

## Aspects concerning the modular development of a robotic system used in waste sorting

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**Abstract.** The paper presents the possible outcomes of a robotic system composed of three different robots, (Cartesian, cylindrical and spherical robot) that work in the same cell. Alongside the various combination possibilities that are determined, the mathematical model is also presented in the form of transformation matrices of the given robots. The CAD models of specific versions and block diagram of the robotic system are also presented.

### 1. Introduction

Waste management includes different types of activities such as: collecting, sorting, treating and storing all types of waste. The main focus of waste management is to reduce the consumption of natural resources, providing disposal and recycling solutions for every residence, company and institute and develops safe methods of eliminating harmful substances that can cause pollution and damage the health of the population and of the Earth [1].

In recent years companies around the world are facing serious backlash when it comes to the amount of waste that is being poorly handled. The government is aware of how serious the issue of pollution is and that neglecting to sort and reuse our waste can have a negative impact on the environment. One efficient and preferred method of managing waste is through recycling. Recycling is more beneficial due to the fact that it can reduce the amount of waste thrown in the environment and can reduce the consumption of natural resources which are limited. The types of waste that can be recycled varies from plastic bottles, glass, aluminium cans to wooden object and many more [2].

Scientists have determined the harmful effects that improper handling of waste can cause such as polluting the air we breathe, the ocean, our streets and cities with foul-smelling residue. Not only is this dangerous to humans but to animals as well, intoxicating even the ones that we use for consumption.

All of these negative aspects can be reduced and prevented by implementing a reliable, easy to use system. The purpose of the paper is to determine the different topological versions of the robot system used in waste management that can be formed using three different robots. Also, the transformation matrices are presented along with the virtual models for a few versions.

The paper is structured in the following manner; a short presentation of the current state of waste management followed by the topology of the robotic system along with the mathematical model and simulations of the robotic structure.



## 2. Current state of waste management

Multiple systems have been developed in order to make recycling a more efficient and dependable method of reducing the amount of waste that we have today. In most cases, recycling centers rely on human operators to go through the waste at the beginning of the sorting operation and pick out the large and visible pieces of cardboard. The second step of the sorting process involves sorting with the help of mechanical systems. Such systems include the single-stream recycling system and multi-stream recycling system which are based on machine equipment that can sort copious amounts of waste and place them in separate bins, each marked for the specific type of waste that have been sorted. The machine equipment includes: optical sorters, separators, OCC screens and so on [3].

Other sorting methods include more technological advanced mechanism such as: robotic arm with a gripper as the end effector, used to pick up the material and transport it to the correct bin. An image processing software is being used, the software operates with the help of image processing technology to identify the type of the waste on the conveyor belt.

A requirement of the system is realising a continuous and relatively fast workflow that can guarantee efficient sorting. This paper presents a robotic system that consist of a Cartesian robot which is suspended from a metallic frame and a spherical and cylindrical robot that are placed on the side of the frame. The positioning of the robots guarantees an efficient work flow due to the proportional distribution of each of their workspace.

## 3. Topology of the robotic system

The paper proposes a robotic system used in waste sorting that incorporates three different robots, a Cartesian robot, a spherical robot and a cylindrical robot, each of them moving independently so that the task can be successfully accomplished.

The Cartesian robot is suspended on a metallic cell, the cylindrical and spherical robot are being placed in different locations, each robot being actuated by a primary prismatic joint. By giving specific parameters to the joints, different trajectories can be imposed at a given time, in order to provide a wide coverage of each individual workspace [4].

The robots are defined in the following manner:

### 3.1 *Parallelepiped Workspace Robot*

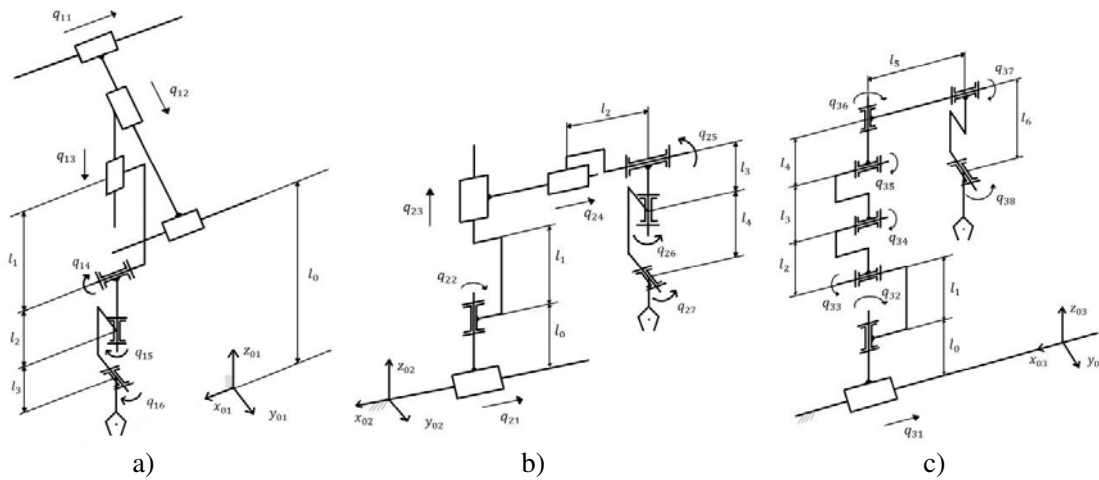
The first robot is the Parallelepiped Workspace Robot (PWS Robot) which has its workspace in the form of a parallelepiped with 6 degrees of freedom. The structural schematic can be seen in figure 1 a).

### 3.2 *Cylindrical Workspace Robot*

The second robot is the cylindrical workspace robot (CWS Robot) which has its workspace in the form of a cylinder. The robot includes an additional prismatic joint at the first joint. The structural schematic can be seen in figure 1 b).

### 3.3 *Spherical Workspace robot*

The third robot in the system is the spherical workspace robot (SWS Robot) which has its workspace in the form of a sphere. Similar to the cylindrical workspace robot is has an additional joint as the first joint of the system. The structural schematic can be seen in figure 1 c).



**Figure 1.** The three robots of the robotic system

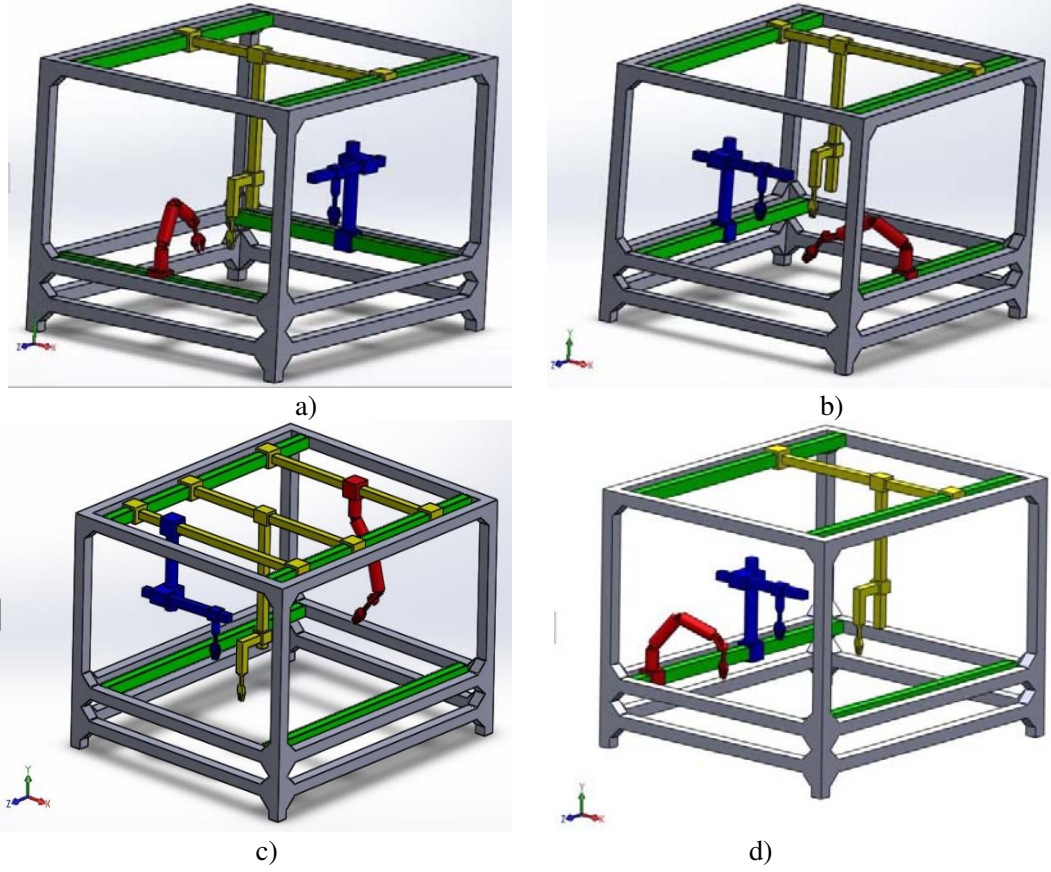
If only the first joint of each robot is taken into consideration, as well as the relative positions in which each of the three joints can be placed, the end results of using 3 robots (PWS, CWS, SWS) are 18 different virtual systems that can be used in waste sorting. These versions are presented systematically in table 1 and were created with the help of a CAD software [5].

- If the axes are consecutive but are not overlapping, then we use the symbol “||”.
- If the axes are consecutive and overlap each other then we use the symbol “≡”.
- These symbols are used in different versions as well, when the axes of the first robot and the third robot are consecutive (ex: version no.4).

**Table 1.** Topological versions of the robotic system

Version no.	$R_1$ first axis	$R_2$ first axis	$R_3$ first axis	Result	Conditions
1	Z	X	X	$R_z^1 R_x^2 R_x^3$	$R_z^1 R_x^2    R_x^3$
2					$R_z^1 R_x^2 \equiv R_x^3$
3			Y	$R_z^1 R_x^2 R_y^3$	$R_z^1 R_x^2 R_y^3$
4			Z	$R_z^1 R_x^2 R_z^3$	$R_z^1 R_x^2 R_z^3   $
5					$R_z^1 R_x^2 R_z^3 \equiv$
6		Y	X	$R_z^1 R_y^2 R_x^3$	$R_z^1 R_y^2 R_x^3$
7			Y	$R_z^1 R_y^2 R_y^3$	$R_z^1 R_y^2    R_y^3$
8					$R_z^1 R_y^2 \equiv R_y^3$
9			Z	$R_z^1 R_y^2 R_z^3$	$R_z^1 R_y^2 R_z^3   $
10					$R_z^1 R_y^2 R_z^3 \equiv$
11		Z	X	$R_z^1 R_z^2 R_x^3$	$R_z^1    R_z^2 R_x^3$
12					$R_z^1 \equiv R_z^2 R_x^3$
13			Y	$R_z^1 R_z^2 R_y^3$	$R_z^1    R_z^2 R_y^3$
14					$R_z^1 \equiv R_z^2 R_y^3$
15					$R_z^1    R_z^2    R_z^3$
16			Z	$R_z^1 R_z^2 R_z^3$	$R_z^1 \equiv R_z^2 \equiv R_z^3$
17					$R_z^1 \equiv R_z^2    R_z^3$
18					$R_z^1    R_z^2 \equiv R_z^3$

Figures 2 a, b, c and d, represent the CAD model of:  $R_z^1 R_x^2 || R_x^3$  (version no. 1),  $R_z^1 || R_z^2 || R_z^3$  (version no. 15),  $R_z^1 \equiv R_z^2 \equiv R_z^3$  (version no. 16) and  $R_z^1 \equiv R_z^2 || R_z^3$  (version no. 17) from table 1.



**Figure 2.** CAD model of four different versions

#### 4. Mathematical model and simulations

The homogenous transformation matrices that correspond to the three robots are as follow:

- The homogenous transformation matrices of the PWS Robot:

$$\begin{aligned}
 A_{11} &= \begin{bmatrix} 1 & 0 & 0 & q_{11} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & l_0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad A_{12} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & q_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad A_{13} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & q_{13} \\ 0 & 0 & 0 & 1 \end{bmatrix}; \\
 A_{14} &= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_{14}) & -\sin(q_{14}) & 0 \\ 0 & \sin(q_{14}) & \cos(q_{14}) & l_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad A_{15} = \begin{bmatrix} \cos(q_{15}) & 0 & \sin(q_{15}) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(q_{15}) & 0 & \cos(q_{15}) & l_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \\
 A_{16} &= \begin{bmatrix} \cos(q_{16}) & -\sin(q_{16}) & 0 & 0 \\ \sin(q_{16}) & \cos(q_{16}) & 0 & 0 \\ 0 & 0 & 1 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)
 \end{aligned}$$

- The homogenous transformation matrices of the CWS Robot:

$$\begin{aligned}
 A_{21} &= \begin{bmatrix} 1 & 0 & 0 & -q_{21} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{22} = \begin{bmatrix} \cos(q_{22}) & -\sin(q_{22}) & 0 & 0 \\ \sin(q_{22}) & \cos(q_{22}) & 0 & 0 \\ 0 & 0 & 1 & l_0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{23} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & q_{23} + l_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\
 A_{24} &= \begin{bmatrix} 1 & 0 & 0 & -q_{24} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{25} = \begin{bmatrix} 1 & 0 & 0 & l_2 \\ 0 & \cos(q_{25}) & -\sin(q_{25}) & 0 \\ 0 & \sin(q_{25}) & \cos(q_{25}) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \\
 A_{26} &= \begin{bmatrix} \cos(q_{26}) & -\sin(q_{26}) & 0 & 0 \\ \sin(q_{26}) & \cos(q_{26}) & 0 & 0 \\ 0 & 0 & 1 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{27} = \begin{bmatrix} \cos(q_{27}) & 0 & \sin(q_{27}) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(q_{27}) & 0 & \cos(q_{27}) & -l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)
 \end{aligned}$$

- The homogenous transformation matrices of the SWS Robot:

$$\begin{aligned}
 A_{31} &= \begin{bmatrix} 1 & 0 & 0 & q_{31} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{32} = \begin{bmatrix} \cos(q_{32}) & -\sin(q_{32}) & 0 & 0 \\ \sin(q_{32}) & \cos(q_{32}) & 0 & 0 \\ 0 & 0 & 1 & l_0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \\
 A_{33} &= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_{33}) & -\sin(q_{33}) & 0 \\ 0 & \sin(q_{33}) & \cos(q_{33}) & l_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{34} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_{34}) & -\sin(q_{34}) & 0 \\ 0 & \sin(q_{34}) & \cos(q_{34}) & l_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \\
 A_{35} &= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_{35}) & -\sin(q_{35}) & 0 \\ 0 & \sin(q_{35}) & \cos(q_{35}) & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{36} = \begin{bmatrix} \cos(q_{36}) & -\sin(q_{36}) & 0 & 0 \\ \sin(q_{36}) & \cos(q_{36}) & 0 & 0 \\ 0 & 0 & 1 & l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \\
 A_{37} &= \begin{bmatrix} 1 & 0 & 0 & l_5 \\ 0 & \cos(q_{37}) & -\sin(q_{37}) & 0 \\ 0 & \sin(q_{37}) & \cos(q_{37}) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_{38} = \begin{bmatrix} \cos(q_{38}) & 0 & \sin(q_{38}) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(q_{38}) & 0 & \cos(q_{38}) & -l_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)
 \end{aligned}$$

Where  $q_{1...z}$  are the generalized coordinates of the robots.

Figure 3 represents the block model created in SimMechanics application which is part of the Matlab software [6],[7]. By using the model created and giving certain parameters in order to actuate it, the final position of the robot can be determined. The main actuators are the first prismatic joint of each robot, the joint controlling the displacement of the base of the robot which allows it to translate.

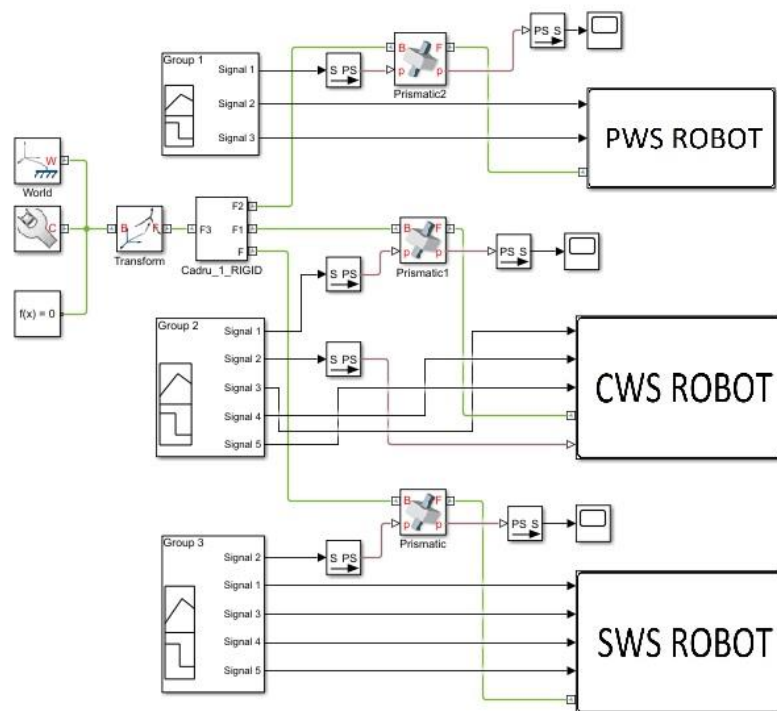


Figure 3. Block model of the robotic system

## 5. Conclusions

The topological versions of the robotic system were developed for the system being used in waste sorting. The homogenous transformation matrices were determined, as well as the CAD modules in Solidworks. The block model of the robotic system was generated in SimMechanics.

## 6. References

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