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Kinematic Analysis of Humanoid Robot Hand

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Abstract The paper deals with kinematic analysis of humanoid robot hand. The first of all the biological aspects of humanoid hand are discussed. Then the kinematic configuration of humanoid robot hand with 23 DOF is designed. This configuration should be able to do operations like grasping, holding or squeezing. In the paper the direct kinematic model is established using homogeneous transformation matrices. Consequently the workspace of particular finger can be obtain by suitable plotting algorithm in Matlab.

Keywords: *hand, humanoid, kinematics, robot*

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1. Introduction

The researches and designers have last few decades tried to create mechanisms which are inspired by the nature. There are a lot of applications and tasks which cannot be performed by conventional mechanisms like wheeled-based mechanism for example because of unavailability of environment. Pipes and channels can be detected by mechanism which by snake is inspired, namely snake-like robot or inchworm robot. For very rough environments can be used legged-based mechanism.

In category of nature inspired mechanisms do not have to be mechanisms which are dedicated only for industrial work or special task in companies. These mechanisms in form of mechatronic products are very useful in medicine as well. The people who lost their limbs can be very thankful for solutions which yields suitable designed and developed mechatronic products like artificial limb which can reacts on the environmental stimuli. One of this product can be "humanoid hand" which by human hand is inspired. [1,6]

2. Biomechanics of Human Hand

One of the approaches to robot designs is design of so-called biomechanic robotic mechanisms. This approach on the knowledge of biologic organisms and their motion abilities is based. In the case of industrial robotics it concerns especially robotic arms, which by their functions and shapes suggest human arm. From the view of gripping the basic part of robotic arm is its end-effector. To suitable design of humanoid hand the biomechanics of human hand has to be investigated.

As can be from the Figure 1 seen, human hand consists of three basic parts, namely phalanges, metacarpus and wrist [2,3]. The phalange part consists of fourteen bones, metacarpus part consists of five bones and wrist consists of eight bones what gives 27 bones together. By this structure, human hand can performs three basic gripping tasks, namely grasping, holding and squeezing. These gripping tasks in the Figure 2 can be seen.

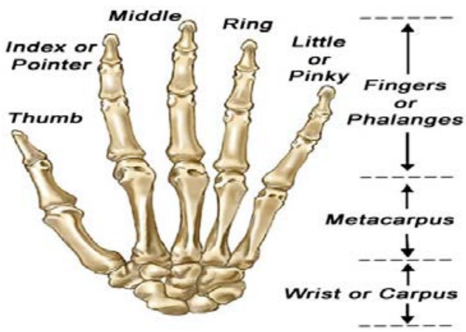

Figure 1. Human hand skeleton

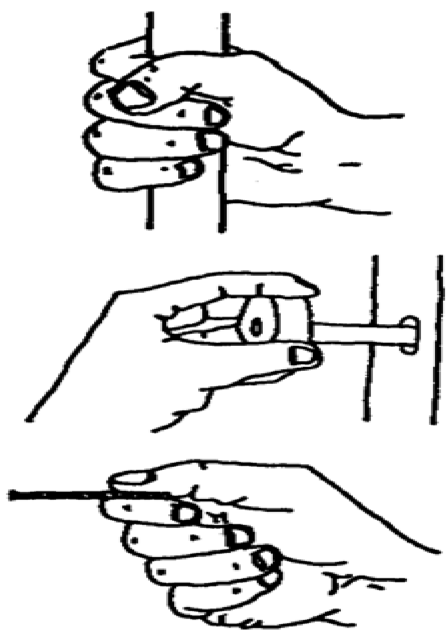

Figure 2. Gripping tasks – grasping, holding, squeezing

By gripping user can reaches high precision and stability. Holding belongs to soft gripping task, which is accurate and stable. Mobility of fingers allows soft gripping and soft contact to the object. The precision and stability of squeezing increase by involvement of other parts of hand.

3. Kinematic Model of Humanoid Hand

The kinematic model of humanoid hand by means of homogeneous transformation matrices will be derived [4]. For kinematic analysis the structure with 23 degrees of freedom is used, see Figure 3.

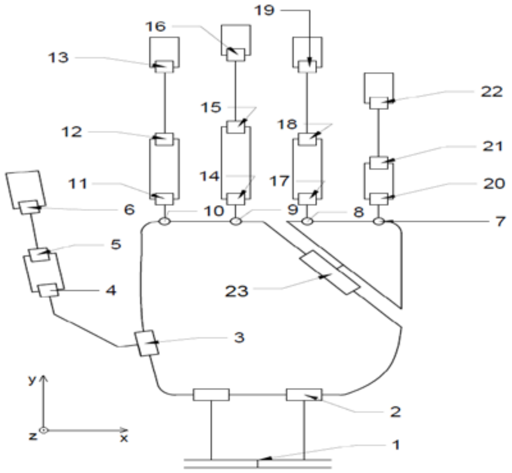

Figure 3. Kinematic configuration of humanoid hand

Rotation of particular joints in the Table 1 are shown.

Table. 1 Rotation of particular joints

Number of joint	Angle [°]	Number of joint	Angle [°]
1	120	12	100
2	120	13	80
3	30	14	90
4	35	15	100
5	90	16	80
6	90	17	90
7	30	18	100
8	30	19	80
9	30	20	90
10	30	21	100
11	90	22	80

3.1. Direct Kinematic Model of Humanoid Robot Hand

For deriving of kinematic model of humanoid robot hand the homogeneous transformation matrices are used. By direct kinematic model we can find the position of end-effector what in our case is end of the fingers. Next, by direct kinematic model we can find the workspace of particular fingers, what is a range of its motion in the space.

In the Figure 4 the coordinates systems of humanoid hand are shown. For final homogeneous transformation matrix there are used basic matrices for rotational motion of coordinate systems

$$\mathbf{R}_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi & 0 \\ 0 & \sin\phi & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$\mathbf{R}_y = \begin{bmatrix} \cos\varphi & 0 & \sin\varphi & 0 \\ 0 & 1 & 0 & 0 \\ \sin\varphi & 0 & \cos\varphi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$\mathbf{R}_z = \begin{bmatrix} \cos\vartheta & -\sin\vartheta & 0 & 0 \\ \sin\vartheta & \cos\vartheta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

For linear motion matrix (4) is used:

$$\mathbf{T}_0^1 = \begin{bmatrix} 1 & 0 & 0 & l_x \\ 0 & 1 & 0 & l_y \\ 0 & 0 & 1 & l_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

By using of basic mentioned matrices we can obtain final homogeneous transformation matrix, which determines final position of particular finger. For example for pointer finger the final matrix is

$$\mathbf{A}_0^{12} = \mathbf{T}_0^1 \mathbf{R}_x \mathbf{T}_2^3 \mathbf{R}_z \mathbf{T}_5^6 \mathbf{R}_x \mathbf{T}_9^{10} \mathbf{R}_x \mathbf{T}_{11}^{12} \quad (5)$$

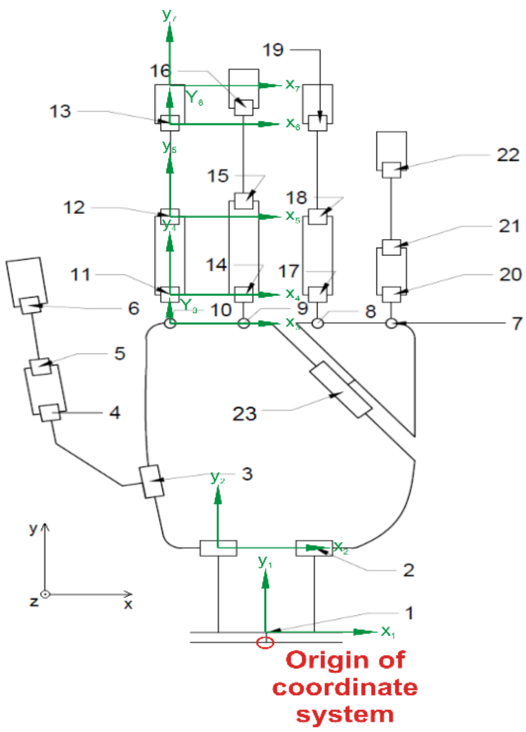

Figure 4. Coordinate systems of humanoid robot hand

Some rotation matrices contain linear motion as well in order to decrease the number of final transformation matrix elements. For determination of finger workspace the key is transition from coordinate system 0 into the end of the finger. [5] Determination of final transformation matrix is relatively simple task and by suitable software can be done.

Using Matlab the term (5) can be calculated. The first three elements of matrix (5) in third column are coordinates (x, y, z) of particular finger end.

4. Workspace of Particular Fingers

The workspace determines the space where the end-effector of mechanism can reach. In our case the end-effector is end of the arbitrary finger of hand. By determination of finger workspace it can be shown where the finger has impact.

The algorithm for workspace plotting in Matlab was done. By increasing angles of particular humanoid hand joints one obtain following figures. By reduction of angle step we can obtain denser map.

The workspace shown in Figure 5 is only theoretical workspace and it has some limitations because of geometrical aspect of humanoid robot hand.

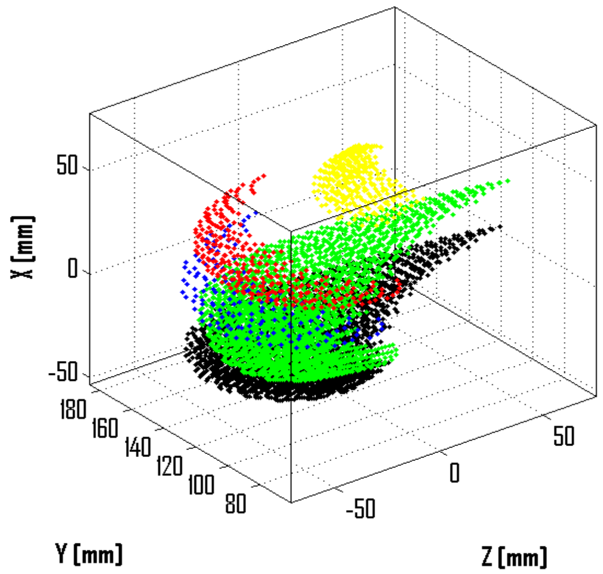

Figure 5. Workspace of particular fingers

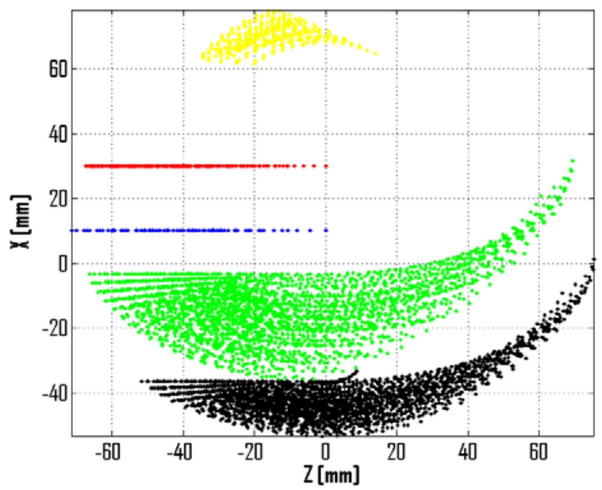

Figure 6. Workspace of particular fingers X-Z

For simulation there were used sizes of biological hand. For simulation was assumed with zero change of the joints marked as 1, 2, 6, 10, 9 and 8. By increasing joint angle 23 the little finger and ring finger move in the plane XY (green and black color).

For particular robot hand tasks like grasping, holding or squeezing should be the inverse kinematics determined and trajectory planning as well. Determination of inverse kinematic model is significantly more difficult in comparison with direct kinematic model.

4.1. CAD Model of Humanoid Robot Hand

After kinematic analysis the 3D model of humanoid hand can be done. For this task the software SolidWorks was used. In the CAD model we did not assume actuators. The CAD model serves us only for better imagination and for observation of possible motions and operations with hand. In the Figure 7 the 3D model of humanoid robot hand is shown. CAD model is designed according the kinematic configuration of Figure 4.

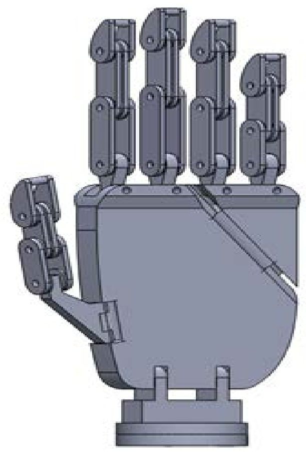

Figure 7. 3D model of humanoid robot hand

The kinematic configuration of hand allows almost the same motions of particular fingers as human hand. Several samples of possible robot hand motions in the Figure 8 are shown.

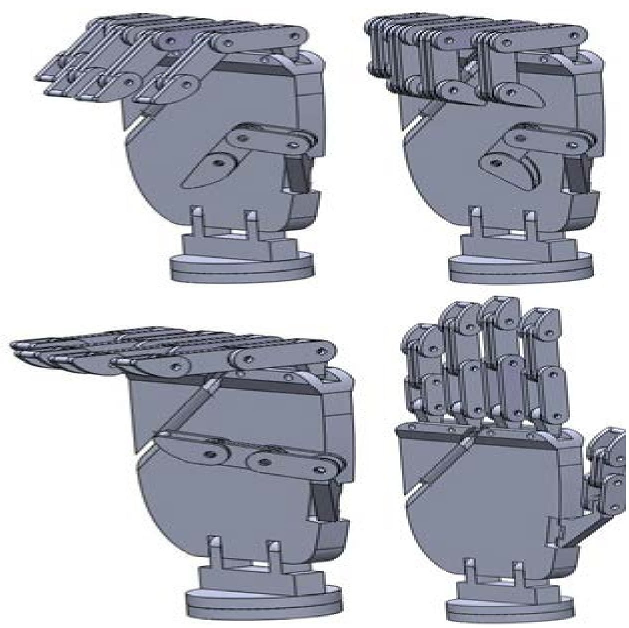

Figure 8. Motion possibilities of designed humanoid robot hand

By means of designed kinematic configuration the hand can for example hold the bottle or credit card, see Figure 9. Mentioned CAD model can servers only for kinematic analysis and visuals purposes.

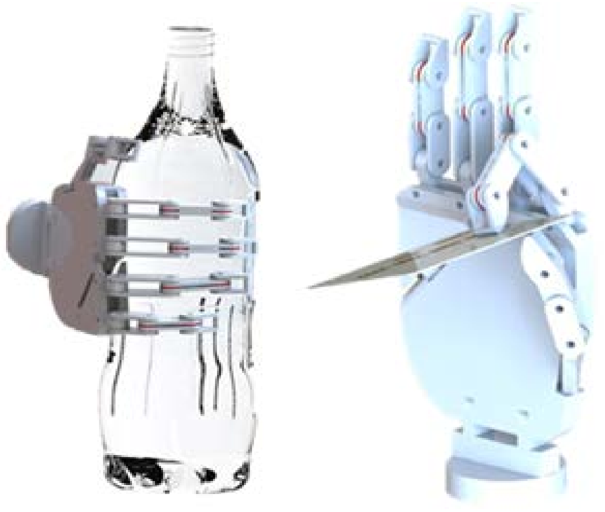

Figure 9. Holding of object

5. Conclusion

Kinematic model of humanoid robot hand presents one of the first steps for engineering design. By direct kinematic model can be obtained the position and orientation of particular fingers. Assuming the full range of motion of fingers we can plot the workspace of fingers what by final transformation matrix is available. By analyzing of workspace the designer can reconsider the suitability of kinematic configuration from the view of ability to perform required operations. In the study the CAD model was designed as well. However, this model can be used only for visualization of possible motions of particular fingers.

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