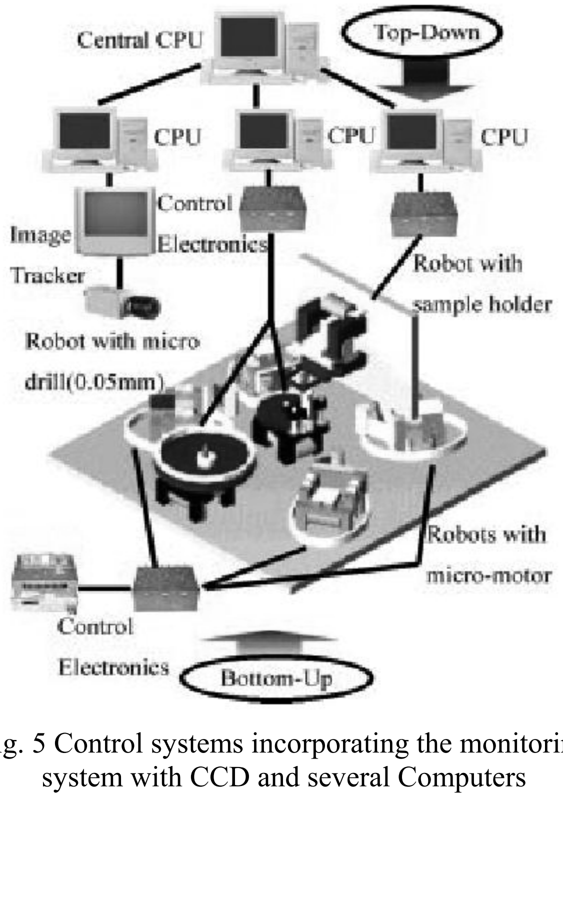

Fig. 5 Control systems incorporating the monitoring system with CCD and several Computers

4.2 Targeting guidance with acoustic signal and the outer frame

Instead of visual inspection, orientation with the acoustic signal is also used for simultaneous control of several micro-robots driving with DC motors. These micro-robots can easily move forward to reducing gear and then return after the operation.

A sound sign by 1 kHz which is generated by acoustic sources in the central part of a drilling reducer-gear can be monitored by micro-robot's microphones so that each robot can move automatically switching the piezoelectric elements.

This simple driving may cause collisions between micro-robots as they all close by the same target. It is known that they are not endowed with the functions to avoid the impact. Because the speed of the micro-robots is very small there will be no damage from the impacts.

Having in view the micro-robot's drive to the reducer-gear drilling, the technique of guidance using outdoor framework is applied complementary with the acoustic guidance system. Ellipsoidal shaped outer frame is fixed on each micro-robot to be able to make contact and a smooth guidance.

Guidance with ellipsoidal outer frame on the smooth collision model

To investigate the behavior of trajectory after the collision of micro-robots is present such a model in Figure 6:

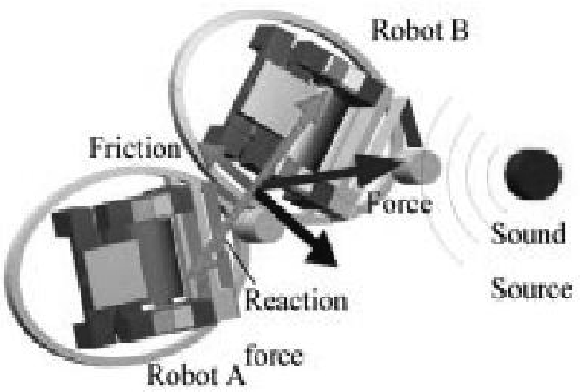

Fig. 6 Simple collision models of a two micro-robots

One expects that two micro-robots which come into contact to generate a pushing force on each other. Micro-robot can still make a displacement to the source of acoustic signal along the other micro-robot's framework.

Using a simple mathematical model, simulation can show the trajectory of possible motion with respect of: the focal point, the angle of impact, the coefficient of friction, and the elliptical curve. The result of such simulations is shown in Figure 7 the micro-robot collides of other micro-robot and then continues its path to the source of signal noise.

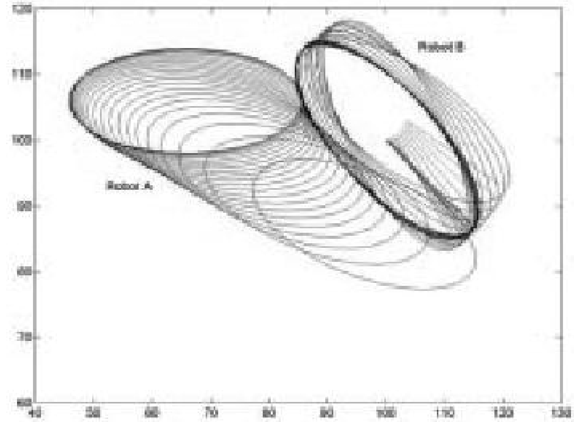

Fig. 7 The result of simulation of a model of acoustic navigation after the collision

It is obvious that micro-robots are moving in accordance with the influences, such as: the principle of action and reaction forces, the moment of inertia and friction forces. However, in certain conditions, such as orthogonal collision or focusing of more robots, the blocking of robots is expected. In such cases will be implemented other control systems.

5 Study case

In this paper were introduced the control multiple systems of a micro-robots for micro-drilling operation. Each micro-robot has a reducer-gear with a micro-drill, a reducer-gear assembly operated by a DC micro-engine, an acoustic orientation and monitoring system, which is implemented to provide a combination of centralized and distributed control. In order to improve efficiency and accuracy, it is developed the precision of measuring instruments, elements of local sensors and the property to make the recovery from blocking state.

5.1 Detailed technical theme

It will design a drilling micro-machine with features:

1. Assigned to a space with dimensions: 50 mm x 20 mm x 15 mm
2. The maximum displacement of a drill c_{bu} = 1000 μm
3. The minimum pushing force on drilling operation $F_{a\,min}$ = 0,1 N

4. The maximum speed on drilling operation n_{max} = 3500 rpm
5. Increment of linear displacement i = 10 µm
6. User interface specifications:
   6.1. Button --- Manual command for linear displacement - "attack" sense;
   6.2. Button --- Manual command for linear displacement - "retraction" sense;
   6.3. Button --- Manual command - 1/2 rotation drill sense;
   6.4. Button --- Manual command – increase drill speed variation;
   6.5. Button --- Manual command – decrease drill speed variation;
   6.6. Button --- On/Off command, lighting system of the operating area;
   6.7. Button --- On/Off command for whole system.
7. The enclosure that includes the operation area will be equipped with an optical system and camera
8. Lighting system will be punctual focusing on the working area, (having in view, for example, photo-luminescent diode light source, and white light optical focused
9. The command for linear displacement will be realized with PWM, tact generator will be the PIC16F877A micro-controller
10. The command for drill speed adjustment will be realized with PWM, tact generator will be the PIC16F877A micro-controller
11. The used software for micro-controller programming: MIKROPASKAL (this is easy to use and may have many applications in robot modeling [4])
12. The adjustment modules will be always separated.

5.2 Mechanical calculations breviary

The mechanical concept regarding the design and performance of the prototype drilling micro-machines consist in:

- The linear displacement of actuators is derived from the balance between the elastic force developed by the compression of helical spring and the electro-magnetic force developed by the actuator coil.

- The guidance in linear motion of the engine is classical by cylinder bushing type - cylindrical guide in the four points of support.

- The push force required by design theme should be within the range of existence of the elastic force way F_{el}, because that is the driving work force in the case of executing holes.

- The electro-magnetic force acting as positioning and energy storage inside the compression element spring type.

In figure 8 is presented the kinematical scheme of drilling micro-machine [3].

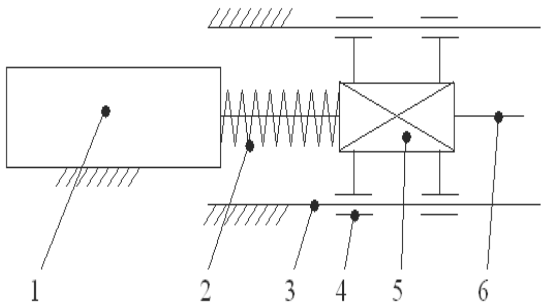

Fig. 8 The kinematic scheme of drilling micro-machine

The signification of elements:

(1) electro-mechanic actuator.

(2) Helical compression spring, the active component during the drilling operation, thus, is developed the necessary pressure.

(3) Cylindrical linear guides.

(4) Cylindrical guide bushing of a sliding engine machine.

(5) Support slide engine machine.

(6) Drilling tool, drill, element of implementation.

Figure 9 shows the workings mode of active element by helical compression spring type, respective the relaxed and compressed state in which are developed active work force and, also, the elastic force F_{el}.

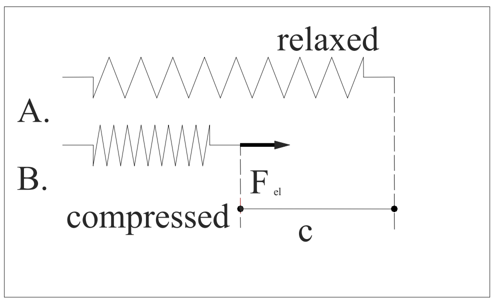

Fig. 9 The active element, helical compression spring

The symbol c is the real displacement that the spring achieves a mechanical energy to develop compression. The active displacement ca, necessary in drilling operation, is a fraction of that displacement c.

In the graph represented in Figure 10, is reproduced the relationship between force and displacement [1].

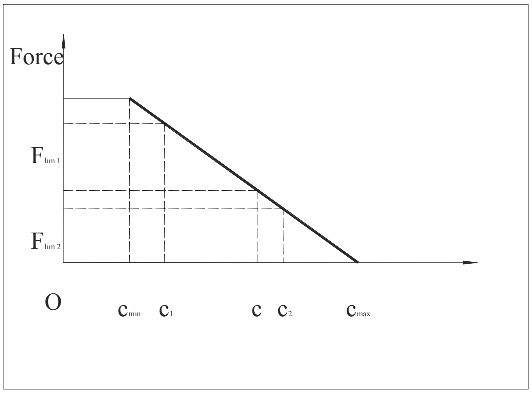

Fig. 10 Graph force-displacements

The significance of notations is as follows:

- c1 and c2 define the maximum displacement that can be developed at the electro-mechanical actuator action.
- c is an instantaneous displacement.
- c1 and c2 define the necessary displacement for a required and a controlled drilling.

At the start of drilling operation the force is F_{lim1}, and at the end it is F_{lim2}, thus, the necessary force decrease when the drill is moving. This fact does not agree in terms of technological operation itself. It will always check that F_{lim2} be more (or equal) than the minimum force necessary in drilling operation. In this sense, will be covered the energy needs by pushing in the material "texture" of the drill [2].

5.3 The determination of compression spring constant

From the data required by the subject one extract next values:

The maximum displacement of drill: c_{bu} = 1000 μm

The minimum pushing force on drilling operation $F_{a\,min}$ = 0.1 N

At a first assessment of data, the minimum necessary constant is:

$$k = \frac{F_{a\,minima}}{c_{bu}} = \frac{100}{1000} = 0.1\left[\frac{mN}{\mu m}\right]$$

The calculus hypothesis of a spring constant:

The minimum displacement c_{bu} will be framed within a minimum interval of 300% expanded both on the left limit side and, also, on the right limit side.

The minimum force F_a will be included within the force interval with a minimum length of 10 x $F_{a\,min}$. The calculus of interval of limit movement and the limit force for determining the spring dimensions are:

The maximum movement or displacement [1]:

$$c_{max} - c_{min} = 3 \cdot c_{bu} + c_{bu} + 3 \cdot c_{bu} = 7 \cdot c_{bu} = 7000[\mu m]$$

The maximum force:

$$F_{max} = 10 \cdot F_{a\,minima} = 10 \cdot 0.1 = 1[N]$$

5.4 Calculation of the constant active element - compression of helical spring:

$$k = \frac{F_{max}}{c_{max} - c_{min}} = \frac{1000}{7000} = 0.143\left[\frac{mN}{\mu m}\right]$$

6 Conclusion

The prototype developed is a technical platform that enables the development of some accuracy studies of micro-positioning with a large impact on the design of new command and control hardware units. The domain of micro-robotics is one of the futures, with applications that will govern the scope of industrial and social activities. The prototype made open the way for laboratory applications, which can exemplify the working principles of this technical field of great importance.

The idea of viewing the command effects of micro-machine through a web-cams and a magnifying optical system, has made significant contributions to the technical quality of the prototype. Future research directions that will develop from this application refer to a series of studies of repeatability precision, with an impact on the experience in the construction of micro-machines.

In comparison with the software designed using classical programming languages like FORTRAN, C, Pascal etc, the proposed software is conceived in an advanced programming language for mathematical computation and allows the design of the converse geometry model for redundant structures in a very short computational time. The proposed software allows for the determination of dynamics errors and the influence of each geometric, kinematics or dynamics parameter.

The proposed software allows also studying the influence of the change of initial conditions, generalized forces from joints and links masses on the diagram of command functions.

The proposed software is easily to use and may have many applications in robot modeling [3].

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