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Vision-based robotic cell design for automated waste manipulation

C Lapusan, C Rad, O Hancu and C Brisan

Department of Mechatronics and Machine Dynamics, Technical University of Cluj-Napoca, Cluj-Napoca, Romania

E-mail: cornel.brisan@mdm.utcluj.ro

Abstract. The paper proposes an integrated design approach for developing an automated solid waste manipulation robot cell. The research address the development of the sensing system that implement vision-based functions and the integration of the sensing system with the Mitsubishi RV-2AJ serial robot. The system is able to identify the necessary geometric parameters of a wide range of municipal solid waste fragments and based on this data to manipulate and store them in specific containers.

1. Introduction

In the last decades recycling has become an important element that could help increasing the life quality of people and in the same time sustain the economy growth. This approach is promoted all over the world through programs that aim to create a solid framework that implement the circular economy concept [1], [2]. The idea is to maintain the value of products, materials and resources in the economy for as long as possible and in the same time to minimize the waste generation.

In order to increase the quantum and efficiency of waste recycling, more and more automated systems must be developed and implemented [3]. The automation of the waste sorting can be approached from two directions: direct sorting and indirect sorting [4]. In case of direct sorting the material properties (magnetic. density, conductivity) are used in the separation process by implementing external fields like magnetic, eddy currents or gravity to sort the waste. For the indirect sorting a set of sensor systems are used to detect the type and location of a specific waste and then automated machines and robots manipulate the identified elements in the sorting process. In this case dedicated sensor systems must be developed [5] that allows easy integration in the sorting system. This paper addresses this problem and focus on developing image processing algorithms that allow identification of the necessary parameters for several types of solid waste, parameters that are used in the manipulation of the identified objects.

2. Robotic cell

In designing the robotic cell, the current work address two important functionalities: *sensing* and *gripping*. The proposed automated waste manipulation system is presented in figure 1. The system is composed from several modules that allow the detection and manipulation of the waste. For feeding the waste a conveyor belt is used.

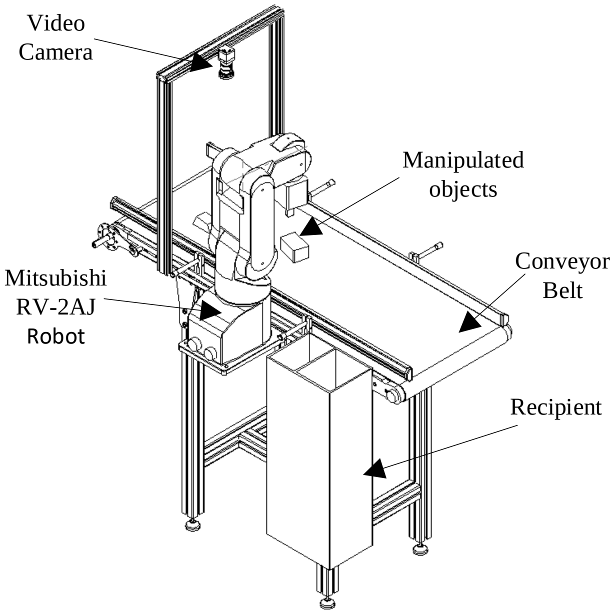


Figure 1. Robotic cell.

The *sensing* function must be able to detect and classify the objects to be manipulated. For each element presented on the conveyor belt the shape, position and orientation is identified/measured using a video camera. The system is able to identify these parameters for a large variety of recyclable municipal solid waste fractions like metal, plastic, paper, glass or wood.

The *gripping* functions focus on manipulating the objects identified by the sensing system in the most efficient way. The control system uses the data from the video sensor to define optimum trajectories for the robot arm in order to grab and move the waste in the designated recipients.

2.1. Robot kinematics

Next the kinematic of the robot is presented. The kinematic equations are used in trajectory planning of the robot. A detail study of the direct and inverse kinematic of the RV-2AJ can be found in [6] and [7].

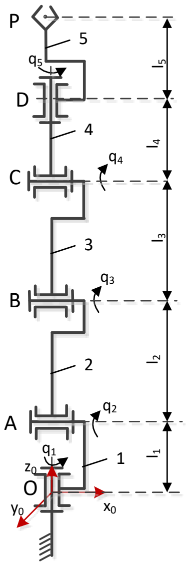


Figure 2. Generalized coordinates of the RV-2AJ robot.

For the direct kinematic problem, the homogenous transformation matrices are used to describe the end effector position and orientation. The values for the robot geometric parameters l_i *{i=1...5}*, used in the matrices, are presented in table 1. The generalized coordinates of the robots are q_i *{i=1...5}*. The system world frame $Ox_0y_0z_0$ is attached to robot fixed frame.

Table 1. Robot geometric parameters for RV-2AJ.

l_i [m]	l_1	l_2	l_3	l_4	l_5
Value	0	0.25	0.16	0.3	0.072

The transformation matrices in the case of the RV-2AJ robot presented in figure 2 for each joint are given as follows:

$$A_1 = \begin{bmatrix} \cos(q_1) & -\sin(q_1) & 0 & 0 \\ \sin(q_1) & \cos(q_1) & 0 & 0 \\ 0 & 0 & 1 & l_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_2) & -\sin(q_2) & 0 \\ 0 & \sin(q_2) & \cos(q_2) & l_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \tag{1}$$

$$A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_3) & -\sin(q_3) & 0 \\ 0 & \sin(q_3) & \cos(q_3) & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}; A_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q_4) & -\sin(q_4) & 0 \\ 0 & \sin(q_4) & \cos(q_4) & l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$A_5 = \begin{bmatrix} \cos(q_5) & -\sin(q_5) & 0 & 0 \\ \sin(q_5) & \cos(q_5) & 0 & 0 \\ 0 & 0 & 1 & l_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In order to obtain the transformation matrix A_0^5 from the base link to the end effector the product of the above matrices is calculated.

$$A_0^5 = A_1 \times A_2 \times A_3 \times A_4 \times A_5 \tag{2}$$

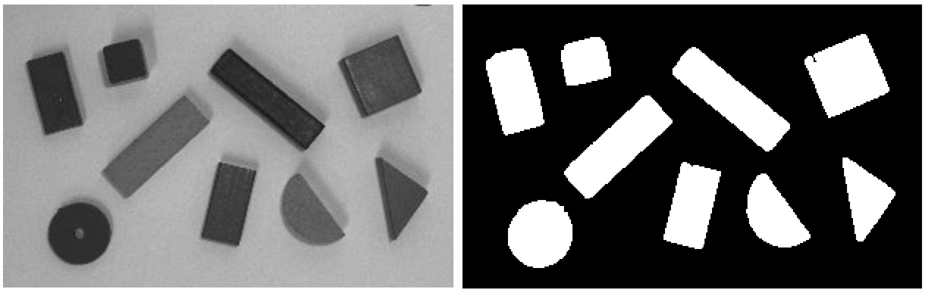
From the A_0^5 matrix the orientation and the cartesian coordinates of the end effector can be express. In equation (3) the cartesian coordinates of the robot are presented:

$$\begin{gathered} p_x = l_5[\cos(q_4)B + \sin(q_4)C] + l_4A + l_3\sin(q1)\sin(q2) \\ p_y = -l_4D - l_5[\cos(q_4)D + \sin(q_4)E] - l_3\cos(q_1)\sin(q_2) \\ p_z = l_1 + l_2 + l_3\cos(q_2) + l_4F + l_5[\cos(q_4)F - \sin(q_4)(\cos(q_2)\sin(q_3) + \sin(q_2)\cos(q_3))] \end{gathered} \tag{3}$$

where:
$B = \cos(q_2)\sin(q_1)\sin(q_3) + \cos(q_3)\sin(q_1)\sin(q_2)$
$C = \cos(q_2)\cos(q_3)\sin(q_1) - \sin(q_1)\sin(q_2)\sin(q_3)$
$D = \cos(q_1)\cos(q_2)\sin(q_3) + \cos(q_1)\cos(q_3)\sin(q_2)$
$E = \cos(q_1)\cos(q_2)\cos(q_3) + \cos(q_1)\sin(q_2)\sin(q_3)$
$F = \cos(q_2)\cos(q_3) - \sin(q_2)\sin(q_3)$

3. Image processing approach

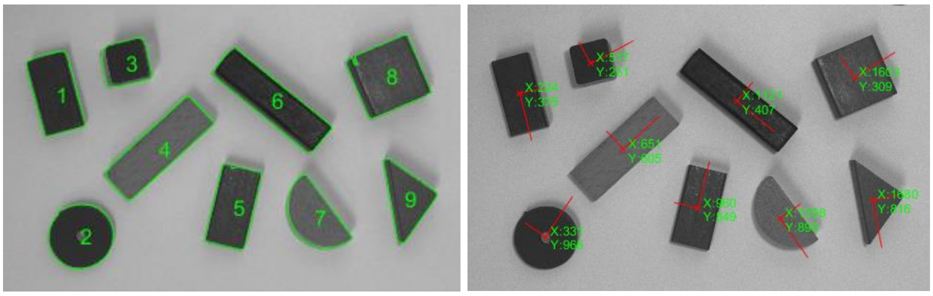
The sensor system is implemented using the DAVID-4M-CAM video camera. The purpose of this system is to identify all the objects on the conveyor belt. For each of this element the following parameters are of interest: position, orientation and shape. The image processing function were implemented using Matlab and the Image Processing Toolbox. The image captured form the camera is in grayscale and have a resolution of 1920x1200 pixels. The image is first filter using a median filtering. This will allow to remove the outliers in the image without reducing its sharpness (figure 3.a).



a) b)

Figure 3. Image processing steps a) acquired image b) processed image

After the filtering process the image segmentation process is taking place. The image is transformed in binary form based on a defined threshold. On the obtained image the *imfill* function is used to fill all the “holes”. The result after this process is presented in figure 3.b.



a) b)

Figure 4. Results of image processing.

For determine the boundary and the position of the object in the captured image the *bwboundaries* function is used. The result is presented in figure 4 a), all the identified objects are numbered and the contour around them is draw. Next the circularity of all identified objects is calculated based on the area A_i and the perimeter P_i of each object. This value is use to determine if the shape fits in a circle, rectangle or another shape. This information is used for planning the gripping operation.

For all elements the orientation and geometric center is determine using the *regionprops* function. The results are presented in figure 4 b).

4. Experimental results

In figure 5 the experimental setup used for testing the functionality of the system is presented. In the testing process the object that are to be manipulated are placed on a work bench. The view area of the camera covers a rectangle with width of 185 [mm] and length of 285 [mm]. The robot work space covers the view area of the camera allowing it to manipulate the detected objects. The gripper used for grabbing the objects implements force control for gripping and allows a maximum payload of 2 [Kg]. The implementation of the image processing and robot control algorithms was made using Matlab. A Graphic User interface was also created, the interface allows to control the system and show the sensor readings.

Figure. 5. Experimental setup.

The developed system was used to create several tests for different solid waste categories. Figure 6 presents the obtained results for: construction waste (concreate, wood, brick, iron element) (figure 6 a), b)), PET recipient waste (figure 6 c), d)), aluminum recipient waste (figure 6 e), f)) and glass recipient waste ((figure 6 g), h)).

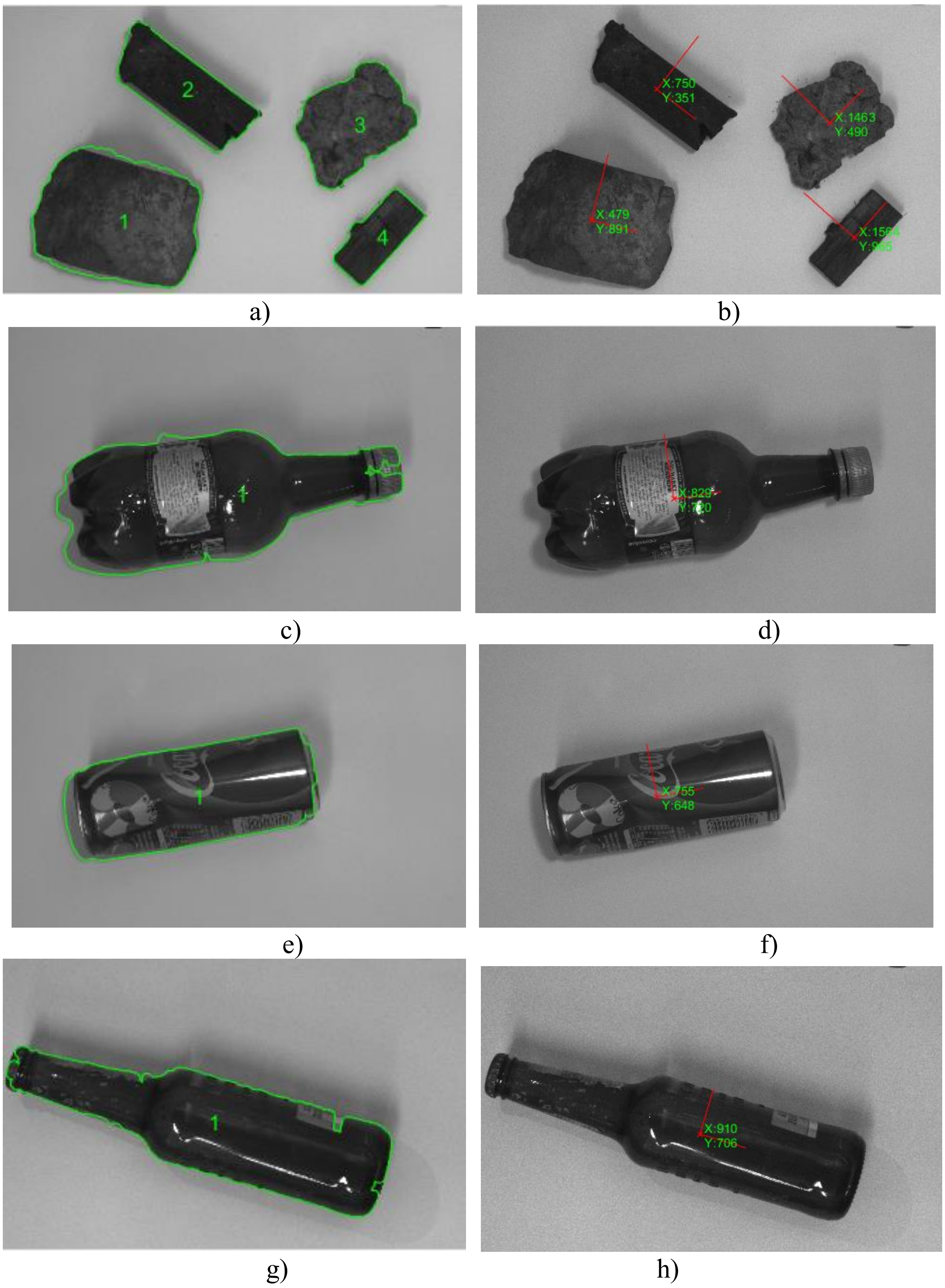


Figure 6. Experimental results.

The experiments developed with the system offered good results in determine the objects shape, orientation and position in the workspace and in manipulating these objects. Based on the data obtained from the sensor system the separation can be made using the size of the object. For planning the object manipulation, the Shortest Process Time (SPT) method was used. This approach offers good results for static ques [8] and ensures minimum average processing time if first the object with the shortest processing time is operated.

The video processing functions had very good result in the case of solid opaque objects with reduce reflectance. The precision concerning the shape and position is decreasing in the case of transparent solid waste.

5. Conclusion

The paper presented the development of an autonomous waste manipulation system using the Mitsubishi RV-2AJ serial robot and an image processing system based on DAVID-4M-CAM and Matlab. The obtained results showed that the proposed system can be used to automatically detect and manipulate solid waste. In the testing procedure several types of solid waste (pet recipients, aluminum recipients, concrete, wood, etc.) were used. The system showed very good results on identifying solid opaque objects and less good results on solid transparent objects. After identifying the kinematic parameters of the objects, the manipulation was realized using the serial robot.

6. References

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Acknowledgments

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