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INVERSE MODELING OF THE STEWART FOOT

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ABSTRACT

The Stewart's leg is used today in the majority of parallel robotic systems, such as the Stewart platform, but also in many other types of mechanisms and kinematic chains, in order to operate them or to transmit motion. A special character in the study of robots is the study of inverse kinematics, with the help of which the map of the motor kinematic parameters necessary to obtain the trajectories imposed on the effector can be made. For this reason, in the proposed mechanism, we will present reverse kinematic modeling in this paper. The kinematic output parameters, ie the parameters of the foot and practically of the end effector, ie those of the point marked with T, will be determined for initiating the working algorithm with the help of logical functions, "If log(ical)", with the observation that here they play the role of input parameters; it is positioned as already specified in the inverse kinematics when the output is considered as input and the input as output. The logical functions used, as well as the entire calculation program used, were written in Math Cad.

Keywords: IFLOG; Math Cad; Stewart platform; Stewart's leg; Robot; Kinematics; Inverse kinematics

1. INTRODUCTION

The parallel structure system that formed the basis of one of the most studied and well-known parallel robots is the Gough platform from 1947. Described as a mechanism with a mobile platform connected to a fixed base by six arms of variable length, the Gough platform was used for testing tire wear in the most varied operating conditions. Since 1965, this parallel configuration (in a slightly modified form) has been proposed as a solution for the development of flight simulators by Stewart.

Parallel structures can be classified into completely parallel structures, whose final effector is connected to the mobile platform by closed kinematic chains; and hybrid or mixed structures consisting of a combination of serial and parallel structures.

The number of degrees of freedom (GDL) in a robot is the number of independent movements that a robot-type mechanism can perform. The total number of degrees of freedom of a body in space cannot exceed 6 (six). The degree of mobility of a robot can be understood as the number of motors that drive it.

The final effector (a gripping mechanism) is the device mounted on the end of a manipulator that performs operations to hold the tool or the manipulated object. The workspace is the volume of points in the space where the final effector of a robot can be located.

By the position of any object or point of the robot in question is meant the value of the linear coordinates in the three-dimensional space of the object (or the respective characteristic point).

Orientation refers to the angular coordinates of an element (of the robot in question) according to the axes of the fixed coordinate system.

Precision (Accuracy) is the ability of the robot to position itself in a certain position with a certain previously allowed limit error.

Repeatability is the robot's ability to repeat its positioning when repetitive movements are required.

Stability refers to the robot's ability to operate with as few oscillations as possible.

A good dynamics of a robot is obtained when it is statically and dynamically balanced when it is positioned correctly and precisely, without oscillations, without vibrations and high noises, with relatively high speeds, in imposed repeatability conditions, and at the necessary work rhythm.

The definition of a parallel robot is very broad: it can also include mechanisms with more actuation systems than the number of degrees of mobility, including the situation in which several robots work in cooperation.

Parallel mechanisms have several main features: at least two kinematic chains support the final effector, and each of them contains at least one actuating element; the number of actuating elements is the same as the number of degrees of the mobility of the final effector; the robot's mobility becomes zero when the actuators are locked.

The main advantages of parallel robots: they have very high stability even in critical positions occupied even during high-speed movement, so that the objects handled by them are always safe; positioning accuracy is extremely high; at least two of the kinematic chains allow the distribution of the load on them; the number of actuators is minimal; the number of sensors required for closed-loop control of the machine is minimal; if the actuators are locked, the parallel robot remains in the position reached the moment when it was locked, i.e. it will become unbalanced, or fall, or drop the manipulated object, as can happen with serial robots. For the most part, the balancing of these parallel systems is done automatically, from the construction, giving them in this way great stability and precision.

In parallel robots, the motors are located on or near the frame, which makes the moving masses much smaller than in the case of robots based on serial structures. This makes it possible to reduce the masses to the constructive execution of the components without the rigidity of the whole system being harmed. This increases the dynamic capacity of the system and decreases the weight of the system.

Because the work platform is supported by several kinematic chains, the reaction forces on the component chains are small, so that it is possible to obtain a satisfactory ratio between the mass of the manipulated object and the mass of the robot. Increasing the rigidity of the system can also be used for micro robots for high positioning accuracy and very small dimensions. Due to the stiffness and the small moving masses, the components of the parallel robots can be executed more easily. This reduces the power requirement in the drive system.

In the case of parallel robots, drive systems with motors based on solid bodies (eg piezo-alloy motors with memory) can also be built. These motors cannot be used in the case of serial structures due to their low driving power. Passive torques of parallel structures contribute to the miniaturization of the system.

Due to the high rigidity of the parallel structures, the positioning accuracy, and repeatability increase. In parallel robots, the errors in the components and in the couplings do not accumulate as in the case of serial robots. Parallel structures have rather compensatory characteristics that are advantageous in micro-assembly and simplify the adjustment, command, and control system.

Due to the fact that the motors are positioned on the frame, they can be separated from the working space of the parallel structure. In this way, the power supply, power, and communication cables can be easily insulated. This improves the ability of robotic systems to work in a clean or aseptic environment (Antonescu & Petrescu, 1985; 1989; Antonescu *et al*., 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001; Atefi et al., 2008; Avaei et al., 2008; Aversa *et al*., 2017a; 2017b; 2017c; 2017d; 2017e; 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h; 2016i; 2016j; 2016k; 2016l; 2016m; 2016n; 2016o; Azaga & Othman, 2008; Cao *et al*., 2013; Dong *et al*., 2013; El-Tous, 2008; Comanescu, 2010; Franklin, 1930; He *et al*., 2013; Jolgaf et al., 2008; Kannappan et al., 2008; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Meena & Rittidech, 2008; Meena et al., 2008; Mirsayar *et al*., 2017; Ng et al., 2008; Padula, Perdereau & Pannirselvam, 2008; 2013; Perumaal & Jawahar, 2013; Petrescu, 2011; 2015a; 2015b; Petrescu & Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e; 2011a; 2011b; 2012a; 2012b; 2013a; 2013b; 2016a; 2016b; 2016c; Petrescu *et al*., 2009; 2016; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; 2018a; 2018b; 2018c; 2018d; 2018e; 2018f; 2018g; 2018h; 2018i; 2018j; 2018k; 2018l; 2018m; 2018n; Pourmahmoud, 2008; Rajasekaran et al., 2008; Shojaeefard et al., 2008; Taher et al., 2008; Tavallaei & Tousi, 2008; Theansuwan & Triratanasirichai, 2008; Zahedi et al., 2008; Zulkifli et al., 2008).

The Stewart's leg is used today in the majority of parallel robotic systems, such as the Stewart platform, but also in many other types of mechanisms and kinematic chains, in order to operate them or to transmit motion. A special character in the study of robots is the study of inverse kinematics, with the help of which the map of the motor kinematic parameters necessary to obtain the trajectories imposed on the effector can be made. For this reason, in the proposed mechanism, we will present reverse kinematic modeling in this paper.

The kinematic output parameters, ie the parameters of the foot and practically of the end effector, ie those of the point marked with T, will be determined for initiating the working algorithm with the help of logical functions, "If log(ical)", with the observation that here they play the role of input parameters; it is positioned as already specified in the inverse kinematics when the output is considered as input and the input as output. The logical functions used, as well as the entire calculation program used, were written in Math Cad 2000.

2. METHODS AND MATERIALS

The paper briefly studies the inverse kinematics of a foot mechanism (Figure 1), formed with the help of Stewart's foot.

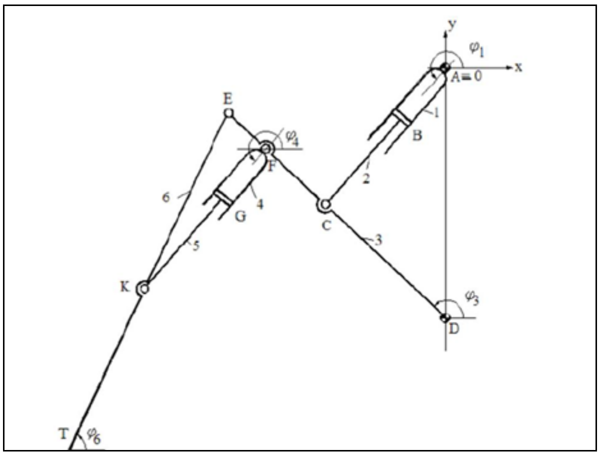

Figure 1: Kinematic scheme of the step mechanism

2.1. Trajectory of the extreme point t

In order to determine the trajectory necessary for the extreme point T, the end effector, which represents the point of contact between the foot and the ground, the logical functions (1-2) "If Log" are used, as follows, where k is the general variable considered:

XTk: = if (k <= 50, X0-c.k, X0- c.50) (1)

YTk: = if [k <= 50, Y0, Y0 + c. (K- 50)] (2)

3. RESULTS AND DISCUSSION

3.1. First, within the program used, in Mathcad 2000, the initial constants are established (3):

XD := 0 YD:= -0.4

TK := 0.7 DF:= 0.7 TE:= 0.8 DE:= 0.8 DC:= 0.3 (3)

Next is established the "TRACK OF THE EXTREME T POINT" (relation 4, Figure 2), where c represents the step:

X0:= -0.3 Y0:= -0.5

k:= 0..100

c:= 0.005

XT_k: = if (k <= 50, X0-c.k, X0- c.50)

YT_k: = if [k <= 50, Y0, Y0 + c. (K- 50)] (4)

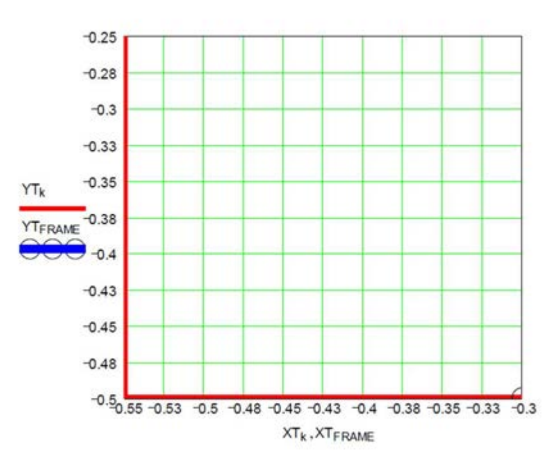

Figure 2: The coordinates of the point T, y as a function of x

3.2. Following are the kinematic calculations on the modular group "Dyad RRR (6,3)".

Write the initial values (5):

Φ60: = 45

Φ30: = 120 (5)

Convert to computer radians (6):

Φ6: = Φ60.π / 180

Φ3: = Φ30.π / 180 (6)

"Given, Solve and Find" are used to solve (8) the following nonlinear system (7), Figure 3.

Given

XT_k-XD+TE.cos(Φ6)-DE.cos(Φ3)=0 (7)

YT_k-YD+TE.sin(Φ6)-DE.sin(Φ3)=0

sol_k:=Find(Φ6,Φ3)

$$\begin{pmatrix} \phi6_k \\ \phi3_k \end{pmatrix} := sol_k$$
$$\begin{pmatrix} \phi60_k \\ \phi30_k \end{pmatrix} := \frac{180}{\pi} \cdot sol_k \qquad (8)$$

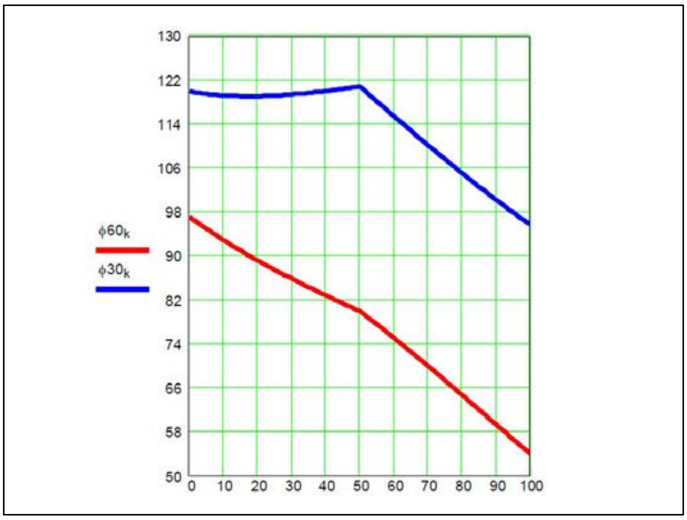

Figure 3: The angle Fi60 and Fi30 values as a function of k

Note: The general input variable k is generally written as a lower index in MathCad2000, while in MathCad 15 it is written as a variable (k) in a function between two small parentheses.

The assignment equal used so far consists of two signs ":" and "=", and can be entered from the corresponding toolbar, while the equal used in an equation is the Boolean "=".

The parameters of the K-coupling, of the C-coupling, and of the F-coupling can now be determined directly by assignment ":=" (9-11):

$$\begin{cases} XK_k := XT_k + TK \cdot \cos(\phi6_k) \\ YK_k := YT_k + TK \cdot \sin(\phi6_k) \end{cases} \qquad (9)$$

$$\begin{cases} XC_k := XD + DC \cdot \cos(\phi3_k) \\ YC_k := YD + DC \cdot \sin(\phi3_k) \end{cases} \qquad (10)$$

$$\begin{cases} XF_k := XD + DF \cdot \cos(\phi3_k) \\ YF_k := YD + DF \cdot \sin(\phi3_k) \end{cases} \qquad (11)$$

3.3. Following are the kinematic calculations on the modular group "Dyad RTR (1,2)".

Write the initial values (12), and the algorithm (13), with diagrams (Figure 4):

Φ10: = 210

Φ1: = Φ10.π / 180

AC:= 0.1 (12)

Given

$0-XC_k+AC.\cos(\Phi1)=0$

$0-YC_k+AC.\sin(\Phi1)=0$

$sol_k:=\text{Find}(AC,\Phi1)$

$$\begin{pmatrix} AC_k \\ \phi 1_k \end{pmatrix} := sol_k$$

$$\phi 10_k = \phi 1_k \cdot \frac{180}{\pi} \tag{13}$$

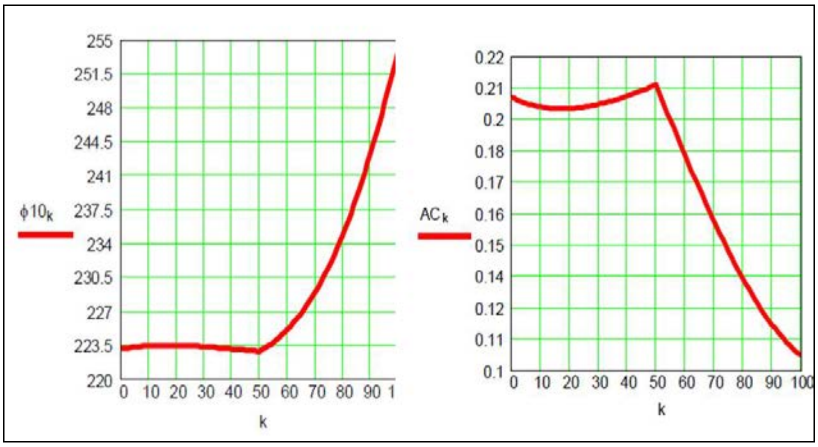

Figure 4: The angle Fi10 and AC values as a function of k

Repeat the procedure for determining the dyad (4,5).

3.4. Following are the kinematic calculations on the modular group "Dyad RTR (4,5)".

Write the initial values (14), and the algorithm (15), with diagrams (Figure 5):

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$\Phi40: = 210$

$\Phi4: = \Phi40.\pi / 180$

$FK:= 0.1$ (14)

Given

$XF_k - XK_k + FK.\cos(\Phi4)=0$

$YF_k - YK_k + FK.\sin(\Phi4)=0$

$sol_k:=Find(FK,\Phi4)$

$$\begin{pmatrix} FK_k \\ \phi4_k \end{pmatrix} := sol_k$$

$$\phi40_k = \phi4_k \cdot \frac{180}{\pi} \tag{15}$$

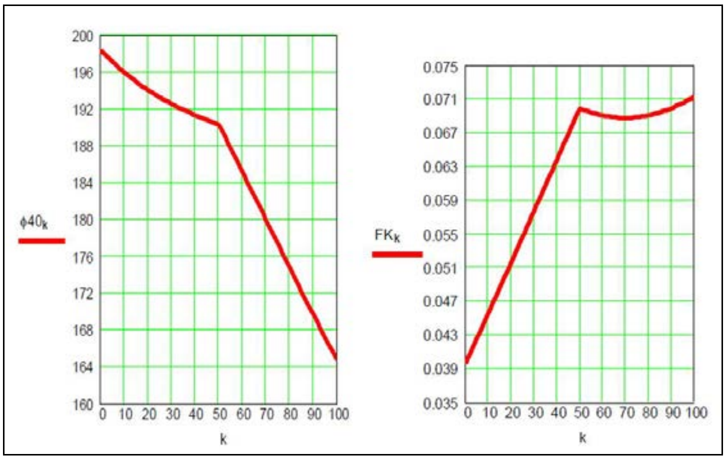

Figure 5: The angle Fi40 and FK values as a function of k

4. CONCLUSIONS

The parallel structure system that formed the basis of one of the most studied and well-known parallel robots is the Gough platform from 1947.

The main advantages of parallel robots: they have very high stability even in critical positions occupied even during high-speed movement, so that the objects handled by them are always safe; positioning accuracy is extremely high; at least two of the kinematic chains allow the distribution of the load on them; the number of actuators is minimal; the number of sensors required for closed-loop control of the machine is minimal; if the actuators are locked, the parallel robot remains in the position reached the moment when it was locked, i.e. it will become unbalanced, or fall, or drop the manipulated object, as can happen with serial robots.

In the case of parallel robots, drive systems with motors based on solid bodies (eg piezo-alloy motors with memory) can also be built. These motors cannot be used in the case of serial structures due to their low driving power. Passive torques of parallel structures contribute to the miniaturization of the system.

Due to the high rigidity of the parallel structures, the positioning accuracy, and repeatability increase. In parallel robots, the errors in the components and in the couplings do not accumulate as in the case of serial robots. Parallel structures have rather compensatory characteristics that are advantageous in micro-assembly and simplify the adjustment, command, and control system.

Due to the fact that the motors are positioned on the frame, they can be separated from the working space of the parallel structure. In this way, the power supply, power, and communication cables can be easily insulated.

In the paper is synthesized the inverse kinematics of a robot leg, which uses in its mechanical structure the Stewart leg mechanism.

Inverse kinematic modeling is generally the most sought after, as the most important, but in most situations, it is also the most difficult to determine. In the presented paper, the MathCad2000 software was used in order to facilitate the calculations, because the software automatically solves the linear and nonlinear systems through its internal procedures that must be called within the program.

As an important function, the "IfLog" logic function was used twice in the program to initiate the calculations, by determining the input variables in the inverse kinematics.

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b) 2-Contract research integration. 19-91-3 from 29.03.1991; Beneficiary: MIS; TOPIC: Research on designing mechanisms with bars, cams and gears, with application in industrial robots.

c) 3-Contract research. GR 69/10.05.2007: NURC in 2762; theme 8: Dynamic analysis of mechanisms and manipulators with bars and gears.

d) 4-Labor contract, no. 35/22.01.2013, the UPB, "Stand for reading performance parameters of kinematics and dynamic mechanisms, using inductive and incremental encoders, to a Mitsubishi Mechatronic System" "PN-II-IN-CI-2012-1-0389".

e) All these matters are copyrighted! Copyrights: 394-qodGnhhtej, from 17-02-2010 13:42:18; 463-vpstuCGsiy, from 20-03-2010 12:45:30; 631-sqfsgqvutm, from 24-05-2010 16:15:22; 933-CrDztEfqow, from 07-01-2011 13:37:52.

7. ETHICS

Authors should address any ethical issues that may arise after the publication of this manuscript.

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