VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
BRNO UNIVERSITY OF TECHNOLOGY

FAKULTA STROJNÍHO INŽENÝRSTVÍ
FACULTY OF MECHANICAL ENGINEERING

ÚSTAV AUTOMATIZACE A INFORMATIKY
INSTITUTE OF AUTOMATION AND COMPUTER SCIENCE

SEMINAR PAPER	INTRODUCTION TO ROBOT & KINEMATICS
AUTHOR NAME	Vojtěch Dražka
LECTOR	Ing. Roman Parák

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DESCRIPTION

The goal of this paper was to introduce industrial robots to the reader and layout basic approach on the problem of their kinematics

KEY WORDS

Robots, Cartesian Robots, SCARA, Kinematics

WHY ROBOTS?

This thesis is mainly focused on construction of industrial robot and what it takes to drive it. But we might ask ourselves what is event the purpose of robots. Why would we need one? Isn't it just some kind of unnecessarily complicated and overpriced peace of technology, which can be replaced with much cheaper and more simple solutions? Answer to this question is „Well yes, but no.".

As in any other professional field, in automation we are looking for the simplest solution possible while considering its pros and cons, including price. In light of these principles it may not be easy to decide, weather to use an industrial robot or not. There are too many factors to take into the equation and even then the solution might not be entirely clear.

Generally speaking we use robots as an alternative for human labor or other machines. Robots are capable of operating 24/7 with high precision, have no problem with precise repeating of ergonomically challenging motion and can operate in dangerous environment. Robots are also highly versatile and can be programmed for various applications. [1]

These and more advantages of industrial robots leads us to use robots more and more, which worries some people, as robots are slowly replacing humans in ways that we would not think of 40 years ago [3]. With the implementation of machine vision robots are now capable of orienting itself and making complex decisions and adapting to its environment.

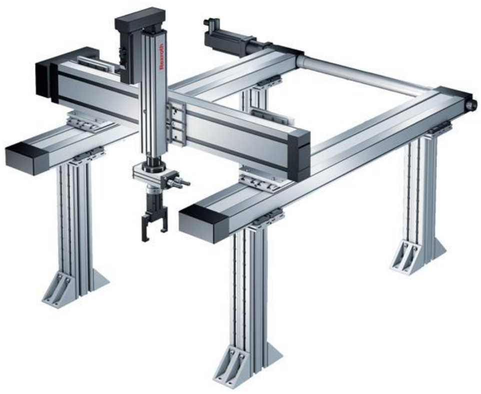
The conclusion from this chapter is, that there is no guideline which can tell us when to use or not to use an industrial robot. But it is clear, that robots are now popular more then ever and that they are being implemented in more and more fields, where automation is needed.

ROBOT TYPES

From the view of construction we can divide robots into several basic categories: [4]

1) Cartesian Robots

These robots have usually at least 3 linear axis and are often used for heavy and precise applications. As mentioned, cartesian robots have 3 linear axis, each rotated by 90° respectively to each other. Often they are equipped with another additional axis for rotational motion. This type of robot is basically the principle of modern 3D printers. Cartesian robot is in picture ***Pic.001***:



Pic.001 – Cartesian Robot [5]

2) SCARA Robots

SCARA (Selective Compliance Assembly Robot Arm) is a multi-arm type of robot. These robots are known for their speed and precision while being relatively small. That is a big advantage and that is why are these robots very popular. A SCARA robot is in picture ***Pic.002***:

Pic.002 – SCARA Robot by Fanuc [6]

3) Dual-Arm Robots

Dual-arm (***Pic.003***) robots are quick and effective, when applied for the right task. They are mainly used for assembly applications in electrotechnical industry.

Pic. 003 – Dual-Arm Robot by ABB [7]

4) Delta robots

These robots resemble to spider. They are made of several (usually 3 for 3 axis) parallelograms connected in the base. This allows robot to function with high precision and high speed. They are suitable for packaging applications. You might also encounter them in pharmaceutical or food industry. Such a robot is in picture ***Pic.004.***

Pic. 004 – Delta Robot by ABB [8]

5) Six-axis robot

Probably the most common type of robot would be the Six-axis robot. They are being made in various sizes for different loads and applications. They might by pricy, but the investment will pay-off in a long term due to minimal operational expanses (as with any robot). As the name suggests, these robots have six axis by default (3 for translation, 3 for rotation) and usually one or more axis are added for the purpose of application. These added axis are usually pneumatical, such as pneumatical grippers or vacuum suction cups. Robot is pictured in ***Pic.005:***

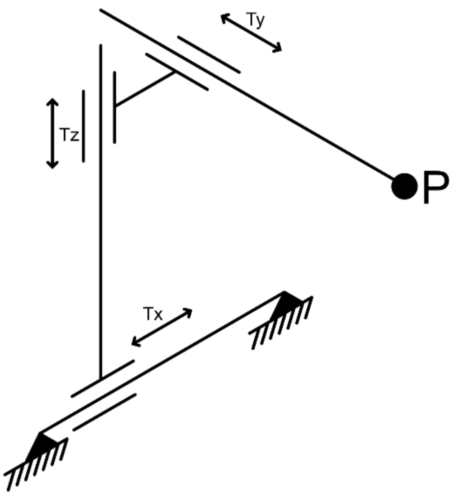
Pic. 005 – Six-axes Robot by Kuka [9]

KINEMATICS

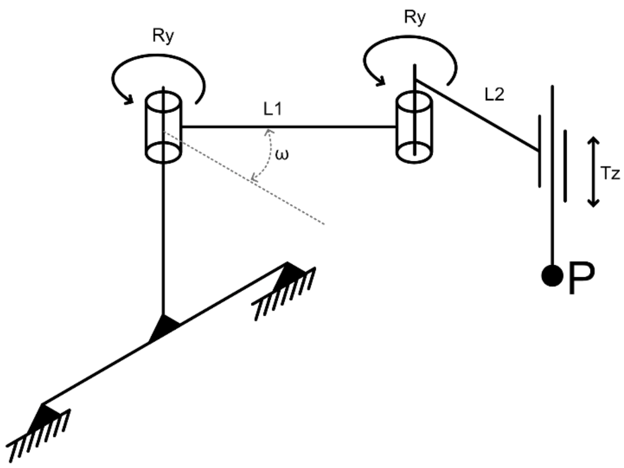
Let’s talk kinematics. There are basically two ways of approach – *Forward Kinematics* and *Inverted Kinematics.* [10] The *Forward Kinematics* approach sets the problem of finding the coordinates of end-effector. The input is position and orientation (rotation) of robot’s joints. The goal of *Inverse Kinematics* on the other hand is to find the position and orientation, when given coordinates of end-effector as an input. Let us see, how we can approach both of these problems on two examples of robot: Cartesian Robot (referred as C Robot from here on) and SCARA Robot (referred as S Robot from here on).

Forward Kinematics

First of all let’s draw a simple scheme of both robots. These schemes are on ***Pic.006*** and ***Pic.007:***



Pic. 006 – Cartesian Robot



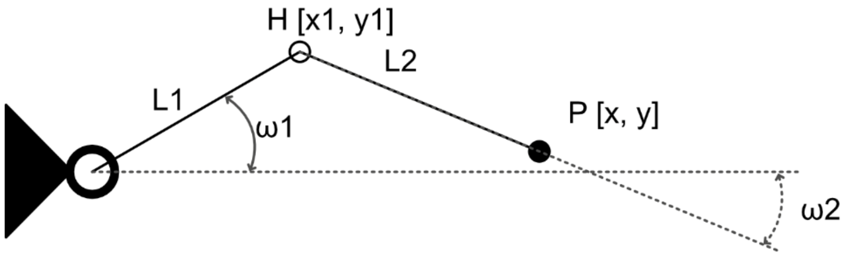
Pic.007 – SCARA Robot

Let’s deal with the simple one first – the C Robot has 3 linear axes. To find the position of end-effector P is very simple. Coordinates of point P corresponds to translations Tx, Ty and Tz made by each axis. Therefor we can write this in matrix, which represents the position of point P as show in equation ***Eq(1):***

$$P = \begin{pmatrix} Tx \\ Ty \\ Tz \end{pmatrix}$$

Eq(1) – Position of point P of C robot

Now let’s have a look on the S Robot from picture 007. Here we can see, that this robot has one linear axis, but also two rotational axis. With elementary knowledge of trigonometry, we should be able to write equations for finding the coordinates of point P. We are going to simplify the scheme on picture 007 and label everything we need to know to get our final position of point P. The simplified scheme is in picture ***Pic.008*** on next page.



Pic.008 – Scheme of S Robot

We now know the length of each arm and also the orientation (rotation) of each joint. There is also a new point H, which will help us during the construction of equations of position of point P. From the scheme, it is evident what coordinates the point H has, hence the following equation for coordinates of point H (*Eq(2)*):

$$x1 = L1 * \cos(\boldsymbol{\omega 1})\,; y1 = L1 * \sin\,(\boldsymbol{\omega 1})$$

Eq(2) – Coordinates of point H

Now that we have defined the position of point H, we will do the same for point P. If we would to construct the equation the same way, it would look quite the same, but instead of x1, L1 and ω1 we would write x2, L2 and ω2. Then we would add these two equations together and get the final equation of position of point P, accordingly to equation Eq(3):

$$x = L1 * \cos(\omega 1) + L2 * \cos(\omega 1 + \omega 2)\,; \mathrm{y} = \ L1 * \sin(\omega 1) + L2 * \sin(\omega 1 + \omega 2)$$

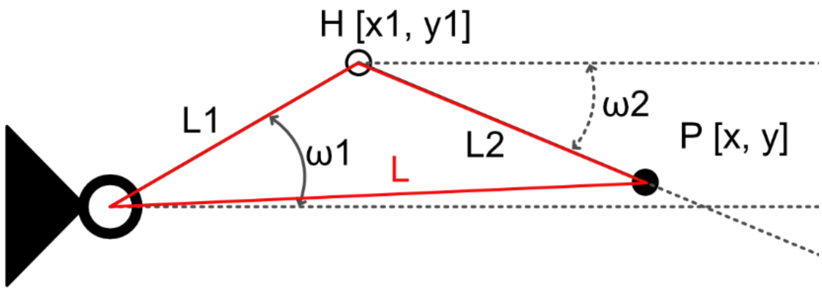
Eq(3) – Coordinates of point P

Next we would say, that the *x = Tx* and that the *y = Ty*. Because There is only one axis left and this axis is linear, as in previous example of C Robot, we can say that *Tz* is the position of linear translation of z-axis. Therefor we may now write the equation for position of end-effector of S Robot in the same form as Eq(1).

INVERSE KINEMATICS

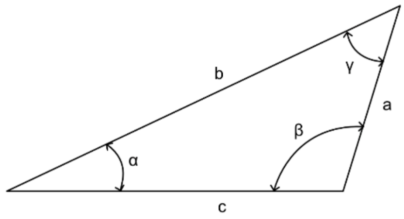
For the C Robot it would be the same thing as in *Forward Kinematics* because the position of point P corresponds to the linear translation of each axis. So we can immediately write the equation Eq(1).

As for the S Robot, lets adjust the scheme from picture 008 and highlight the triangle, that the arms of robot create (***Pic.009)***. It is trangle with sides of length L1, L2 and L. To calculate the orientation of joints ω1 and ω2, we will need to calculate the angles of our triangle first.



Pic.009 – Edited Scheme

To calculate the angles of triangle with knowledge only of length of its sides, we will use the *Law of Cosines:*



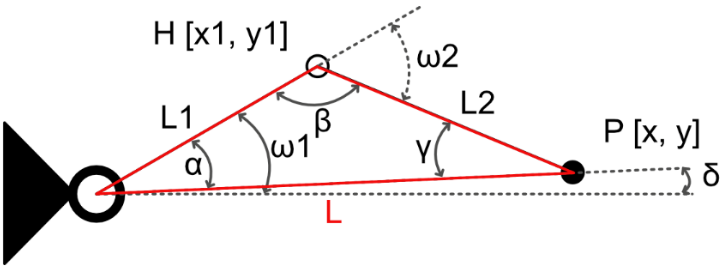
Pic.010 – Law of Cosines

The Law of Cosines allows us to calculate each angle by following equations:

$$c^2 = \; a^2 + \; b^2 - 2ab * \cos{(\gamma)}$$

Eq(4) – Law of Cosines

Length of both arms L1 and L2 are known to us. With help of Pythagoras theorem we can also find L, which is the distance from [0; 0] to [x; y]. $L = \sqrt{x^2 + y^2}$.



Pic.011 – Edited scheme

In ***Pic.011*** we can see labeled angles, which will help us to find ω1 and ω2. We can see from the picture, that $\omega 1 = \delta + \; \alpha$ and that $\omega 2 = 180° - \; \beta$. First, we will use the law of cosines on our triangle to compute the angles α and β:

$$L^2 = L_1^2 + \; L_2^2 - 2 * L_1 * L_2 * \cos(\beta) => \cos(\beta) = \frac{L_1^2 + \; L_2^2 - \; L^2}{2 * L_1 * L_2}$$

$$L_2^2 = L^2 + L_1^2 + 2 * L * L_1^2 * \cos{(\alpha)} => \cos(\alpha) = \frac{L^2 + \; L_1^2 - L_2^2}{2 * L * L_1}$$

From Pythagoras theorem we can also easily find the angle $\cos(\delta) = \frac{x}{L} = \frac{x}{\sqrt{x^2+y^2}}$.

Now we have everything we need to calculate the rotation of both joints. This calculation displays equation Eq(5):

$$\omega 1 = \delta + \; \alpha = \arccos\left(\frac{x}{\sqrt{x^2 + y^2}}\right) + arcos(\frac{\sqrt{x^2 + y^2}^2 + \; L_1^2 - L_2^2}{2 * \sqrt{x^2 + y^2} * L_1})$$

$$\omega 2 = 180° - \; \beta = 180° - \arccos(\frac{L_1^2 + \; L_2^2 - \; \sqrt{x^2 + y^2}^2}{2 * L_1 * L_2})$$

Eq(5) – Calculation of joints rotation

CONCLUSION

This paper contains meditation on why we use industrial robots and then short description of 5 basic types of industrial robots (in terms of their construction). This paper next focuses on the problem of kinematics of robots – *forward and inverse kinematics* and shows how we can approach this problem practically, which I demonstrated on two robots mentioned in previous chapter. My goal was also to talk a bit about main principles of robot's construction and how to drive it. Unfortunately, that would make this paper longer than it should be.

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