Geometry and Inverse Kinematic at the MP3R Mobile Systems

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Abstract: The development and diversification of machines and mechanisms with applications in all fields require new scientific researches for the systematization and improvement of existing mechanical systems by creating new mechanisms adapted to modern requirements, which involve increasingly complex topological structures. The modern industry, the practice of designing and building machinery is increasingly based on the results of scientific and applied research. Each industrial achievement has backed theoretical and experimental computer-assisted research, which solves increasingly complex problems with advanced computing programs using an increasingly specialized software. The robotization of technological processes determines and influences the emergence of new industries, applications under special environmental conditions, the approach of new types of technological operations, manipulation of objects in the alien space, teleoperators in the top disciplines like medicine, robots covering a whole field greater service provision in our modern, computerized society. Movable, robotic, mechatronic mechanical systems have entered nearly all industrial spheres. Today, we can no longer conceive of industrial production without these extremely useful systems. They are still said to steal from people's jobs. Even so, it should be made clear that these systems create value, work in difficult, repetitive, non-pausing, high-quality work, without getting tired, without getting sick, without salary, and producing value who are paid and people left without jobs, so that they can work elsewhere in more pleasant, more advantageous conditions, with the necessary breaks. In other words, robots do not destroy people but help them in the process of work. Let us not remember the fact that in some environments people could not even work. In fact, the robot's profitability for work without stopping, repetitive, and qualitative, is no longer in question. In addition, there are many heavy operations that are absolutely necessary for the presence of robots. You can not create microchips with people directly without interposing the robot. Man can not directly work with objects of such small size. Neither difficult medical operations can be designed without robotic mechatronic systems. The most used robotic mechanical systems are the anthropomorphic ones in the class of serial systems. To this we have studied the direct kinematics in previous castings, and in this paper we are going to study the inverse kinematics.

Keywords: Mechanism, Robots, Mechatronics, Mechanical Systems
Introduction

The development and diversification of machines and mechanisms with applications in all fields require new scientific researches for the systematization and improvement of existing mechanical systems by creating new mechanisms adapted to modern requirements, which involve increasingly complex topological structures.

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The robotization of technological processes determines and influences the emergence of new industries, applications under special environmental conditions, the approach of new types of technological operations, manipulation of objects in the alien space, teleoperators in the top disciplines like medicine, robots covering a whole field greater service provision in our modern, computerized society. Movable, robotic, mechatronic mechanical systems have entered nearly all industrial spheres.

Today, we can no longer conceive of industrial production without these extremely useful systems. They are still said to steal from people's jobs. Even so, it should be made clear that these systems create value, work in difficult, repetitive, non-pausing, high-quality work, without getting tired, without getting sick, without salary, and producing value who are paid and people left without jobs, so that they can work elsewhere in more pleasant, more advantageous conditions, with the necessary breaks. In other words, robots do not destroy people but help them in the process of work.

Let us not remember the fact that in some environments people could not even work. In fact, the robot's profitability for work without stopping, repetitive, and qualitative, is no longer in question. In addition, there are many heavy operations that are absolutely necessary for the presence of robots. You can't create microchips with people directly without interposing the robot. Man can not directly work with objects of such small size. Neither difficult medical operations can be done without robotic mechatronic systems.

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As examples of such combined mechanisms, several kinematic schemes of gears and gears can be observed, presented by Kojevnikov (1969), Volm (AUTORENKOLLEKTIV, 1968), Şaskin (1963; 1971), Maros (1958), Rehwald and Luck (2000-2001), Antonescu (1993; 2003; Antonescu and Mitrache, 1989).

The main problems with plane and spatial gears and gears refer to kinematic analysis and geometric-kinematic synthesis under certain conditions imposed by technological processes, Bruja and Dima (2011), Buda and Mateucă (1989), Luck and Modler (1995), Niemeyer (2000), Tutunaru (1969), Popescu (1977), Braune (2000), Dutita et al. (1989), Lichtenheldt (1995), Lederer (1993), Lin (1999), Modler and Wadewitz (1998; 2001; Modler, 1979), Neumann (1979; 2001), Stoica (1977), Petrescu and Petrescu (2011c-d; Petrescu, 2012d-e); (Petrescu, 2016; 2017a-q; Aversa et al., 2017a-e; 2016a-o; Miresayar et al., 2017; Petrescu and Petrescu, 2016a-c; 2013a-d; 2012a-d; 2011a-b; Petrescu, 2012a-c; 2009; Petrescu and Calautit, 2016a-b; Petrescu et al., 2016a-b; Maros, 1958; Modler and Wadewitz, 2001; Manolescu et al., 1968; Margine, 1999).

Materials and Methods

Inverse kinematic manipulators and serial robots will be exemplified for the 3R cinematic model (Fig. 1). In the inverse kinematics, we already know the direct relation relations (1) and we have to determine the inverse relations, ie to determine the independent rotations $\phi_1$, $\phi_2$, $\phi_3$ of the three movable elements, depending on the kinematic parameters imposed to the enforcer $x_M$, $y_M$, $z_M$, known (given, imposed). With the determined independent angles, then the relative rotations corresponding to the movements of the three drive motors in the rotation couplers (drives of the actuators) will be located:

![Fig. 1. The geometry and kinematics of a MP3R](image-url)
\[
x_{u} = d_{1} \cos \phi_{0} + d_{2} \cos \phi_{0} \cdot \cos \phi_{b} - a_{1} \sin \phi_{0} + d_{1} \cos \phi_{0} \cdot \cos \phi_{b} - a_{1} \sin \phi_{b} \\
y_{u} = d_{1} \sin \phi_{0} + d_{2} \sin \phi_{0} \cdot \cos \phi_{b} + a_{2} \cos \phi_{0} + d_{1} \sin \phi_{0} + a_{2} \cos \phi_{b} \\
z_{u} = d_{1} \sin \phi_{0} + d_{1} \sin \phi_{b} + a_{1}
\]

(1)

The fixed coordinate system was denoted by \(O_{0}x_{0}y_{0}z_{0}\). The mobile systems (rigidized) of the three mobile elements (1, 2, 3) have indices 1, 2 and 3. Their orientation has been chosen conveniently.

The system (1) is a transcendental system of three equations (1.1-1.3) with three unknowns \((\phi_{0}, \phi_{b}, \phi_{a})\) to be determined; the equations of the system 1 are rearranged in the form that can be seen in the system (1'):

\[
x_{u} = d_{1} \cdot \cos \phi_{0} - a_{1} \cdot \sin \phi_{0} + d_{2} \cdot \cos \phi_{0} \cdot \cos \phi_{b} - a_{1} \cdot \sin \phi_{0} + d_{1} \cdot \cos \phi_{0} \cdot \cos \phi_{b} (1.1)
\]

\[
y_{u} = d_{1} \cdot \sin \phi_{0} + a_{2} \cdot \cos \phi_{0} + d_{2} \cdot \cos \phi_{0} \cdot \sin \phi_{b} + a_{2} \cdot \cos \phi_{0} + d_{1} \cdot \cos \phi_{b} \cdot \sin \phi_{b} (1.2)
\]

\[
z_{u} = a_{1} + d_{1} \cdot \sin \phi_{b} + d_{1} \cdot \sin \phi_{b} (1.3)
\]

(1')

It is desirable to solve the system (1') directly by obtaining independent exact solutions.

The first step is the multiplication of the equation (1.1) with \(-\sin \phi_{0}\) and of the relation (1.2) with \(\cos \phi_{0}\), after which the two resulting expressions are obtained by obtaining the trigonometric equation (2) which is solved with the solutions (3), i.e., for the first independent parameter \(\phi_{0}\) trigonometric functions of cosine and sine functions:

\[
-x_{u} \cdot \sin \phi_{0} + y_{u} \cdot \cos \phi_{0} = a_{1} + a_{1}
\]

(2)

\[
\cos \phi_{0} = \frac{(a_{1} + a_{1}) \cdot x_{u} \cdot y_{u} \pm \sqrt{x_{u}^{2} + y_{u}^{2} - (a_{1} + a_{1})^{2}}}{x_{u}^{2} + y_{u}^{2}}
\]

\[
\sin \phi_{0} = \frac{-(a_{1} + a_{1}) \cdot x_{u} \pm \sqrt{x_{u}^{2} + y_{u}^{2} - (a_{1} + a_{1})^{2}}}{x_{u}^{2} + y_{u}^{2}}
\]

(3)

When we want to get the value of an angle directly when we know sin and cos functions, we use the expression (4):

\[
\phi_{0} = \text{arcsin} (\sin \phi_{0}) \cdot \text{arccos} (\cos \phi_{0})
\]

(4)

The angle is given directly by the arctic function, and its sinus sign, which can be +1 or -1, sends the angle in its quadrant, in the top or bottom half circle.

At the next step we multiply equation (1.1) with \(\cos \phi_{0}\) and relation (1.2) with \(\sin \phi_{0}\), we add the obtained expressions and obtain the trigonometric equation (5):

\[
x_{u} \cdot \cos \phi_{0} + y_{u} \cdot \sin \phi_{0} - d_{1} = d_{1} \cdot \cos \phi_{b} + d_{1} \cdot \cos \phi_{b} (5)
\]

(5)

This together with relation (1.3) forms the system (6) generating the last independent parameters:

\[
x_{u} \cdot \cos \phi_{0} + y_{u} \cdot \sin \phi_{0} - d_{1} = d_{1} \cdot \cos \phi_{b} + d_{1} \cdot \cos \phi_{b} (5)
\]

\[
z_{u} - a_{1} = d_{1} \cdot \sin \phi_{b} + d_{1} \cdot \sin \phi_{b} (1.3)
\]

(6)

With the notations (7) we obtain for the equation system (6) the direct and exact solutions (8); equations (6) take shape (6 '):

\[
C_{1} = d_{1} \cdot \cos \phi_{0} + d_{1} \cdot \cos \phi_{0} (5')
\]

\[
C_{1} = d_{1} \cdot \sin \phi_{0} + d_{1} \cdot \sin \phi_{0} (1.3')
\]

(6')

The system (6 ') is written in the form (6' '):

\[
C_{1} = d_{1} \cdot \cos \phi_{0} = d_{1} \cdot \cos \phi_{0} (5')
\]

\[
C_{1} = d_{1} \cdot \sin \phi_{0} = d_{1} \cdot \sin \phi_{0} (1.3')
\]

(6' ')

Equations (6' ') rise to squares each and then add, yielding (6'' ) expression:

\[
K = 2 \cdot C_{1} \cdot d_{1} \cdot \cos \phi_{0} = 2 \cdot C_{2} \cdot d_{1} \cdot \sin \phi_{0}
\]

(6'' ')

The expression (6'' ') rises to the square and results in a second degree equation in \(\cos \phi_{0}\) which it generates the solutions for \(\cos \phi_{0}\) and for the sin changes the form of the equation (6'' ') the terms with sin and cos permeating each other so that after lifting the square expression of the equation to be in \(\sin \phi_{0}\) and thus generating the solutions for the sin function.

With the two sin and cos phrases it is possible to calculate exactly the value of the angle, which will be given by the arctic, and will take over the upper semicircle for a positive sinus, and the inferior half circle for a negative sinus sign.

The algorithm can be resumed for the angle \(\phi_{0}\) similarly, putting the system (6 '') corresponding (do the rocks \(\cos \phi_{0}\) with \(\cos \phi_{0}\) and \(\sin \phi_{0}\) with \(\sin \phi_{0}\);) follows the algorithm described above by picking up the square, etc...

To make sure that all solutions satisfy the system simultaneously, trigonometric \(\phi_{0}\) angle values are extracted directly from the system (6 ''). Their expression depends directly on the value of the angle calculated at
the previous step (\( \phi_0 \)), but all values surely satisfy the system from which they were deducted:

\[
\begin{aligned}
C_z &= x_{ia} \cdot \cos \phi_0 + y_{ia} \cdot \sin \phi_0 - d_i \\
C_y &= \dot{x}_{ia} \cdot \sin \phi_0 - \dot{y}_{ia} \cdot \cos \phi_0 + \dot{x}_{ia} \\
k &= C_{i1}^2 + C_{i2}^2 + d_i^2 - d_i^2 \\
\cos \phi_0 &= \frac{k \cdot C_i \pm C_i \sqrt{4 \cdot C_{i1}^2 \cdot d_i^2 - 4 \cdot C_{i2}^2 \cdot d_i^2 - k^2}}{2 \cdot (C_{i1}^2 + C_{i2}^2) \cdot d_i} \\
\sin \phi_0 &= \frac{k \cdot C_{i2} + C_i \sqrt{4 \cdot C_{i1}^2 \cdot d_i^2 - 4 \cdot C_{i2}^2 \cdot d_i^2 - k^2}}{2 \cdot (C_{i1}^2 + C_{i2}^2) \cdot d_i} \\
\phi_0 &= \text{semn} (\sin \phi_0) \cdot \arccos (\cos \phi_0) \\
\cos \phi_0 &= \frac{C_i - d_i \cdot \cos \phi_0}{d_i} \\
\sin \phi_0 &= \frac{C_i - d_i \cdot \sin \phi_0}{d_i} \\
\phi_0 &= \text{semn} (\sin \phi_0) \cdot \arccos (\cos \phi_0)
\end{aligned}
\]

(7)

We multiply the first relationship of the system (12) with \( \cos \phi_0 \) and the second one with \( \sin \phi_0 \), after which we collect the resulting relations and get the expression (13):

\[
\begin{aligned}
\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0 - d_i \cdot \sin \phi_0 \cdot \omega_0 &= -d_i \cdot \sin \phi_0 \cdot \cos \phi_0 \cdot \omega_0 \\
\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0 - d_i \cdot \sin \phi_0 \cdot \omega_0 &= 0
\end{aligned}
\]

(13)

The relationship (13) is written in the form (14):

\[
\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0 - d_i \cdot \sin \phi_0 \cdot \omega_0 = 0
\]

(14)

The relationship (14) is in the form (15):

\[
\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0 - d_i \cdot \sin \phi_0 \cdot \omega_0 = 0
\]

(15)

From (15) we explain the angular velocity of the second actuator, and we get the relation (16):

\[
\omega_0 = \frac{\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0}{d_i \cdot \sin (\phi_0 - \phi_0)}
\]

(16)

Then we multiply the first relation of the system (12) with \( \cos \phi_0 \) and the second one with \( \sin \phi_0 \), after which we collect the resulting relations and get the expression (17):

\[
\begin{aligned}
\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0 + d_i \cdot \sin \phi_0 \cdot \cos \phi_0 \cdot \omega_0 &= -d_i \cdot \sin \phi_0 \cdot \cos \phi_0 \cdot \omega_0 \\
\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0 - d_i \cdot \sin \phi_0 \cdot \omega_0 &= 0
\end{aligned}
\]

(17)

The relationship (17) is written in the form (18):

\[
\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0 = d_i \cdot \sin (\phi_0 - \phi_0) \cdot \omega_0
\]

(18)

From (18) we explain the angular velocity of the last actuator, and we get the relation (19):

\[
\omega_0 = \frac{\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0}{d_i \cdot \sin (\phi_0 - \phi_0)}
\]

(19)

The angular speeds of the three actuators will be further explained in the system (20):
\[
\begin{align*}
\omega_3 &= \dot{x}_y \cdot \cos \phi_0 - \dot{x}_y \cdot \sin \phi_0 \\
\omega_2 &= \dot{x}_y \cdot \cos \phi_0 + \dot{y}_y \cdot \sin \phi_0 \\
\omega_1 &= \frac{\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0}{d_1 \cdot \sin(\phi_0 - \phi_0)} \\
\omega_0 &= \frac{\dot{C}_1 \cdot \cos \phi_0 + \dot{C}_2 \cdot \sin \phi_0}{d_1 \cdot \sin(\phi_0 - \phi_0)}
\end{align*}
\] (20)

Several parameters must be calculated for their determination.

With relation (21) we note the variable parameter \( C_1 \):

\[
C_1 = \dot{x}_y \cdot \cos \phi_0 + \dot{y}_y \cdot \sin \phi_0 - d_i
\] (21)

We derive (21) and get \( \dot{C}_1 \) (relationship 22):

\[
\dot{C}_1 = \dot{x}_y \cdot \cos \phi_0 - \dot{x}_y \cdot \sin \phi_0 \cdot \omega_0 + \dot{y}_y \cdot \sin \phi_0 + \dot{y}_y \cdot \cos \phi_0 \cdot \omega_0
\] (22)

Variable \( C_2 \) is the simpler expression (23):

\[
C_2 = \dot{z}_y - a_i
\] (23)

The relation (23) is derived and obtained for \( \dot{C}_2 \) expression (24):

\[
\dot{C}_2 = \ddot{z}_y
\] (24)

Discussion

The development and diversification of machines and mechanisms with applications in all fields require new scientific researches for the systematization and improvement of existing mechanical systems by creating new mechanisms adapted to modern requirements, which involve increasingly complex topological structures.

The modern industry, the practice of designing and building machinery is increasingly based on the results of scientific and applied research.

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Conclusion

The inverse kinematics is the one that corresponds to the daily reality in which the robots are programmed to work in order to perform certain operations, to observe some imposed trajectories so that they move precisely to achieve and achieve the desired trajectory and all necessary kinematic parameters.

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