Abstract: Mechatronic robotic systems are today widely used worldwide to ease human work, but especially where work is dangerous, in toxic, radioactive, chemical, explosive atmospheres, without air such as underwater or in the cosmos, or in places hard to reach the man. Robots can take the tedious repetitive work under any circumstances and they can perform a difficult operation for a long time, with no meal or rest breaks. They say the robots have stolen people's jobs. False! Robots have taken from man only those difficult jobs that baptized man and destroyed him. Robots have been created just as a prolongation of man as his real support in the faster, constantly accomplishing of difficult, repetitive, physically and mentally tired work and operations. Robots have emerged many years ago as a requirement of the automotive industry and especially that of road vehicles, especially automobiles. Meanwhile, they have diversified and branched a great deal in almost all industrial spheres. But the most important future of robots must be completely different. They have to help us conquer the cosmic space. The robot must become an extension of man in his divine mission of constructor and conqueror of the universe. Of all the types of industrial robots you use, the most common are the anthropomorphic serial robots, which is why we want to start studying and presenting the robots, with that generally common in robots, anthropomorphic serial systems. The kinematics of serial manipulators and robots will be exemplified for the 3R cinematic model to a medium difficulty system, ideal for understanding the actual phenomenon, but also for explaining the basic knowledge needed for calculating calculations and simpler or more complex systems. The fixed coordinate system was denoted by $x_0y_0z_0$. The mobile systems (rigid) of the three mobile elements (1, 2, 3) have indices 1, 2 and 3. Their orientation was conveniently chosen but other orientations could be chosen. Known kinematic parameters in the direct kinematics are the absolute rotation angles of the three moving elements: $\phi_{10}$, $\phi_{20}$, $\phi_{30}$, angles related to the rotation of the three actuators (electric motors) mounted in the kinematic rotation couplers. The output parameters are the three absolute coordinates $x_M$, $y_M$, $z_M$ of point M, ie the kinematic parameters (coordinates) of the end-effector (the actuator element (the final), which can be a grasping hand, a solder tip, painted, cut, etc ...).

Keywords: Cinematic of the MP-3R Systems, Geometry, Kinematic Parameters

Introduction

Mechatronic robotic systems are today widely used worldwide to ease human work, but especially where work is dangerous, in toxic, radioactive, chemical, explosive atmospheres, without air such as underwater or in the cosmos, or in places hard to reach the man.
Robots can take the tedious repetitive work under any circumstances and they can perform a difficult operation for a long time, with no meal or rest breaks. They say the robots have stolen people’s jobs. False! Robots have taken from man only those difficult jobs that baptized man and destroyed him. Robots have been created just as a prolongation of man as his real support in the faster, constantly accomplishing of difficult, repetitive, physically and mentally tired work and operations. Robots have emerged many years ago as a requirement of the automotive industry and especially that of road vehicles, especially automobiles. Meanwhile, they have diversified and branched a great deal in almost all industrial spheres. But the most important future of robots must be for a long time, with no meal or rest breaks. They say the circumstances and they can perform a difficult operation.

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Materials and Methods

The kinematics of serial manipulators and robots will be exemplified for the 3R cinematic model (Figure 1), a medium difficulty system, ideal for understanding the actual phenomenon, but also for explaining the basic knowledge needed for calculating calculations and simpler or more complex systems.

The fixed coordinate system was denoted by \( x_0O_0y_0\z_0 \). The mobile systems (rigid) of the three mobile elements (1, 2, 3) have indices 1, 2 and 3. Their orientation was conveniently chosen but other orientations could be chosen. Known kinematic parameters in the direct kinematics are the absolute rotation angles of the three moving elements: \( \phi_{10}, \phi_{20}, \phi_{30} \), angles related to the rotation of the three actuators (electric motors) mounted in the kinematic rotation couplers. The output parameters are the three absolute coordinates \( x_{10}, y_{10}, z_{10} \) of point \( M \), i.e., the kinematic parameters (coordinates) of the end-effector (the actuator element (the final), which can be a grasping hand, a solder tip, painted, cut, etc...).

To begin with, write the vector matrix \( (A_{01}) \) to change the coordinates of the origin of the coordinate system by translating from \( O_0 \) to \( O_1 \), the axes remain parallel to themselves at all times (1):

\[
A_{01} = \begin{bmatrix}
0 \\
0 \\
a_0 \\
\end{bmatrix}
\]

Next, write the \( T_{01} \) rotation matrix of the system \( x_1O_1y_1z_1 \) to the system \( x_0O_0y_0\z_0 \) (this is a square matrix \( 3 \times 3 \), (2):

\[
T_{01} = \begin{bmatrix}
\alpha_x & \beta_x & \gamma_x \\
\alpha_y & \beta_y & \gamma_y \\
\alpha_z & \beta_z & \gamma_z \\
\end{bmatrix} = \begin{bmatrix}
\cos \phi_0 & -\sin \phi_0 & 0 \\
\sin \phi_0 & \cos \phi_0 & 0 \\
0 & 0 & 1 \\
\end{bmatrix}
\]

On the first column (belonging to the coordinates of \( O_{1X_1} \)) the coordinates of the \( O_{1X_1} \) unit vector the axes of the old system \( x_0O_0y_0\z_0 \) are passed; it is practically the projections of the \( O_{1X_1} \) unit vector on the axes of the old \( x_0O_0y_0\z_0 \) coordinate system translated into \( O_1 \) (not rotated, thus only the actual rotation without translation) occurs (3):

\[
\begin{bmatrix}
\alpha_x \\
\alpha_y \\
\alpha_z \\
\end{bmatrix}
\]

On the second column of the \( T_{01} \) matrix, the coordinates of the \( O_{1Y_1} \) axis unit vector the axes of the old \( x_0O_0y_0\z_0 \) system are translated into \( O_1 \) without rotation (basically the coordinates of this unit vector the old translational but non-rotating reference axes), (4):

\[
\begin{bmatrix}
\beta_x \\
\beta_y \\
\beta_z \\
\end{bmatrix}
\]

On the third column of the \( T_{01} \) matrix, the coordinates of the \( O_{1Z_1} \) axis unit vector the axes of the old \( x_0O_0y_0\z_0 \) system are translated into \( O_1 \) without rotation (basically the coordinates of this unit vector the old referenced but non-routed reference axes), (5):

\[
\begin{bmatrix}
\gamma_x \\
\gamma_y \\
\gamma_z \\
\end{bmatrix}
\]

In the chosen case, the unit vector of \( O_{1X_1} \) (the unit vector always has module (1) has the following coordinates compared to the old axle system \( x_0O_0y_0\z_0 \) translated into \( O_1 \) without rotation (6):
\[ \begin{align*}
\alpha_x &= 1 \cdot \cos \phi_1 = \cos \phi_1 \\
\alpha_y &= 1 \cdot \sin \phi_1 = \sin \phi_1 \\
\alpha_z &= 1 \cdot \cos 90^\circ = 1 \cdot 0 = 0
\end{align*} \] (6)

\[ A_{12} = \begin{bmatrix} d_1 \\ a_1 \\ 0 \end{bmatrix} \] (9)

On the old \( O_1x_1 \) axis, \( O_2 \) was translated with \( d_1 \), \( O_1y_1 \), \( O_2 \) was translated with \( a_2 \) and \( O_2z_1 \) was not translated.

\( O_2x_2 \)'s unit vector, the \( x_1O_1y_1z_1 \) system (translated, but not rotated) coordinates (10):

\[ \alpha = 1; \quad \gamma_2 = 0; \quad \alpha_z = 0 \] (10)

\( O_2y_2 \)'s unit vector has in relation to the \( x_1O_1y_1z_1 \) system translated into \( O_2 \) (not rotated) the coordinates (11):

\[ \beta_x = 0; \quad \beta_y = 0; \quad \beta_z = 1 \] (11)

Because now \( O_2y_2 \), was taken the new \( O_2z_2 \) axis:

The \( O_2z_2 \) unit vector has, in relation to the \( x_1O_1y_1z_1 \) system, translated into \( O_2 \) (not rotated) the coordinates (12):

\[ \gamma_x = 0; \quad \gamma_y = -1; \quad \gamma_z = 0 \] (12)

Since the \( O_2z_2 \) axis took the place of the \( O_1y_1 \) axis, it was of the opposite direction.

The square of the transfer (rotation) is written (13):

\[ T_{12} = \begin{bmatrix} \alpha_x & \beta_x & \gamma_x \\ \alpha_y & \beta_y & \gamma_y \\ \alpha_z & \beta_z & \gamma_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \] (13)

Fig. 1: The geometry and cinematic of a MP-3R
The transition from the $x_3O_3y_3z_3$ system to the $x_2O_2y_2z_2$ coordinate system is also done in two distinct stages, one translation and one rotation.

$O_2$ translates into $O_3$ (the axes are kept parallel to themselves), (14):

$$A_{32} = \begin{bmatrix} d_x \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} \\ -a_z \end{bmatrix}$$

(14)

Then $O_3$ stands and the axes rotate. The unit vector of $O_3x_3$ has, in relation to the axes system $x_2O_2y_2z_2$, translated in $O_3$ (unrotated) the coordinates $\alpha$ (15):

$$\alpha_x = 1; \alpha_y = 0; \alpha_z = 0$$

(15)

$O_3y_3$’s unit vector the $x_2O_2y_2z_2$ axis system is translated into $O_3$ (without to be rotated) coordinates $\beta$ (16):

$$\beta_x = 0; \beta_y = 1; \beta_z = 0$$

(16)

$O_3z_3$’s unit vector the $x_2O_2y_2z_2$ axis system translated into $O_3$ (not rotated) coordinates $\gamma$ (17):

$$\gamma_x = 0; \gamma_y = 0; \gamma_z = 1$$

(17)

Practically, the $x_3O_3y_3z_3$ did not turn at all at all against the $x_2O_2y_2z_2$ system (from 2 to 3 only a translation took place). The matrix of rotation in this case is the unit matrix (18):

$$T_{32} = \begin{bmatrix} \alpha_x & \beta_x & \gamma_x \\ \alpha_y & \beta_y & \gamma_y \\ \alpha_z & \beta_z & \gamma_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

(18)

The vector matrix (column) that positions the $M$ point in the $x_3O_3y_3z_3$ coordinate system is written (19):

$$X_{3M} = \begin{bmatrix} x_{3M} \\ y_{3M} \\ z_{3M} \end{bmatrix} = \begin{bmatrix} d_x \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} \\ 0 \end{bmatrix}$$

(19)

The coordinates of the point $M$ in the system (2) $x_2O_2y_2z_2$ (i.e., towards it) are obtained by a matrix transformation of the form (20):

$$X_{2M} = A_{32} + T_{32} \cdot X_{3M}$$

(20)

Perform the matrix product first (21):

$$T_{32} \cdot X_{3M} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} d_x \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} \\ 0 \end{bmatrix} = \begin{bmatrix} d_x \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} \\ 0 \end{bmatrix}$$

(21)

The coordinates of the $M$ point in (against) the system (1) $x_1O_1y_1z_1$ are obtained as follows (23-25):

$$X_{1M} = A_{21} + T_{12} \cdot X_{2M}$$

(23)

$$T_{12} \cdot X_{2M} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} d_x \cdot \cos \phi_{30} + d_y \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} + d_y \cdot \sin \phi_{30} \\ a_z \end{bmatrix} = \begin{bmatrix} d_x \cdot \cos \phi_{30} + d_y \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} + d_y \cdot \sin \phi_{30} \\ a_z \end{bmatrix}$$

(24)

$$X_{1M} = A_{21} + T_{12} \cdot X_{2M} = \begin{bmatrix} d_x \cdot \cos \phi_{30} + d_y \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} + d_y \cdot \sin \phi_{30} \\ a_z + a_3 \end{bmatrix}$$

(25)

The coordinates of point $M$ in the fixed system $x_0O_0y_0z_0$ are written (26-28):

$$X_{0M} = A_{10} + T_{10} \cdot X_{1M}$$

(26)

$$T_{10} \cdot X_{1M} = \begin{bmatrix} d_x \cdot \sin \phi_{30} + d_y \cdot \cos \phi_{30} & 0 & a_3 + a_5 \\ -d_x \cdot \cos \phi_{30} + d_y \cdot \sin \phi_{30} & 0 & a_3 + a_5 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} d_x \cdot \cos \phi_{30} + d_y \cdot \cos \phi_{30} \\ d_x \cdot \sin \phi_{30} + d_y \cdot \sin \phi_{30} \\ a_z \end{bmatrix}$$

(27a)

$$T_{10} \cdot X_{1M} = \begin{bmatrix} d_x \cdot \sin \phi_{30} + d_y \cdot \cos \phi_{30} \\ -d_x \cdot \cos \phi_{30} + d_y \cdot \sin \phi_{30} \\ 0 \end{bmatrix} \begin{bmatrix} a_3 + a_5 \\ a_3 + a_5 \\ 1 \end{bmatrix}$$

(27b)
\[
X_{\text{MM}} = A_0 + T_{01} \cdot X_{\text{IM}}
\]

\[
= \begin{bmatrix}
(d_1 + d_2 + \cos \phi_{30} + d_1 \cdot \cos \phi_{30}) \\
\cdot \cos \phi_{30} - (a_1 + a_1) \cdot \sin \phi_{30} \\
\cdot \sin \phi_{30} + (a_1 + a_1) \cdot \cos \phi_{30} \\
\end{bmatrix} + \begin{bmatrix}
d_1 \cdot \cos \phi_{30} + a_1 \cdot \cos \phi_{30} \\
\cdot \sin \phi_{30} + d_1 \cdot \sin \phi_{30} \\
\end{bmatrix}
\]

\[
X_{0M} \text{ takes the form of (29):}
\]

\[
X_{\text{MM}} = \begin{bmatrix}
x_M \\
y_M \\
z_M
\end{bmatrix} = \begin{bmatrix}
d_1 \cdot \cos \phi_{30} - a_1 \cdot \sin \phi_{30} + d_1 \cdot \cos \phi_{30} \cdot \cos \phi_{30} \\
\cdot \cos \phi_{30} - (a_1 + a_1) \cdot \sin \phi_{30} \\
\cdot \sin \phi_{30} + (a_1 + a_1) \cdot \cos \phi_{30} \\
a_1 \cdot \cos \phi_{30} + d_1 \cdot \sin \phi_{30}
\end{bmatrix}
\]

\[
T_{0i} \cdot T_{12} = \begin{bmatrix}
\cos \phi_{30} & 0 & 0 \\
\sin \phi_{30} & \cos \phi_{30} & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

\[
T_{0i} \cdot T_{12} \cdot T_{23} = \begin{bmatrix}
\cos \phi_{30} & 0 & 0 \\
\sin \phi_{30} & 0 & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

\[
\text{Results}
\]

The same calculations will be further pursued by a direct method, taking into account the matrix calculations (30a):

\[
X_{\text{MM}} = A_0 + T_{01} \cdot X_{\text{IM}} = A_0 + T_{01} \cdot (A_2 + T_{12} \cdot X_{\text{MM}}) =
\]

\[
= A_0 + T_{01} \cdot A_2 + T_{01} \cdot T_{12} \cdot X_{\text{MM}} =
\]

\[
= A_0 + T_{01} \cdot A_2 + T_{01} \cdot T_{12} \cdot (A_2 + T_{12} \cdot X_{\text{MM}}) =
\]

\[
= A_0 + T_{01} \cdot A_2 + T_{01} \cdot T_{12} \cdot A_2 + T_{01} \cdot T_{12} \cdot T_{23} \cdot X_{\text{MM}}
\]

The relationship is retained (30b):

\[
X_{\text{MM}} = A_0 + T_{01} \cdot A_2 + T_{01} \cdot T_{12} \cdot A_2 + T_{01} \cdot T_{12} \cdot T_{23} \cdot X_{\text{MM}}
\]

Perform matrix products in the expression (30') while remaining in the form of a matrix amount (31-36):

\[
T_{01} \cdot A_2 = \begin{bmatrix}
\cos \phi_{30} & -\sin \phi_{30} & 0 \\
\sin \phi_{30} & \cos \phi_{30} & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
d_1 \\
a_1 \\
0
\end{bmatrix}
\]

\[
= \begin{bmatrix}
d_1 \cdot \cos \phi_{30} - a_1 \cdot \sin \phi_{30} \\
\cdot \sin \phi_{30} + d_1 \cdot \sin \phi_{30} \\
\end{bmatrix}
\]

\[
X_{\text{MM}} \text{ of the point } M \text{ (the end effector) according to}
\]

\[
19
\]
the three independent angular displacements $\varphi_{10}$, $\varphi_{20}$, $\varphi_{30}$, obtained with actuators (37-38).

\[
\begin{align*}
  x_M &= f_x(\varphi_{10}, \varphi_{20}, \varphi_{30}) \\
  y_M &= f_y(\varphi_{10}, \varphi_{20}, \varphi_{30}) \\
  z_M &= f_z(\varphi_{10}, \varphi_{20}, \varphi_{30})
\end{align*}
\] (37)

\[
\begin{align*}
  x_M &= d_1 \cdot \cos \varphi_{10} - a_2 \cdot \sin \varphi_{10} + d_2 \cdot \cos \varphi_{20} \cdot \cos \varphi_{30} \\
  y_M &= d_1 \cdot \sin \varphi_{10} + d_2 \cdot \cos \varphi_{20} \cdot \cos \varphi_{30} \\
  z_M &= a_1 + d_2 \cdot \sin \varphi_{30} + d_1 \cdot \sin \varphi_{10}
\end{align*}
\] (38)

The calculations are made with absolute angular displacements, but actuator displacements do not all coincide with the independent ones. They are thus determined (39):

\[
\begin{align*}
  \varphi_{10} &= \varphi_{10} \\
  \varphi_{20} &= \varphi_{20} \\
  \varphi_{30} &= \varphi_{30} - \varphi_{20}
\end{align*}
\] (39)

The first two relative rotations of the actuators coincide with the independent rotation (used in the calculations), but the third relative rotation of the last actuator is obtained as a difference between two absolute rotations.

Speeds and accelerations are obtained by deriving relationships (38) over time.

**Conclusion**

The work presents an analytical method for determination of cinematic parameters in a 3R robotics module.

An exact algebraic, matrix, calculation method is presented.

Direct kinematics obtains the Cartesian coordinates $x_M, y_M, z_M$ of the point $M$ (the end effector) according to the three independent angular displacements $\varphi_{10}$, $\varphi_{20}$, $\varphi_{30}$, obtained with actuators (37-38).

The calculations are made with absolute angular displacements, but actuator displacements do not all coincide with the independent ones. They are thus determined (39).

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**Author’s Contributions**

This section should state the contributions made by each author in the preparation, development and publication of this manuscript.

**Ethics**

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

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