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AUTONOMOUS PASSIVE ELECTRONIC COMPONENTS SORTER

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Abstract

Sorting of passive electronic components like resistors, capacitors and inductors is a very time-consuming work in every electronic laboratory as well as industries. This project is an attempt to develop an automatic system that can sort resistors and inductors. A computer vision-based method is used to identify the component whether it is a resistor or an inductor, and if it is a resistor, the resistance is also calculated by decoding the color bands. A web camera is used to record live video of the platform on which the component will be placed. The system is trained using a machine learning approach called Haar Cascade Classifier and various image processing algorithms are deployed for the identification purpose. The error rates of component detection and resistance value determination have been analyzed under two different lighting conditions. To achieve the functionality of autonomous operation, a customized SCARA manipulator is developed and integrated with the computer vision system. The manipulator is programmed using an Arduino Uno board to place the identified components to their respective bins. The forward kinematics of the manipulator is also derived using Denavit-Hartenberg method.

1. Introduction

Most electronic gadgets have small electronic circuits that can control the machine and process information. More generally, electronic circuits are the lifelines of numerous electrical appliances. An electronic circuit is one that directs and controls current to perform various functions together with signal amplification, computation, and data transmission. Among the different types of components used to build an electronic circuit, passive components which include resistors, capacitors and inductors, are of great significance. These two terminal devices cannot offer gain, amplification or directionality to a circuit but instead they can attenuate a given electrical signal, produce a phase shift to the signal or provide some sort of feedback. Hence every electronic industry as well as educational institutions having electronic laboratories require huge amount of such components. Due to the fact that the values of certain components like resistors and inductors are color coded, manual sorting becomes more tedious in terms of time consumed and accuracy of recognition.

In this context, an automatic system that is capable of sorting these components becomes significant. The two basic functionalities of such a system will be the identification of components and the proper placement of the components accordingly. The most common approach used towards resistor recognition is by deploying the Ohm's Law wherein, a known voltage or current is passed through the resistor and the other is measured. Then the resistance is calculated using the law V = IR. An alternate method is to use computer vision to process the image of a resistor and decode the color bands printed on its body. Computer vision involves using a combination of camera hardware and computer algorithms to allow robots to process visual data from the world. So, in this project the latter method is adopted since it can provide a vision assistance to the robotic section and can be combined with machine learning approaches to detect inductors along with resistors. The second task to be accomplished is the correct allocation of the identified components, for which a pick and place robotic arm is the best option. For the system to perform automatically, the arm must perform two pick and place operations. One to take the components one at a time to the identification spot, and the other, to place them in their corresponding bins, once the identification is over. The small size of the components makes it necessary to perform the pick and place operations with high accuracy and precision. The search for such an arm resulted in the selection of SCARA (Selective Compliance Articulated Robotic Arm) for this project. In today’s scenario, SCARA is one of the best options for pick and place applications due it's high repeatability and since it can move in the X-Y-Z plane by rotating in the Z-axis.

Reading color-band resistor value is normally performed by eyes for color identification and calculation with color code mapping as in Figure 1.

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Twelve colors are selected to print on the color bands (CBs) depending on the representative resistor value. In rule, reading the resistor value for a 4-band resistor can be computed by Eq. (1) where Ci, M and τ denote the i'th color code, multiplier, and tolerance, respectively. In normal CB sequence, the CB of tolerance should be at the right-most side when the resistor is placed horizontally.

$$R= M. (\Sigma_{i=1}^{2} 10^{2-i}. Ci) \pm \tau \quad (1)$$

Color (code)	C_1	C_2	C_3	M	τ
Black (0)	—	0	0	10^0	—
Brown (1)	1	1	1	10^1	1%
Red (2)	2	2	2	10^2	2%
Orange (3)	3	3	3	10^3	—
Yellow (4)	4	4	4	10^4	—
Green (5)	5	5	5	10^5	0.5%
Blue (6)	6	6	6	10^6	0.25%
Violet (7)	7	7	7	10^7	0.1%
Gray (8)	8	8	8	—	0.05%
White (9)	9	9	9	—	—
Gold (10)	—	—	10	10^{-1}	5%
Silver (11)	—	—	11	10^{-2}	10%

Figure 1 Color code mapping

2. Literature Review

Two patents are filed regarding the automatic classification of resistors. First one was filed in 1945 which is US2468843 - "Apparatus for electrically testing and classifying resistors" and the second one US2468843 - "Apparatus for electrically testing and classifying resistors", was filed in 1960. A rotary resistor feeding technique is employed in the system. The former patent performs basic sorting into different sections and the latter is an extended version of the former wherein it categorizes complex impedances. The main limitation found in the two patents is that they have a very complex electrical as well as mechanical design. Recently, certain works have been done regarding the sorting of resistors alone according to their value. Almost all of them use Ohm's Law to find the resistance value. On June 6th 2019, Cornell University's website showed an automated resistor sorter which had a 3-D printed structure with a measurement arm and feeding slot. The limitation is that the user has to place resistors one at a time to a feeding slot in the arm. The system is based on PIC microcontroller and has the provision to adjust the limits of the bins via a LCD display and a potentiometer. Another work done related to this employs the concept in which the voltage drop across a resistor is bootstrapped with the mechanical movements of servos to produce the required output [Paul2019].

Besides categorization, several resistor images researches have also been carried out. Chen and Wang [Chen2016] presented a study of reading color-band resistors via computer vision and developed a diffuse light source design to reduce the effects of specular surface of resistors. The system implements a ring type 24-LED structure, in which only some of them are switched on automatically according to the orientation of the resistor when it is kept on the platform. The National Instruments (NI) color classification interface is adopted to train and classify the extracted colors. By the K-NN classifier, a color is classified into a class based on a voting mechanism. M. F. Demir et.al. [Demir2018], in their paper, proposed an online video processing framework to automatically calculate the resistance value and the tolerance of a resistor under normal lighting condition via an android mobile application. HSV color space is used to minimize the effect of color illuminations. Color band classification is done by training the system using 200 images of

50 different resistors taken under room lighting. Mitani Y. et.al. [Mitani2010] presented a method to read resistors using image processing techniques. Color region segmentation is based on k-means method by combining color feature vector and position feature vector. In the segmented image, extraction of colors is carried out using histogram approach. For color classification, 1- NN Classifier is used. The training samples are the preliminary extracted colors from the real images different from the test samples under each of the different illuminations. The paper proposed by R. Kumar et.al.[Kumar2014] was directed towards the development of a robust image processing algorithm which is a prerequisite for the successful working of a pick and place robotic arm intended for object sorting tasks. Once the object is detected, a rectangular bounding box is created around it and cropped as outlined by the box. The location of the object is obtained from the (x, y) values of the bounding box in MATLAB and is used by the arm to perform the desired pick and place operation.

Manzoor S. et. al. [Manzoor2014], in their paper, presented a 6 DOF robotic manipulator for pick and place operations using a Logitech web camera to provide vision assistance. The framework combines robot modeling and control and image-processing to perform desired operations. V. Kumar et. al. [Kumar2018] proposed a computer vision based 6 DoF robotic arm where a raspberry pi is used to implement the vision system and picamera acts as the vision sensor. The robotic manipulator is based on the Arduino Mega 2560 microcontroller. Here a 3D vision system is developed which is able to detect the objects as well as their distance from the end effector of the arm and transmit the signals to the drive system of the robotic arm. Wen Bo Li et. al. [Wen2015] developed a 4DOF SCARA robot with three revolute and one prismatic joint (3R1P) to realize pick and place tasks of the circular and rectangular work pieces. The trajectory planning is further implemented. An Electromagnet clamp, installed on Axis 4, is applied as the end effector and a camera is installed on it. The control interface was designed via Visual C++ to control the robot for achieving pick-and-place tasks. Ahmed Issa et. al. [Issa2017] developed a vision assisted SCARA manipulator, for which control software, animation and simulation were developed using LabVIEW and Arduino. In addition to that, a vision system was developed and integrated with the manipulator system where a mobile phone camera was used to acquire images, then transmit them wirelessly to LabVIEW's Vision Assistant codes for processing and calibration. The developed vision system allowed detection and calculation of object positions within the manipulator's workspace.

3. Methodology

The block diagram of the proposed system is shown in figure 2. The system has two different sections:

1. The vision system for capturing and processing real-time video to identify the passive electronic component; and in case of resistor, value determination is also done.
2. The robotic system receives output of the vision system and according to the component identified, perform the desired pick and place operations.

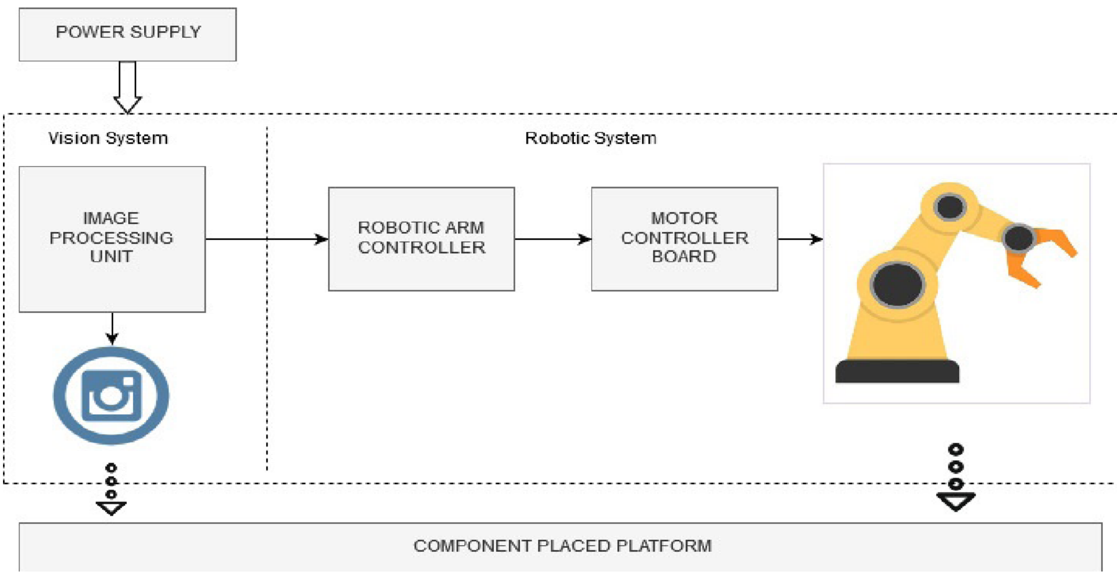


Figure. 2 Block diagram of the system

3.1 Vision System

The vision system performs the task of component identification. A high-resolution vision sensor is required to get a quality image of the resistor, which is then processed using the image processing algorithms, to identify the component. Here, a web camera is used as the vision sensor and is positioned directly above the platform to get a clear view of the platform. Tech-Com SSD- 355 40 Mega Pixels Web Camera is being used in this project and is shown in figure 3. The laptop serves as the image processing unit, OpenCV-python is installed in the unit to achieve computer vision. Once a resistor is detected, image processing techniques are applied to decode the color code.

Figure 3 Web camera

Component Identification

The image taken by the vision sensor is processed by the unit in which the image processing algorithms are implemented to identify the component as shown in figure 4.

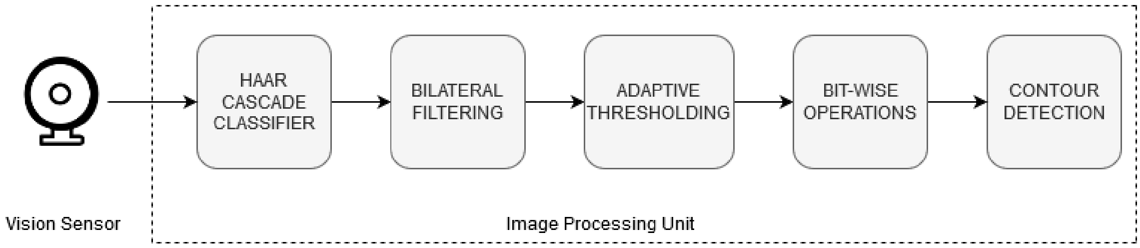


Figure 4 Component Identification Process

The first stage is the Haar cascade classifier which detects the presence of a resistor or an inductor. Haar feature-based cascade classifiers are an effective object detection method proposed by Paul Viola and Michael Jones in their paper, "Rapid Object Detection using a Boosted Cascade of Simple Features" in 2001 [Viola2001]. It is a machine learning (ML) based approach where a cascade function is trained from a large number of positive and negative images and is then used to detect objects in other images. Resistors and inductors are similar in their structure and pattern, both can be detected using the same classifier. Here, the system is trained using a Haar cascade classifier for resistors. Once detected, the difference in color of the bodies of the resistor and inductor are used to distinguish them. When detected as a resistor, the image is again processed to decode the color band. Bilateral filter is applied on the resistor image to reduce the noise and smoothen the image while preserving the edges. To obtain a binary image, adaptive thresholding is carried out on the grayscale of the filtered image wherein, the threshold value is calculated for smaller windows whose size is as specified. By performing bitwise operations on the binary image, the color bands can be specifically obtained as white pixels and the rest of the image as black pixels. By further processing, the color of each band is determined. Contour detection is done to identify the valid color bands depending on the area predefined for a standard color band. If the number of valid contours lie in the range 3 to 5, the value of the resistance is calculated in the normal manner.

3.2 Robotic System

In the context of this project, a SCARA with PRR (Prismatic-Revolute-Revolute) configuration will be developed. The arm shall be going up and down along the core Z axis, an inner link rotating about the shoulder Z axis, an outer link rotating about the elbow Z-axis and an end-effector. To perform the pick and place operation, a suitable end - effector is also important. Here, since the components are small and have the same geometry, a parallel jaw gripper is selected. Parallel grippers have two slides that close parallel to the work piece to grip its outside edges. A parallel jaw gripper employing rack and pinion mechanism is used as the end effector. A rack and pinion is a kind of linear actuator consisting of a circular gear (pinion) with a linear gear (rack) that converts rotational motion into linear motion. Consequently, it has considerably more grip than conventional lever grippers.

The various parts that form the structure of the manipulator can be developed through 3D printing technology. To create the joint movements of the robotic structure, 3 NEMA 17 stepper motors have been used. One for the prismatic joint along the base Z-axis and one each for the revolute joints of the inner and outer links respectively. NEMA 17 is a bipolar hybrid stepper motor with a phase angle of 1.8 degrees and a holding torque of 3.7 kg-cm. An MG995 digital servo motor is used to rotate the pinion to produce the gripping action of the end effector.

The NEMA 17 stepper motor is controlled by a pair of suitable H-bridges (one for each coil) and hence requires an appropriate motor driver. The commonly used driver for NEMA 17 is the A4988 stepper driver. Each stepper motor requires a separate driver to which STEP and DIRECTION signals for each motor is given as inputs through the microcontroller. The driver is capable of running the motor using the two inputs with the help of an in-built translator and can provide up to 2A current per coil of the motor.

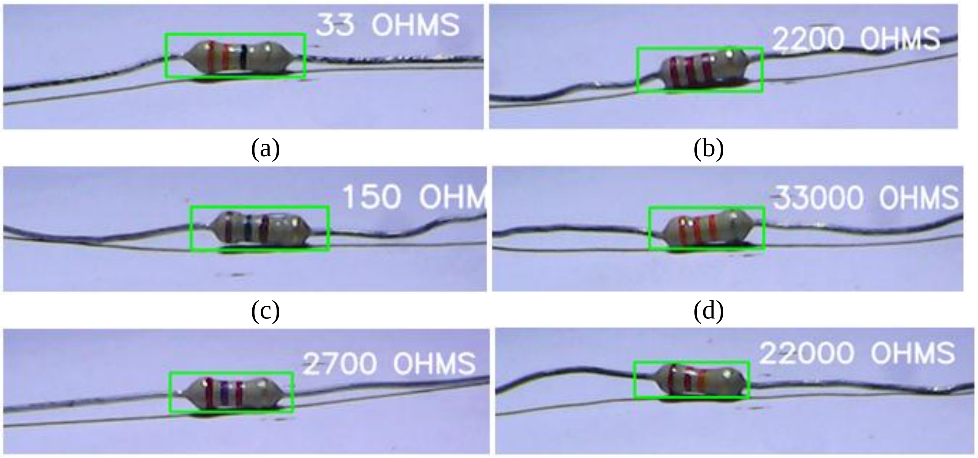
Here Arduino UNO is used as the microcontroller of the robotic section since it has enough digital pins to control the step and direction of the stepper motors and also to control the servo motor. Also, the board is compatible with different communication facilities and hence can easily communicate with a computer or other microcontrollers. Here this feature is necessary since the output of the computer vision section has to be received and the arm should be run accordingly.

4. Results and Discussion

The computer vision system for reading resistor values was implemented using a web camera positioned above the platform. To avoid the errors in component identification due to the variations in the natural light, an arrangement is made using an 8 mm LED as light source. The range of motion (ROM) of the arm is also considered while fixing the positions of the camera and the light arrangement. OpenCV-python installed in the PC is used to process the real-time video being captured by the vision sensor. The setup is shown in figure 7.

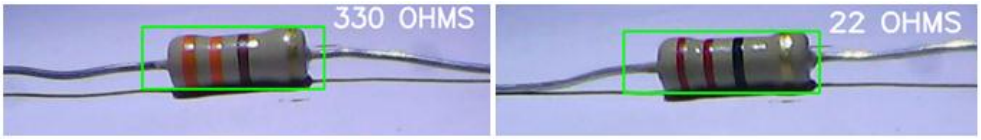
Figure 7: Image Acquisition Setup

OpenCV-python is used to develop the code for component recognition. Both inductors and resistors have a similar structure, but differ in the color of their body. Haar Cascade Classifier is used to detect the presence of a resistor/inductor on the platform. Once the classifier returns a true value, (i.e., either a resistor or an inductor is detected), then the color of the body of the component is checked to find whether it is a resistor or an inductor. If it is a resistor, color code is decoded by using the specified ranges for the ten colors - black, brown, red, orange, yellow, green, blue, violet, gray and white. The range for each color is determined using an OpenCV-python code for range-detection and substituted in the main program. The resistance whose value is identified is highlighted by a green rectangle and the value is also displayed. If the color codes are not properly detected, or the no. of color bands detected is less than three or more than five, then the resistor is highlighted using a red rectangle. Tolerance bands are not considered due to their highly reflective nature. If the component is identified as an inductor, then it is highlighted, using a blue rectangle. The system was able to distinguish resistors and inductors. One watt, half watt and quarter watt resistors were successfully identified. The results obtained are shown in the figures 8 to 11.



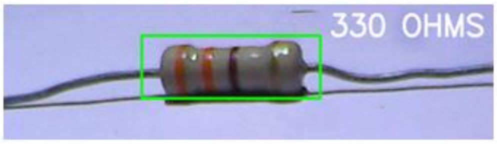
(a) (b) (c) (d) (e) (f)

Figure 8: Identification of quarter watt resistors



(a) (b)

Figure 9 : Identification of one watt resistors



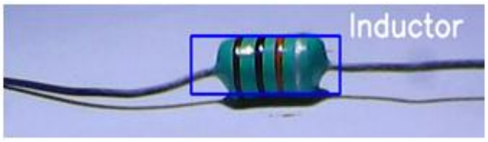


Figure 10: Identification of half watt resistor

Figure 11: Identification of inductor

(Bl- Black, Br - Brown, R - Red, O - Orange, Y - Yellow, G - Green, V - Violet)

Table 1: Observation results under natural light

Component		Failed Numbers			Error Description
		Detection	CB Extraction	CB Identification	
Inductor 1		2	-	-	Undetected
Inductor 2		0	-	-	-
One Watt	Brown-Black-Brown	0	0	0	-
	Orange-Orange-Brown	0	0	0	-
	Red-Red-Black	0	0	0	-
	Yellow-Violet-Brown	0	5	5	Yellow Unrecognized.

					Brown recognized as black.
Half - Watt	Orange-Orange-Brown	0	0	0	-
	Brown-Black-Red	0	0	4	Brown recognized as black.
	Yellow-Violet-Red	0	5	5	Violet recognized as gray. Yellow unrecognized.
Quarter-Watt	Brown-Black-Brown	1	0	2	Brown recognized as black.
	Orange-Orange-Orange	0	2	2	Middle band unrecognized. Orange recognized as red.
	Red-Violet-Red	2	0	3	Violet recognized as black.
	Red-Red-Red	2	3	0	Middle band unrecognized.
	Orange-Orange-Black	3	3	0	Black unrecognized.
	Brown-Green-Brown	2	0	0	Undetected
	Red-Red-Orange	2	0	2	Orange recognized as red.
Total		14	18	23	

Table 2: Observation results under external light

Component		Failed Numbers			Error Description
		Detection	CB Extraction	CB Identification	
Inductor 1		0	-	-	-
Inductor 2		0	-	-	-
One Watt	Brown-Black-Brown	0	0	0	-
	Orange-Orange-Brown	0	0	0	-
	Red-Red-Black	0	0	0	-
	Yellow-Violet-Brown	0	0	1	Brown recognized as black.
Half - Watt	Orange-Orange-Brown	0	0	0	-
	Brown-Black-Red	0	0	2	Brown recognized as black.

	Yellow-Violet-Red	0	3	0	Yellow unrecognized.
Quar ter- Watt	Brown-Black-Brown	0	0	2	Brown recognized as black.
	Orange-Orange-Orange	0	0	0	-
	Red-Violet-Red	0	0	0	-
	Red-Red-Red	0	0	0	-
	Orange-Orange-Black	0	1	0	Black unrecognized.
	Brown-Green-Brown	0	0	0	-
	Red-Red-Orange	0	0	0	-
Total		0	4	5	

The results obtained were analyzed to calculate the error rates of component detection, color band extraction and color band identification. 14 types of resistors and 2 types of inductors were considered for the analysis. 5 resistors and 10 inductors in each type were used for testing the performance of the implemented system under natural and external light conditions and the results were tabulated.

From the tables 1 and 2, it can be found that errors are high in the case of quarter watt resistors when compared to other components. Also, the system is unable to detect and identify certain bands. Clearly, yellow is undetectable and errors mostly occur in the detection of violet, orange and brown colors. Based on the failed numbers in component detection, color band extraction and identification, we can determine the error rate of each as 15.5%, 25.7% and 32.8% respectively.

In the case where external light is provided, it is evident that it is possible to reduce the errors in the system. The system is capable of detecting resistors and inductors without any error and extract and identify mostly all color bands. It can also be inferred that errors are caused by yellow and brown bands. A reason for this is that in some resistors, brown and black bands appear to be similar. The similarity between the color of the resistor body and yellow also becomes a hindrance to the proper detection of yellow colored bands. The error rates of component detection, color band extraction and identification under external light source are obtained as 0, 5.7% and 7.2% respectively.

A SCARA robotic arm was developed to perform the pick and place operations needed for the autonomous operation of the system. The various parts of the arm were 3D printed and the structure was completed using steel rods, NEMA 17 stepper motors, pulleys and timing belts. Parallel jaw gripper was developed and joined to the SCARA arm to complete the structure. The arm developed for the project is shown in the figure 12.

Figure 12: SCARA

The forward kinematics of the arm is derived using Denavit-Hartenberg (DH) Method and as the initial step, coordinate frames have to be assigned at each joint of the manipulator as in figure 13.

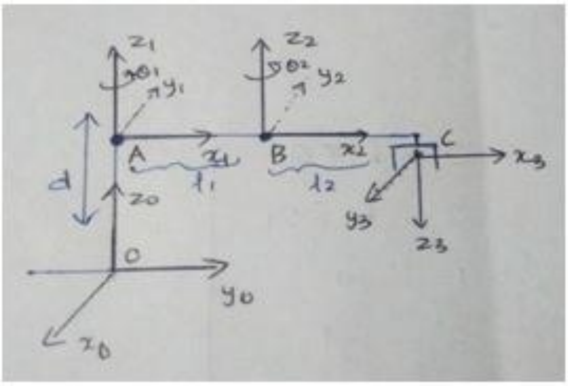


Figure 13: Joint Coordinate Frames

The four DH parameters - d, a, α and θ were determined as in table 3.

Table 3: DH Parameters

Joints (i)	θ_i	d_i	a_i	α_i
1	0	d	0	0
2	θ_1	0	AB	0
3	θ_2	0	BC	0
4	0	0	0	Π

where d_i - distance between x_{i-1} and x_i through z_{i-1} (joint distance)
a_i - distance between z_{i-1} and z_i through x_{i-1} (link length)
θ_i - angle of rotation from x_{i-1} to x_i about z_{i-1} (joint angle)
α_i - angle of rotation from z_{i-1} to z_i about x_i (link twist angle)

The transformation matrices of adjacent joints were determined using the DH Transformation Matrix and the arm matrix was obtained as the product of the joint matrices. {C_1 - cos (θ_1); S_1 - sin (θ_1); C_{1+2} - cos ($\theta_1 + \theta_2$)}

$$^0T_4 = {}^0T_1 . {}^1T_2 . {}^2T_3 . {}^3T_4$$

$$^0T_4 = \begin{pmatrix} C_{1+2} & S_{1+2} & 0 & (L_1.C_1 + L_2.C_{1+2}) \\ S_{1+2} & -C_{1+2} & 0 & (L_1.S_1 + L_2.S_{1+2}) \\ 0 & 0 & -1 & d \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The forward kinematic equations for the developed arm can be obtained from the arm matrix as:
$x = L_1.C_1 + L_2.C_{1+2}$
$y = L_1.S_1 + L_2.S_{1+2}$
$z = d$

The equations can be proved by providing common values for joint angles and verifying the end effector position. For joint angles 1 and 2 being 0 and (π/2) respectively, the end effector position is obtained as (L_1, L_2, d) and this can be verified by applying the joint angles in the arm.

For each identified component, a particular character is sent by the vision section to the Arduino via serial communication. According to the data being received serially, the joint movements of the arm are directed by the Arduino to pick and place the component to its respective bin, place the next component onto the identification platform and wait for the next signal.

5. Conclusion

An automatic system for sorting passive electronic components is proposed in this project. The system includes two sections - vision system and robotic system. The computer vision section has been implemented using a webcam as the vision sensor and a PC as the image processing unit. Lighting is adjusted by providing suitable arrangements. OpenCV-python code is used for component identification and it is successful. Inductors and resistors are detected correctly and resistors of different wattages are also identified accurately. A SCARA manipulator is developed and integrated with the vision system to achieve fully autonomous functioning. The arm is actuated using stepper and servo motors which are controlled by Arduino via suitable motor drivers. The control signals to the arm are sent by the Arduino according to the output of the vision system so that the components are placed in their corresponding bins. The applications will increase even more if the system is made capable of decoding the color code of inductors and detecting the value written on capacitors so that they can also be classified according to their value. In the case of the robotic section, by changing the end effector type, the same arm can be used for several other pick and place operations. The motor powers could be improved in future studies to create a commercial and industrial robotic arm.

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