

Integration of low-cost vision system with the Fanuc M-1ia robot for sorting and assembly operations

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Abstract: - Machine vision has given robots the advantage of gathering more information from the workspace around them. The enactment of machine vision to improve robotic performance is becoming an essential component for the amalgamation of robot technology in the manufacturing process. Machine vision increases the robot's collaboration with the work setting and provides inordinate system flexibility. This paper describes a low-cost robotic vision system for assembling workpieces transported along a conveyor. The vision system identifies workpieces of different profiles and determines their respective coordinates as well as the orientation of the workpieces. Corresponding sorting algorithms are implemented in order to simulate the manufacturing environment. This paper will discuss the theory of image processing, equipment selected, experimental procedures and conclusions drawn. The vision algorithm will be presented in the paper. A low-cost vision sensor is to be implemented in order to perform object tracking as well as object detection to determine both the shape of the workpiece and the position of the workpiece relative to the camera. The controller is thus required to perform image processing and data acquisition. Coordinates and data are to be traversed between the controller and robot in real-time.

Key-Words: Machine vision, robotics, automation

1 Introduction

Machine vision or vision tracking is an application in industry in which workpieces on any given surface are detected. The vision system is able to communicate with robots, rotary tables and presses to form a smarter more advanced manufacturing process. Vision tracking makes use of various forms of image processing which comprises of object detection and object tracking whereby video imaging is received via an industrial webcam.

Machine vision has given robots the advantage of gathering more information from the workspace around them. Vision systems allow robots to detect parts travelling on a conveyor and perform required movements in order to select those parts or determine whether certain parts have faults, as used in quality control.

Computer vision is a science that develops algorithms for automatically extracting and analyzing useful information from observed images using a computer [1]

Object detection is used to recognize certain objects within the video sequence. Frame matching is a form of object detection in which frames are captured through a stationary camera through constant intervals. The differing image of the captured frames is altered to binary which produce distinctive differences between the object and background in which edge detection can be performed effectively [2].

Edge detection on an image represents changes in textures, lines and colours. One form of edge detection used is the left-right search [3]. Assuming a pointer moves from one pixel to another, at any time the pointer reaches a pixel containing

segments of the blob, it will turn left. Consequently, if the pointer reaches a blank pixel, it will turn right. So the process will continue in order to represent a line drawing of a blob object.

Optical flow ascends from the comparative motion of objects and the observer, thus giving important information about the spatial arrangement of the objects observed and the rate of change of this arrangement [4]. It involves calculating the image optical flow field as well as performing clustering processing according to the optical flow distribution characteristics [5].

2 Development of Vision System

A personal computer (PC) is used as the cell controller and is able to communicate with the Fanuc R-30iB controller using the Fanuc Robotics Controller Interface which transfers data by means of an Ethernet connection. The controller interface allows the PC to monitor and switch I/O's on the CRMA15 peripheral interface as well as update the robot position registers. The PC receives a video image from a webcam which is linked using a universal serial bus (USB). AForge.NET is an open source framework used in the field of Computer Vision to perform essential tasks in image processing. AForge.Net is used to perform object detection in determining the workpiece profile as well as the position of the workpiece relative to the camera.

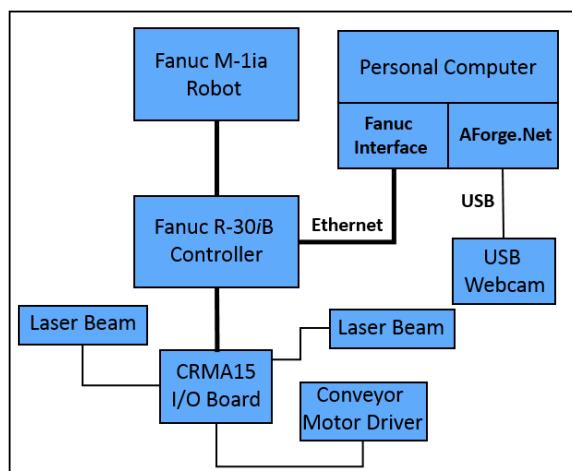


Fig 1. System block diagram

2.1 Camera Selection

Three cameras were compared and tested in order to produce the best quality video feed for producing an efficient vision system. Cameras were compared based on image resolution, cost and lens distortion. The three cameras compared included an Industrial CMOS Web Camera, Sony IMX179 Camera and the Microsoft Life Cam HD-3000 Camera.

The Microsoft Life-Cam HD-3000 performed optimally as it produced a 720P video image which will perform sufficiently for edge detection and reduce any risk of premature lighting, thus the camera can perform in any sufficient lighting condition. The camera contains a non-distortion lens which eliminates additional computation required for calibration. Additionally, the camera is of the most affordable choice costing R495 [6]. Therefore, the Microsoft Life-Cam HD-3000 is selected as the camera used for the vision system.

2.2 Image Processing

Image processing is performed on a computer using Visual Studio. Visual Studio is a Microsoft based integrated development environment used to develop programs, web apps and web sites.

Visual Studio is a suitable development environment to use in order to create a program for the vision system using C# as a default developing language. Visual Studio itself does not support forms of image processing such as object detection, object recognition and object classification. However, direct library links are available to perform such tasks. One in particular is AForge.NET, used by developers and researchers in the field of Artificial Intelligence and Computer Vision to perform essential tasks in image processing [7].

Therefore, AForge.Net is a suitable framework to use in order to perform accurate and precise object recognition to

determine the shape of the part as well as object tracking in recording the respective coordinates of the workpiece relative to the camera frame.

2.3 Calibration Procedure

Camera calibration is a vital step in securing both accuracy and the ability of the vision system to perform at an optimal level. When performing object tracking through image processing, an object's coordinates relative to the camera frame is given in pixels. However, a measurement in pixels cannot be transformed to robot coordinates. Therefore, it is necessary to perform a calibration as the camera produces measurements in pixels.

Calibration is implemented as a scaling tool to convert the measurement in pixels to a measurement in millimeters which is used by the robot coordinate system.

The vision system is calibrated using a linear based calibration technique. Linear based calibration is a technique in which three or more collinear points are used to measure world coordinates on a camera frame. This technique involves one snapshot of a set of collinear points of a known orientation relative to the camera frame and a known distance between the points in world coordinates. Linear regression between coordinates in the world frame and camera frame produce an equation for determining the relative position of various points on the camera frame in world coordinates. Figure 46 below illustrates the calibration template used in order to calibrate the vision system using a linear based calibration technique.

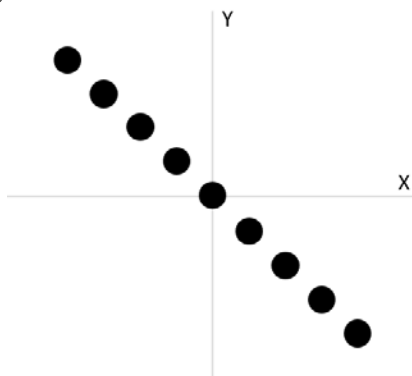


Fig 2. Calibration template

2.4 Communication between PC and Robot

Fanuc Robotics offers a direct library link which allows for communication between a windows-based PC and the robot controller using a C# programming language [8]. The direct library link file is easily accessible in Visual Studio and can be added as a reference.

Since the Fanuc M-11a robot makes use of the RS-232-C port, communication between the PC and Fanuc M-11a is performed through the RS-232-C via an Ethernet connection in order to update position registers and switch selected input and output ports.

Using various built-in methods provided by FANUC Robotics Controller Interface. A program can be written in Visual Studio in which the values of position registers on the robot controller can be manipulated. The status of digital inputs and outputs can be monitored in real-time through Visual Studio using the FANUC Robotics Controller Interface. The library link offers programming objects which can be used to simulate the status of digital inputs and outputs. In addition to updating various position registers on the robot controller, the library link is capable of monitoring the real-time position of the robot through Visual Studio.

2.5 Part Detection

In order for the vision system to perform object detection of the workpiece for determining its respective coordinates, the vision system must determine exactly when a workpiece moves within the camera field of view.

A laser and photoelectric sensor is fixed to either side of the conveyor to determine when the workpiece is about to move within the camera field of view. When the workpiece breaks the laser, the photoelectric sensor will not receive any light from the laser. The photoelectric sensor then switches a digital input on the

robot controller, the status of the digital input can be monitored using Fanuc Robotics Controller Interface library in Visual Studio. Once the digital input has been set to a high, the camera must capture an image of the part on the conveyor while it is still moving at a constant velocity. An average delay of 0.15 seconds must be accounted for when the photo-electric sensor is activated until the image is captured.

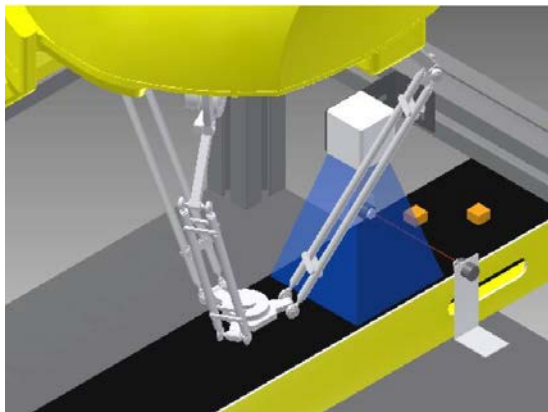


Fig 3. Setup of robotic cell

2.5 Graphic User Interface

The user interface is designed using a windows form application, designed and programmed in Visual Studio. The user interface is designed to be effective and easy to use.

The calibration procedure includes placing a calibration template in front of the camera field of view. Vertical and horizontal guidelines on the interface allow the correct placement of the calibration template directly in the middle of the camera field of view. Once the calibration has commenced, linear regression is performed to calibrate the position of circles on the calibration to world coordinates in millimeters.

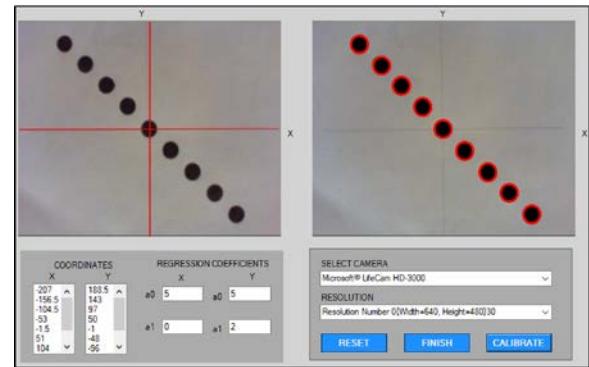


Fig 4. Calibration user interface

Once calibration is complete, an additional window is opened once the vision system is fully operational. The picture box on the left hand side of the window depicts the live video feed from the webcam. The picture box on the right hand side of the window shows the captured image of the workpiece on the conveyor once the laser beam has been broken, signaling the presence of the workpiece in the camera field of view.

The coordinates of the captured workpiece are displayed on the panel below the captured image. Both the coordinates of the workpiece in the camera frame and robot frame are displayed on the window. The camera coordinates displayed are in units of pixels, which represent the position of the workpiece relative to the center of the camera frame. The robot coordinates displayed are measured in units of millimeters.



Fig 5. Operational user interface

3 Overall Design Description

The camera used is a Microsoft Life-Cam HD-3000 which returns a video feed of

720P through the USB 2.0 interface, thereby eliminating the need for additional lighting. The video feed is then processed using AForge.Net, which is used to determine both the workpiece profile and the coordinates of the workpiece. Once the coordinates of the workpiece have been determined, Fanuc Robotics Controller Interface is used to send the workpiece coordinates to the robot by updating position registers.

Workpieces are manually loaded onto the conveyor at any given position or orientation. Once a workpiece moves into the line of sight of the laser beam fitted on the conveyor, the status of digital input 101 on the robot controller is changed. Giving a certain time delay for the workpiece to fall completely within the camera field of view, an image of the workpiece is captured.

Once the image has been captured, image processing and object detection occurs. The shape, position and orientation of the workpiece relative to the camera is determined using the AForge.Net.

The position of the workpiece relative to the camera field of view is transferred to the robot coordinate system by means of matrix transformations. The equation below illustrates the matrices used to transfer coordinates relative to the robot base.

$$T_{Workpiece}^{Robot\ Base} = T_{Camera}^{Robot\ Base} \cdot T_{Workpiece}^{Camera}$$

Therefore, the matrix that denotes the position (X, Y, Z) and orientation about the Z-axis of the workpiece relative to the robot base is represented as follows:

$$T_{Workpiece}^{Robot\ Base} = \begin{bmatrix} C\theta & -S\theta & 0 & p_x \\ S\theta & C\theta & 0 & p_y \\ 0 & 0 & 1 & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

However, as the camera captures an image of the workpiece and image processing occurs to determine the relative position and orientation, the workpiece is still

moving along the conveyor. Therefore, the vision system will determine the exact time taken for image processing and matrix transformation to occur. Once the time is known with a fixed conveyor speed, the position of the workpiece is updated as it moves along the conveyor.

After all processing measures have been completed, the coordinates and orientation of the workpiece are passed to a position register on the robot controller.

The robot will then continue to wait at a home position until the status of a digital input has been changed, therefore signaling that the robot may move to the updated position register and select the moving workpiece from the conveyor. Additionally, the status of digital outputs are changed to notify the robot as to whether the workpiece is of a quadrilateral or triangular profile. Therefore sorting each profile accordingly.

The subroutines of both the cell controller and robot controller are represented below. Figure 6 illustrates the routine followed by the cell controller whilst the vision system is operational.

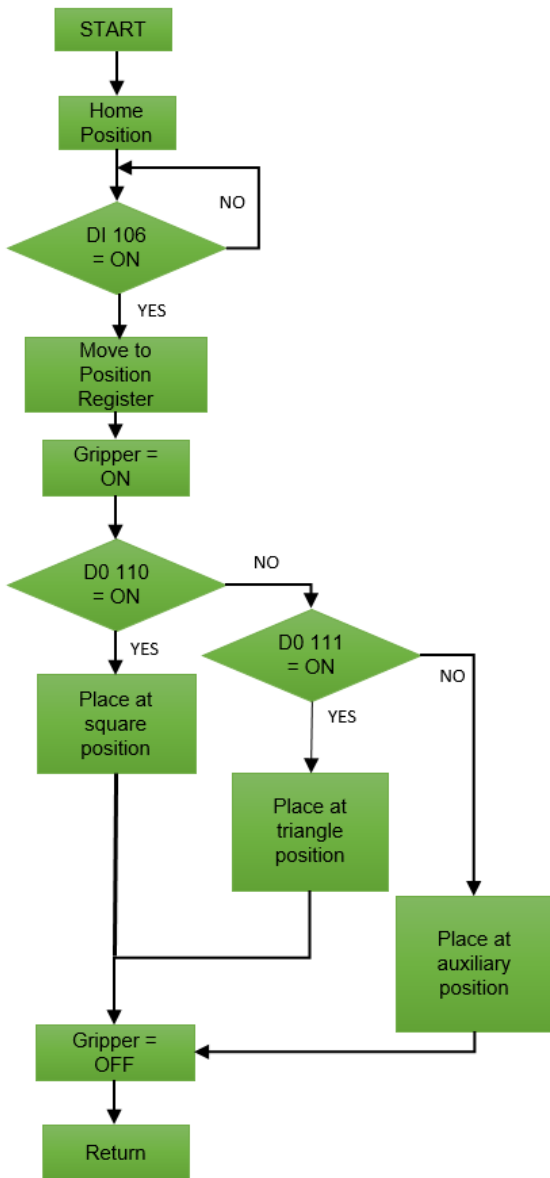


Fig 6. Robot controller block diagram

Similarly, Figure 7 illustrates the subroutine followed by the robot controller once activated by the cell controller.

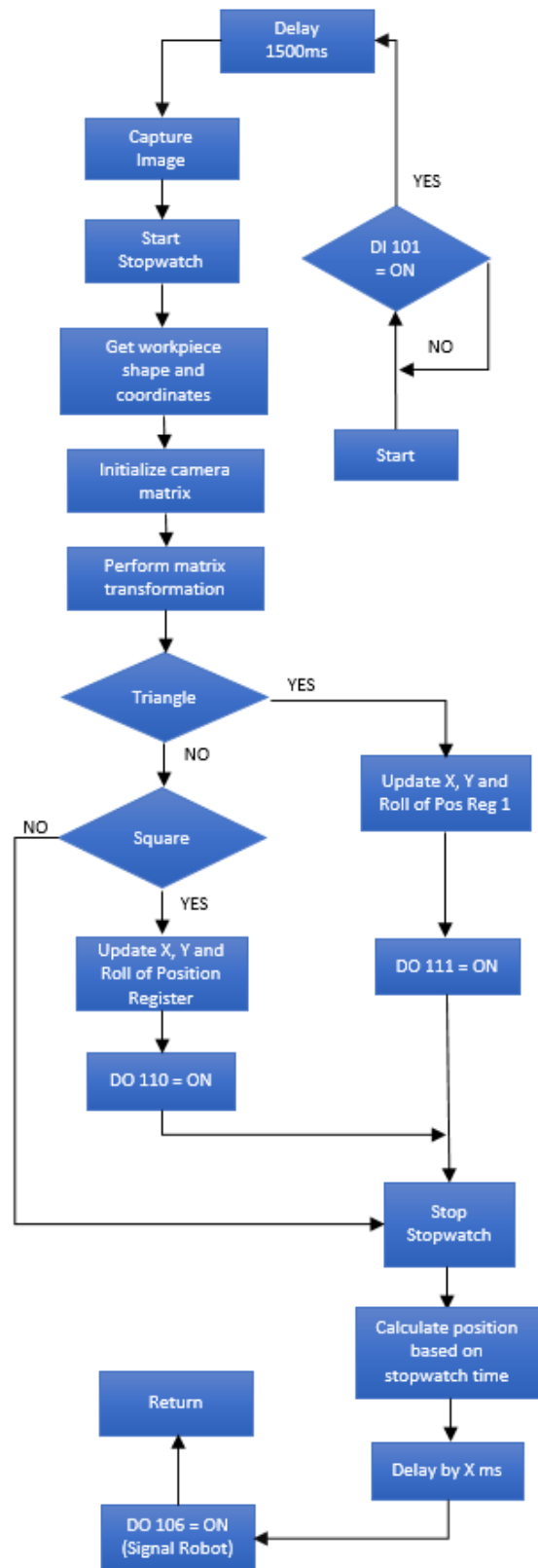


Fig 7. Cell controller block diagram

4 Statistical Analysis

4.1 Repeatability

The repeatability test was performed using circles to avoid any variations in the offset due to the orientation of the workpiece. The accuracy at which the robot picks a workpiece off the conveyor will be determined by the distance from the tool center point to the center of the workpiece. This distance can be measured once the part has been placed as the position at which the robot tool center point will be once the part is placed is known. The position of the tool center point forms the center point of the 1mm grid on which the part is placed. The offset is then determined by measuring the distance of the workpiece center to the center of the 1mm grid.

Ten measurements are taken of the offset of the center of the part and the center point at which the part should be placed. A repeatability test is performed on the data collected to determine the accuracy of the vision system.

Table 1. Repeatability results

Repeatability					
	X Offset (mm)	Y Offset (mm)	$\sqrt{x^2 + y^2} = x_i$	$x_i - \bar{x}$	$(x_i - \bar{x})^2$
1	-1	0	1	-0.75	0.56
2	0	-1	1	0.75	0.56
3	-2	-2	2.82	1.07	2.89
4	0	-3	3	1.25	1.56
5	0.5	0	0.5	-1.25	1.56
6	2	0.5	2.06	0.3	0.09
7	1	2	2.24	0.49	0.24
8	-1	-1	1.41	-0.34	0.12
9	0	-1	1	-0.75	0.56
10	1.5	-2	2.5	0.75	0.56
					8.7

Mean value of repeatability test:

$$x = \frac{\sum_{i=1}^N x_i}{N}$$

$$x = 1.753$$

Standard deviation of repeatability test:

$$s_x = \sqrt{\frac{\sum_{i=1}^N (\bar{x} - x_i)^2}{N-1}}$$

$$s_x = 0.9831$$

Standard deviation of means of the repeatability test:

$$s_{\bar{x}} = \frac{s_x}{\sqrt{N}}$$

$$s_{\bar{x}} = 0.31$$

True value:

$$x' = \bar{x} \pm t_{v,p} s_{\bar{x}}$$

Such that,

$$v = N - 1 = 9$$

$$P = 95\%$$

From t-table:

$$t_{9,95} = 2.262$$

Thus the true value is as follows:

$$x' = 1.753 \pm 0.7$$

Since

$$x^2 + y^2 = x_i^2$$

$$x = y = 1.24 \pm 0.495 \text{ mm}$$

To conclude, for the given set of results, the accuracy of the vision system in both the X and Y direction is 1.24mm.

4.2 Calibration

The vision system, as previously mentioned is calibrated using a linear based calibration technique. Linear based calibration is a technique in which three or more collinear points are used to measure world coordinates on a camera frame. This technique involves one snapshot of a set of collinear points of a known orientation relative to the camera frame and a known distance between the points in world coordinates [9]. Linear regression between coordinates in the world frame and camera frame produce an equation for determining the relative position of various points on the camera frame in world coordinates.

A table is drawn containing the distances between each circle on the calibration template and the coordinates of these circles measured in pixels by the vision system. Linear Regression analysis is performed on both X and Y coordinates of the camera frame.

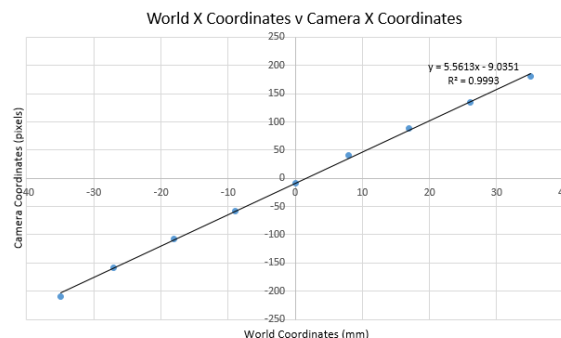


Fig 8. Regression analysis for X coordinates

The line of best fit is represented by the equation:

$$y_c = 5.5613x + 9.0251$$

The correlation coefficient of determination is given by $R^2 = 0.9993$

The correlation coefficient of determination is a key product of regression analysis. It is interpreted as the proportion of the variance in the dependent variable that is predicted from the independent variable [10]. However, the coefficient of determination may lack internal validity as no direct cause and effect can be inferred. That stated, the association of two variables could be explained by a third variable [11]. Thus the correlation coefficient values are not effective estimators in the random error present in the equation represented by y_c instead, a precise estimate of the slope of the fit can be calculated by its standard error.

The standard error of fit is given by:

$$s_{yx} = \sqrt{\frac{\sum_{i=1}^N (y_i - y_{ci})^2}{v}}$$

$$v = N - (m + 1) = 7$$

$$s_{yx} = 798.05$$

The best fit equation with 95% confidence:

$$y_c = a_1x + a_0 \pm t_{v,P} \frac{s_{yx}}{\sqrt{N}}$$

$$P = 95\%$$

$$t_{7,95} = 2.365$$

$$y_c = 5.5613x + 9.0251 \pm 629.13(95\%)$$

Similarly, for the Y coordinates. The statistical measurements are as follows:

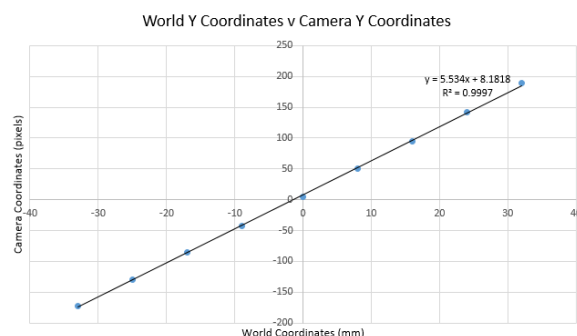


Fig 9. Regression analysis for Y coordinates

The best fit equation with 95% confidence:

$$y_c = a_1x + a_0 \pm t_{v,P} \frac{s_{yx}}{\sqrt{N}}$$

$$P = 95\%$$

$$t_{7,95} = 2.365$$

$$y_c = 5.5613x + 9.0251 \pm 655.93(95\%)$$

5 Conclusion

The vision system is successfully able to identify two profiles of workpieces, namely squares and triangles. The vision system is able to determine the position of both X and Y as well as the orientation of moving workpieces on the conveyor. After performing calibration and repeatability tests, an accuracy of 1.24mm in both the X and Y direction has been achieved. The velocity of workpieces moving along the conveyor is determined, therefore the vision system can adjust accordingly to assemble workpieces moving at various velocities. All of the listed requirements of the vision system has therefore been achieved, creating a low-cost vision system capable of selecting and correctly sorting moving workpieces from a conveyor.

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