# MATERIAL HANDLING AND ROBOTS. WORKSPACE OF A SPECIFIC KINEMATICS CHAIN

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**Abstract.** In automated manufacturing systems, material handling is done, very often, using structures as robotic arms/manipulators. Design of these manufacturing systems is done either by a team that may not include robotics specialists or in a very short period of time. Present paper is describing the steps that a manufacturing systems designer should follow to choose a robotic arm/ manipulator and the software oriented on generating the workspace of a particular kinematic structure, with certain dimensions. The software is part of a toolbox for robots, made by the author of this paper, toolbox for Matlab programming environment and simulation.

**Keywords:** material handling, robotic arm, manipulator, workspace, Matlab

## 1. Material handling equipment

Manufacturing facilities design and material handling affect the productivity and profitability of a company more than almost any other major decision. Manufacturing facilities design is the organisation of the company's physical facilities to promote the efficient use of resources such as equipment, material, energy and people. Facilities design includes plant location and building design, plant layout and material handling [1].

Material handling is the function of moving the right material to right place, at the right time, in the right amount, in sequence, and in the right position or condition to minimize production costs. Material handling is a sum of five distinct dimensions as shown in figure 1.

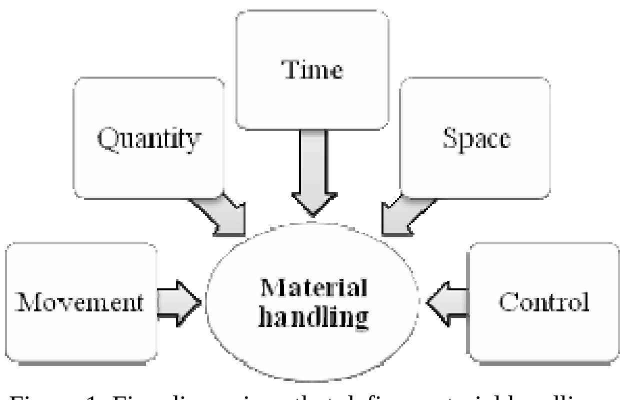


Figure 1. Five dimensions that define material handling

Movement involves the actual transportation or transfer of material from one point to the next. Quantity per move dictates type and nature of the material handling equipment and also the cost per unit for the conveyance of the goods. Time dimension determines how quickly the material can move through the facility. Space aspect of the material handling depends on the required space for storage of the material handling equipment and its movement, as well as the queuing or staging space for the material itself. The tracking of the material, positive identification and inventory management are some aspects of the control dimension [1].

Material can be manually or automatically removed, one at a time or by the thousands, it can be placed in a fixed location or at random one and it can be stored on the floor or in a high position in the warehouse. A material handling equipment list will include over 500 different types (classifications) of equipments, and if this number is multiplied by the different models, size and brand names will result several thousand pieces of equipment.

According to the literature [1], material handling equipment has been grouped into four general categories: fixed-path/ point-to-point; fixed-area; variable-path, variable area; auxiliary tools and equipments. Material handling systems (MHS) are also classified on three levels [2]:

*level 1* (MHS brings raw materials and deliver finished goods to and from the boundary of the facility),

*level 2* (MHS brings raw materials and completed parts and subassemblies between departments), and

*level 3* (MHS moves parts and components between workstations and individual machines – point-to-point movement).

## 2. Robots in MHS

The present paper is focused on level 3 MHS, the equipments that serves to handle a workstation. In this classification can be included the manipulators and robots.

Manipulators are specially designed to perform lifting, rotating, turning and positioning tasks. Whether manual, hydraulic, pneumatic or electric, manipulators can be installed on either a stationary or a portable base and can be utilized to perform a variety of tasks to enhance worker productivity and safety. The manipulators are often used in warehouse or machine-tools feeding or packaging applications.

On the other hand, robots can be used to perform also a variety of tasks, including loading and unloading, painting, welding and a vast array of material handling tasks.

When in the MHS are used robots, choosing one structure is a very important task that can directly influence the cost of MHS. It is said that it should be chosen a kinematic structure that has the right number of joints to be able to avoid redundancy that generates higher cost, complexity and more advanced knowledge.

In finding the right robot there should be chosen some parameters [3]: kinematic chain; driving type; number of axis; load capacity or payload; reach or work envelope is the maximum distance that a robot can extend an arm to perform a task; movement along/ around the axes; application type; mounting place of the robot.

In the above parameters list, among the first features to be chosen is the type and number of joints, and the workspace and operating area of the robot.

This is the main reason why the author of this paper decided to develop a toolbox for Matlab programming and simulation environment. This toolbox allows the user to determine, based on direct and inverse kinematics, the end point of the gripper, the resulting workspace for a given kinematic chain, etc. Also, toolbox is used in the analysis of robot dynamics.

## 3 Kinematic chain and workspace

Robots can have two kinematic chains, depending on type and number of joints and relative position of these axes. Thus: *position kinematic chain* (main chain) – contains not more than three joints (rotary or sliding, normal or parallel); *orientation kinematic chain* (subordinate chain).

The overall scale of the task sets the required workspace of the manipulator. In some cases, the details of the shape of the workspace and the location of workspace singularities will be important considerations. The intrusion of the manipulator itself in the workspace can sometimes be a factor. Depending on the kinematic design, operating a robot in a given application could require more or less space around the fixtures in order to avoid collisions. Restricted environments can affect the choice of kinematic configuration [4].

When a manipulator has less than 6 DOFs, it cannot attain general goal positions and orientations in 3D. In many realistic situations, manipulators with four or five degrees of freedom are employed that operate out of a plane, but that clearly cannot reach general goals. Each such manipulator must be studied to understand its workspace. In general, the workspace of such a robot is a subset of a subspace that can be associated with any particular robot.

Workspace also depends on the tool-frame transformation, because it is usually the tool-tip that is discussed when it is considered the reachable points in space. Generally, the tool transformation is performed independently of the manipulator kinematics and inverse kinematics, so often it is led to consider the workspace of the wrist frame.

A robot is designed so that specifying the values of local joint parameters, such as the angle of rotary joints and the travel of sliding joints, specifies the position of every component of a machine using its kinematics equations. To do this the robot is described by a sequence of lines representing the axes $\hat{z}_j$ of equivalent revolute or sliding joints and the common normal lines $\hat{x}_j$ which form the kinematic skeleton of the chain. This construction allows the specification of the location of each link of the robot relative to the base by the matrix equation.

## 4. Robotic toolbox. Workspace

The robotic toolbox developed by the author is oriented on Matlab programming and simulation environment. The interface is created also in Matlab, based on GUI toolbox [5].

The main idea for this toolbox is to offer the right tool (both for specialists and non-specialist) in choosing and computing the characteristic parameters of a manipulator/ robot. Thus, there were written functions that describe static, kinematic and dynamic aspects regarding a manipulator/ robot.

In this stage, the toolbox is developed only of open-loop kinematic chains, but it can be extended.

Determining the workspace of a robot means to compute, based on homogenous operators, the volume described by the end-effector. The toolbox allows the user to see, for a chosen structure, the workspace of the manipulator/ robot.

The *workspace* function uses one general function, called *rotation*. This function includes both rotational (cosines matrix) and sliding movements ($x_{Tx}$, $y_{Ty}$ and $z_{Tz}$) between one coordinate system to another. Thus, this function implements the sliding movement (equation 1):

$$Tr = \left(\begin{array}{ccc|c} \alpha_1 & \alpha_2 & \alpha_3 & x_{T_x} \\ \beta_1 & \beta_2 & \beta_3 & y_{T_y} \\ \gamma_1 & \gamma_2 & \gamma_3 & z_{T_z} \\ \hline 0 & 0 & 0 & 1 \end{array}\right) \qquad (1)$$

The *rotation* function can be particularised by changing the three parameters that characterised it: rotation axis, rotation angle and starting homogeneous coordinates of the rotating frame origin.

The toolbox is created as an interactive filter that allows the user to choose the desired structure of the robot: number and type of joint and relative position between these.

To exemplify the results obtained let us consider two examples of robot structures (SCARA and articulated). Thus, consider SCARA robot with the kinematic chain shown in figure 2.

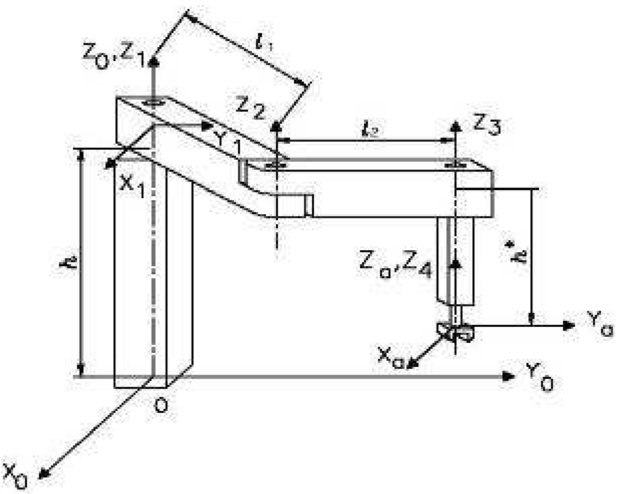


Figure 2. SCARA manipulator

The kinematic parameters of the structure were considered: $q_1 \in [-110^o, 110^o]$, $q_2 \in [-150^o, 150^o]$, $q_3 \in [0, 0.15]$, $L_1 = 0.35$, $L_2 = 0.25$, $H = 0.36$. The robot is a R || R || T type.

On the interface *MinJP* and *MaxJP* parameters define the minimum and maximum values of the joint parameter (angle, for rotational joint or displacement, for linear joint). These parameters define the movement interval of each joint. The *Relative position* area allows the user to define the relative position between two consecutive joints and has two options: *parallel* and *normal*. The *Link length* signifies the dimension of the link that connects two consecutive joints (in figure 2 the length are $l_1$, $l_2$ and $h$).

The steps that should be followed in obtaining the workspace are: insert the number of joints (*NoJ*) and *Confirm NoJ*. In this moment will be activated only the parameters for a set of joints equally with the introduced number of joints. After all the parameters are introduced (chosen the type of joints – *Rotation /Translation*, variation interval of joint parameters and the length of the link), push the button *Generate workspace* (figure 3).

The workspace of the SCARA structure is shown in figure 4.


Figure 3. Data interface for SCARA structure

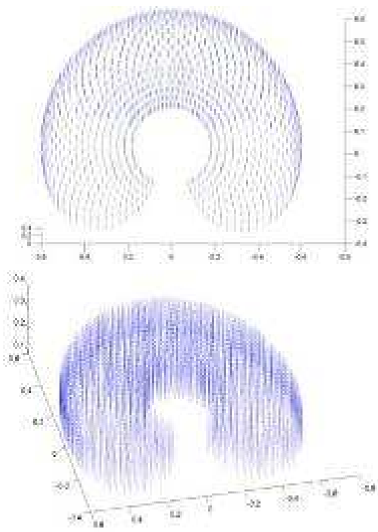

Figure 4. SCARA *workspace*

The second example is an articulated robotic arm with the structure from figure 5.

The kinematic parameters of the structure are: $q_1 \in [-90^o, 90^o]$, $q_2 \in [0^o, 180^o]$, $q_3 \in [-65^o, 90^o]$, $q_4 \in [-90^o, 90^o]$, $q_5 \in [-90^o, 90^o]$, $L_1 = 55$; $L_2 = 120$; $L_3 = 120$; $L_4 = 50$. The robot is a R⊥R||R||R⊥R type.

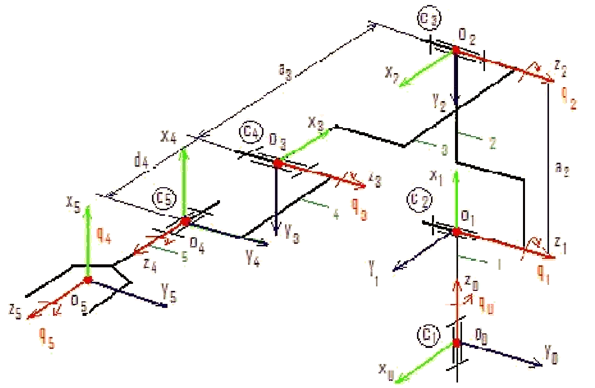

Figure 5. Articulated robot

The interface of *Workspace_Toolbox* for the articulated structure is shown in figure 6.

Figure 6. Data interface for articulated structure

The *workspace* of this structure is shown in figure 7.

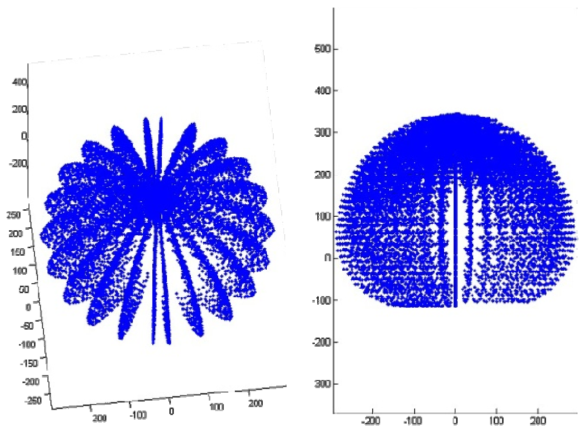

Figure 7. Articulated robot *workspace*

## 5. Conclusion

In an automated system, it is a real challenge to make a coherent whole, compound from different systems, optimally designed or chosen. This whole should not be redundant because this characteristic always causes an increase of costs.

*Workspace_Toolbox* information product is just one component of a more complex toolbox, *RMH (RobotsMaterialHandling)* developed by the author of this paper as component for Matlab. Toolbox is made for robotic structures used for material handling.

It is impossible to achieve complete software for robotic structures mainly due to the complexity of kinematic structures, dynamic control elements or material handling individual cases that have multiple solutions.

The *Workspace_toolbox* is recommended to be used in pre-design step, where it should be compare the desired workspace with the available or attainable one.

The results obtained with the software were validated, especially for the two examples presented in the paper, by existing robots.

## References


1. Stephens, M.P., Meyers, F.E. (2009) *Manufacturing facilities design and material handling*. Prentice Hall, ISBN 978-013-500-105-9, New Jersey, USA
2. Garcia-Diaz, A., MacGregor, S.J. (2008) *Facilities planning and design*. Pearson Hall, ISBN 978-0-13-235043-3, New Jersey, USA
3. *** *GlobalSpec*. The Engineering Search Engine, Available from: www.globalspec.com/, Accessed: 10/08/2011
4. Craig, J.J. (2005) *Introduction to robotics. Mechanics and control*. Prentice Hall, ISBN 0-13-123629-6, New Jersey, USA
5. Hahn, B. (2002) *Essential MATLAB for scientists and engineering*. Elsevier Publishing House, ISBN 978-0-7506-5240, Oxford, United Kingdom