©2016 Published in 4th International Symposium on Innovative Technologies in Engineering and Science 3-5 November 2016 (ISITES2016 Alanya/Antalya - Turkey)

Image-Based Automation System for Sorting Plastic Bottle Caps Using PLC and SCADA

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Abstract

Automation and robotics are rapidly developing today. Recently, image processing and situation analysis have started to constitute an important part of industrial automation processes. In this study, sorting (categorization) of plastic bottle caps by their colors and geometric shapes was achieved based on image processing. The prototype used for this consisted of a conveyor belt, a camera, an Arduino card, a robotic arm and a PLC. Control over the system is achieved via PLC (Programmable Logic Controller), SCADA (Supervisory Control and Data Acquisition) and the Arduino card. Integrity and color of the caps are detected on the prototype with the method of image processing. The C# programming language was used for this. The caps are grabbed by the robotic arm and stacked based on their geometric shapes and colors. The system can be monitored and controlled on the SCADA screen. While the prototype may be used as an R&D tool for industrial automation processes, it may also be used as education material for schools.

Keywords: Image processing, automation, PLC, SCADA, robotic arm.

1. Introduction

High-quality and hygienic production technology is one of the most important factors among the indicators of development for countries today. This is even more important for processes where water, the most essential subject for life, is brought from its source to the final stage for consumption. Experts suggest that water will be a more important strategic resource than oil in the near future. This situation makes any kind of research on water even more significant. One of the stages of preparing drinking water for consumption is capping the bottles. Improper capping operation may cause serious hygiene issues.

In this study, a prototype was constructed for checking the integrity and color of plastic bottle caps. Integrity is inspected based on the geometric shape of the caps. The caps that are not in compliance with the pre-defined dimensions and geometric shape introduced to the system are declared faulty. Control of color and integrity is facilitated by the same camera.

Some of the studies conducted on the image based control system are given in the references section [1-5].

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2. Materials and Method

The units used in the system are briefly described below.

2.1. Webcam

An HD web camera with a resolution of 1080p was used for image processing.

Figure 1. HD Web-Cam

2.2. Bunker

This is the system that drops the caps used in the system onto the conveyor band with the help of 1 NEMA 17 Stepper motor. The plastic parts of the bunker were drawn in SolidWorks before as solid pieces and printed using a Nova 3D printer in 100 microns with 25% fill density.

2.3. Electronic control unit

The microcontroller model/brand Arduino ATmega328 was used for controlling the system.

This is the card controlling the movements of the conveyor belt and the robotic arm by comparing the signals coming from the image processing interface.

The Arduino Nano embedded system was used for practicality. A relay (for controlling the conveyor belt), 2 MZ80 object detection sensors, 3 servos and 1 stepper motor are connected to our electronic card.

Figure 2. Arduino nano ATmega328

2.4. Sensors

In order to detect the placement of caps, MZ80 sensors were placed in order to face the front of the camera and the front of the robotic arm. While MZ80 is a digital sensor, it provides an output of 1 when an object is detected, and 0 when there is no object. The sensor is an industrial infrared sensor with a range of 80 cm.

Figure 3. Mz80 sensors

2.5. Robot Arm

The robot has three axes. Its movements are facilitated by 4 servo motors. We constructed it in a 3D printer in 100 micron layers and with 25% fill density. Its function is to drop the caps into the correct box.

Figure 4. Robotic Arm

2.6. Conveyor

The conveyor belt has the dimensions of 1400x350x10 mm its movement is achieved by one DC motor with reducer. It is made out of PVC and it is white. The purpose of the white color is to achieve lower amount of glow in comparison to black while processing images.

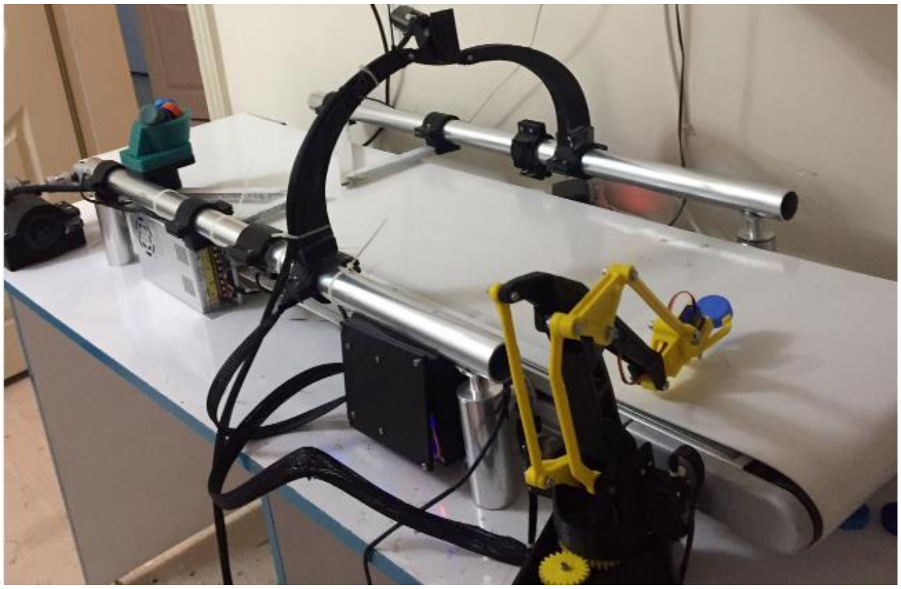


Figure 5. Conveyor system

2.7. PLC

PLC of model/brand Siemens S7-1200 CPU 1214C DC/DC/DC was used. Its function is to control the servo motors used in the robotic arm and monitor and control the system via the SCADA screen.

3. Prototype Implementation

The operation scenario of the cap automation prototype implementation is as the following: caps are randomly dropped onto the conveyor belt from the bunker one by one. In case of more than one cap falling onto the belt, the caps are put into an order on the belt with the help of the mechanism. When the cap moving on the conveyor belt is detected by the sensor, the belt is stopped. The cap scanned by the camera is assessed based on its geometric shape and color. The data are sent to the Arduino card. If the cap is different from the geometry of a pre-defined solid cap, it is defined as faulty and dropped to the faulty box by the robotic arm without looking at its color. If the cap is defined as solid, it is categorized based on its color and dropped into the box with its own color. The conveyor belt is stopped again by the second sensor before the robotic arm places the caps into the relevant box. The PLC moves the robotic arm based on the digital data it receives from the Arduino card. The function of the sensors is to determine a reference placement point for the camera and the robotic arm. When the operations on the first cap are completed, the same process is repeated periodically for other caps. In this study, three different colors of caps, as blue, red and yellow, were used.

Figures 6, 7 and 8 respectively show the model, flow chart and the block diagram of the system.

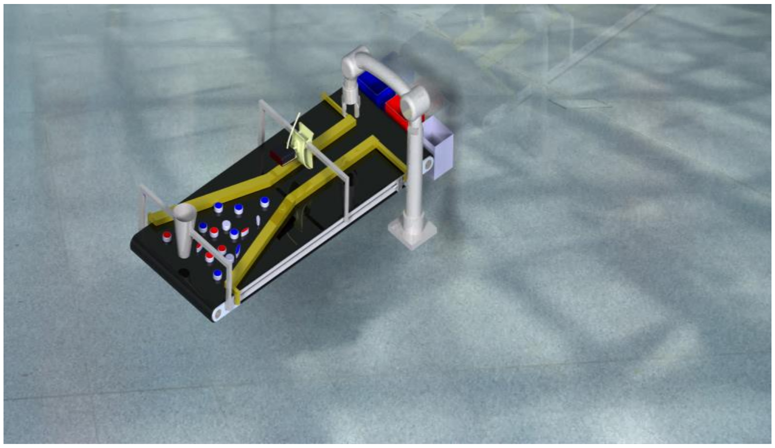
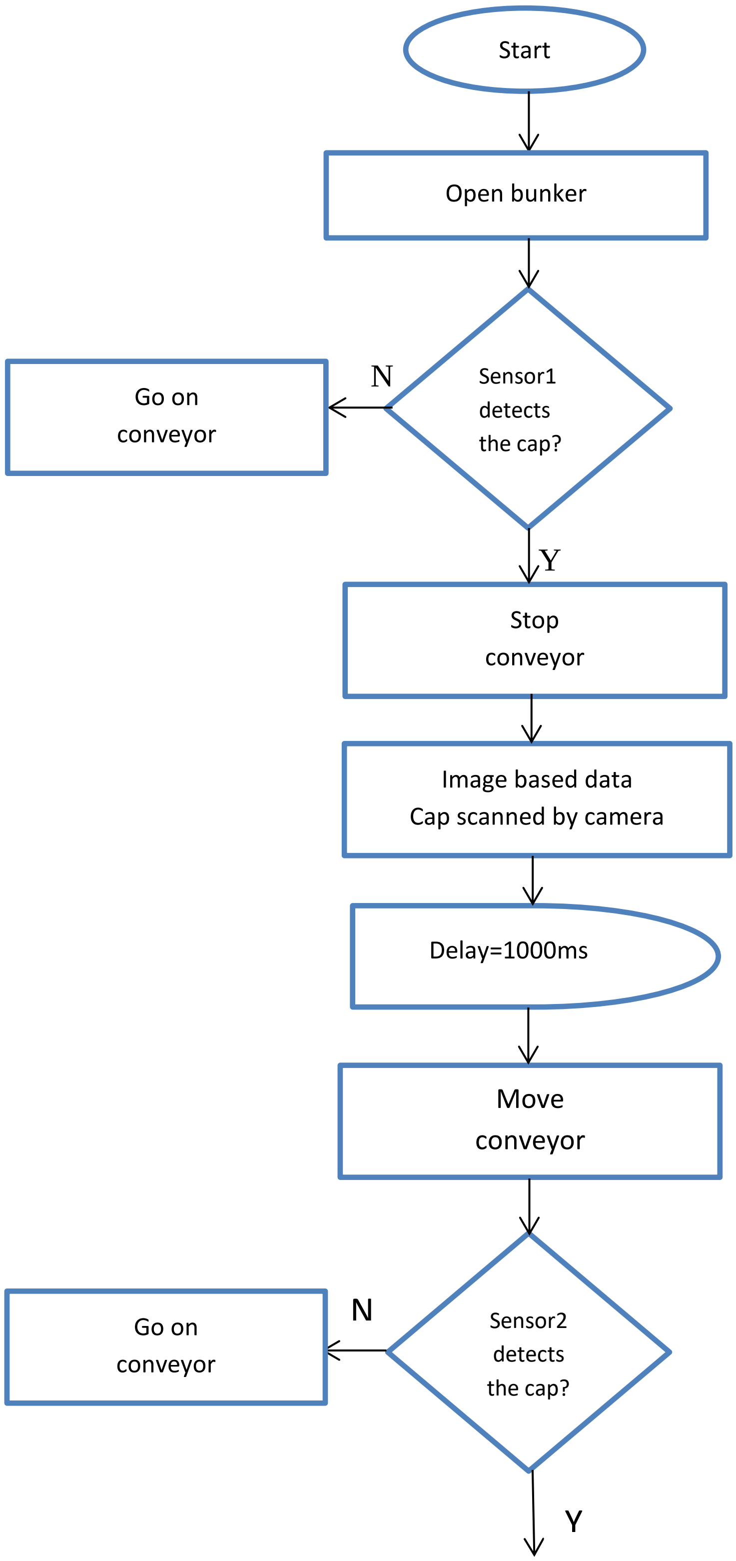


Figure 6. Model Studies

The system features 2 object detection sensors. These sensors provide digital outputs (1 when there is an object, 0 when there is not). The 1st sensor checks the area in front of the image processing camera, while the second one checks the area in front of the robotic arm. The purpose for the sensors is to determine the placement of the caps on the conveyor belt in critical positions. Accordingly, the 1st sensor sees immediately in front of the camera over the conveyor belt. The belt is stopped when the sensor detects the object; the camera system firstly takes dimensions, calculates averages, and conducts color space filtering. Then it produces a shape analysis and determines whether it is a circle. If it is not a circle, its color is not checked. If it is, its color and shape analysis is conducted by taking the average of the pixels on the cap, and the data of the analyzed cap is sent to Arduino. In the following, Arduino sets the output pins high based on the obtained cap data and sends information to the PLC. In the meantime, the conveyor belt moves. When the caps moving on the conveyor belt are positioned in front of the robotic arm, the belt is stopped again and the PLC moves the robotic arm based on the acquired information, therefore stacking the caps in the boxes.

The bunker and the robotic arm used in the prototype were constructed completely by us using 3D printer. The system used a total of six motors including on DC motor with reducer, one stepper motor and four servo motors. The DC motor with reducer controls the movement of the conveyor, the stepper motor controls opening and closing the bunker, and the servo motors control the movements of the robotic arm. The DC motor and the stepper motor are controlled by the Arduino card, while the servo motors are controlled by the PLC.


Start
Open bunker
Sensor1
detects
the cap?
N
Go on
conveyor
Y
Stop
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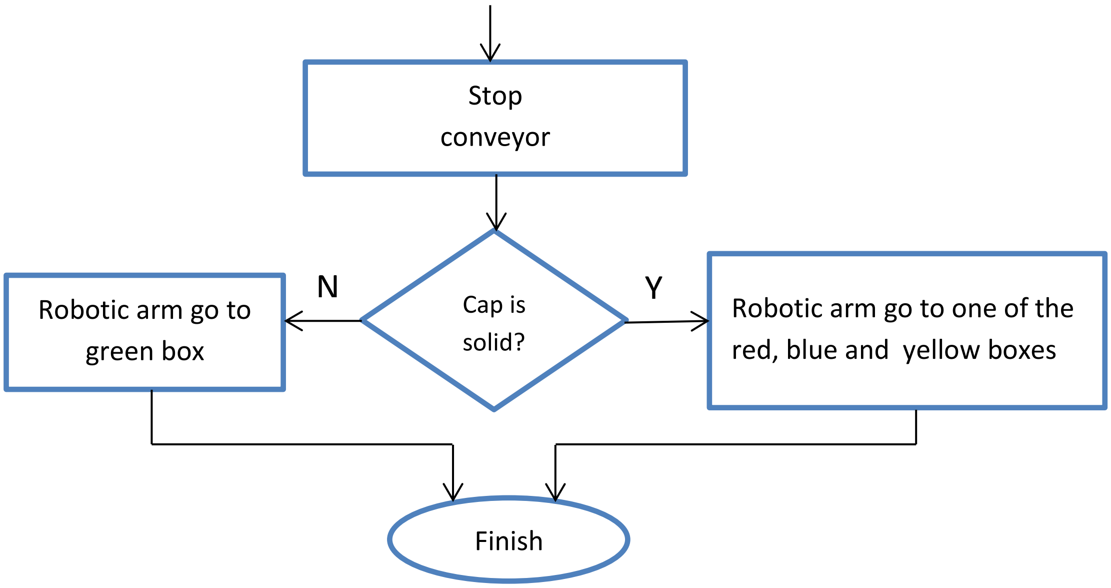


Figure 7. Flow card

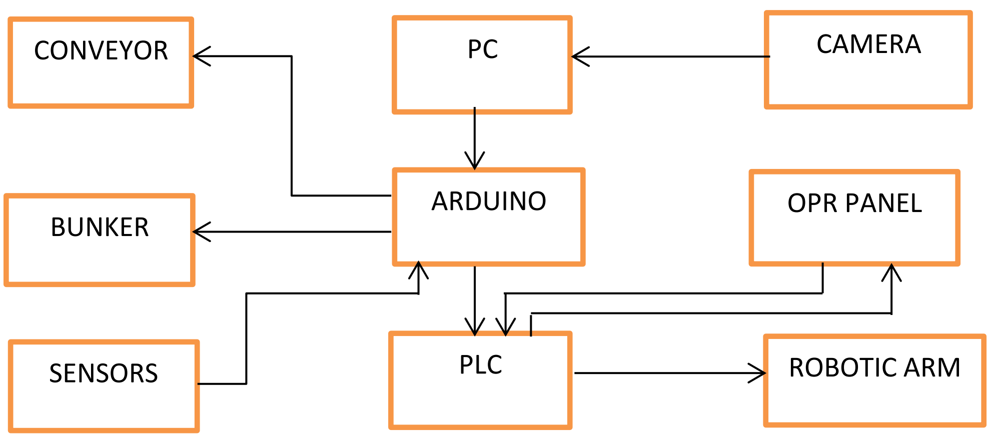


Figure 8. The block diagram of the system

The image processing operations, an important part of the systems, are achieved as the following: pictures of the caps on the conveyor belt are taken with the help of the interface program we wrote using the C# programming language, and 2 basic filtering processes are used. These are the grayscale transformation and noise reduction filters. After applying these filters, selectivity of objects around us is achieved with the help of the color codes of 3 primary colors provided in the library. For the dimensions and shapes of the objects, the filtered pixels, meaning the concentrated clustering of the filtered image, should be taken into account. Clustering is detected by the method of matrices.

Image processing implementations use industrial smart cameras of PC-based web-cams. Here, web-cam was chosen as it has considerably lower cost in comparison to other options.

Operations in the interface program are run like the following;

- Data from the image source (camera) are transferred to the interface.
- The image is pre-filtered using resizing, taking the median values, and applying color space filtering (HSLFiltering).
- Using the ShapeChecker method, whether there is a circle in the image is checked.
- If cap geometry is achieved, in order to find the color of the cap, average color densities of the pixels on the cap are calculated, Hue (color tone) values are checked in the corresponding HSL color model, and the color value of the cap is derived.
- The color of the cap is estimated by comparing the calculated Hue value with certain value intervals.

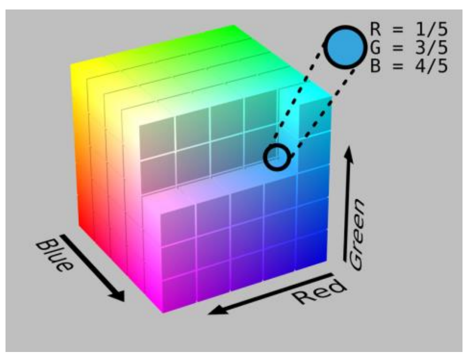


Figure 9. RGB Hue Cube

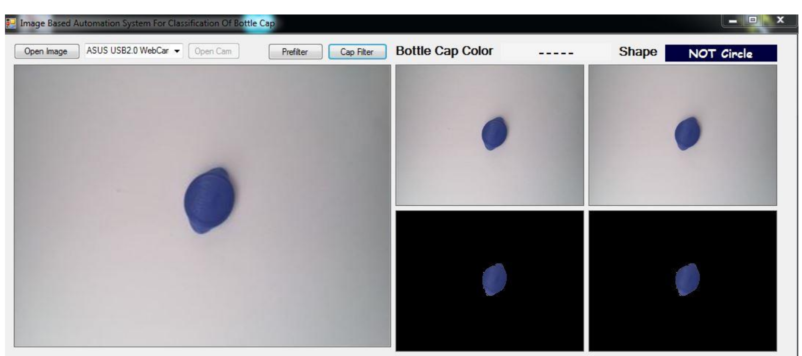


Figure 10. Image processing interface program geometric shape identification

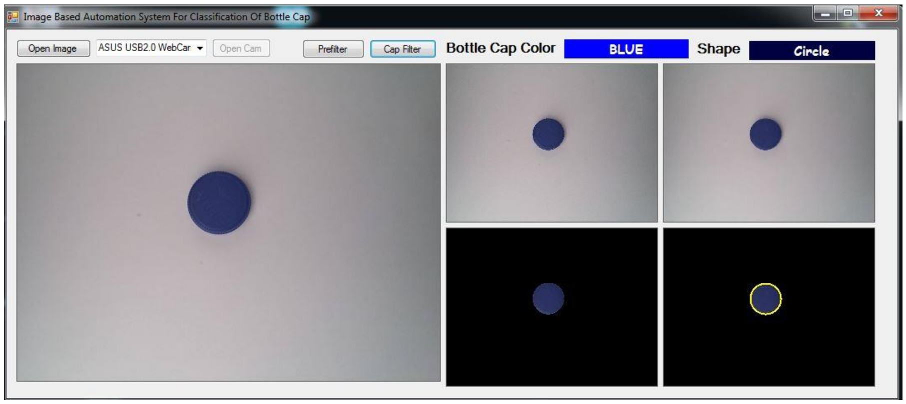


Figure 11 .Image processing interface program blue color identification

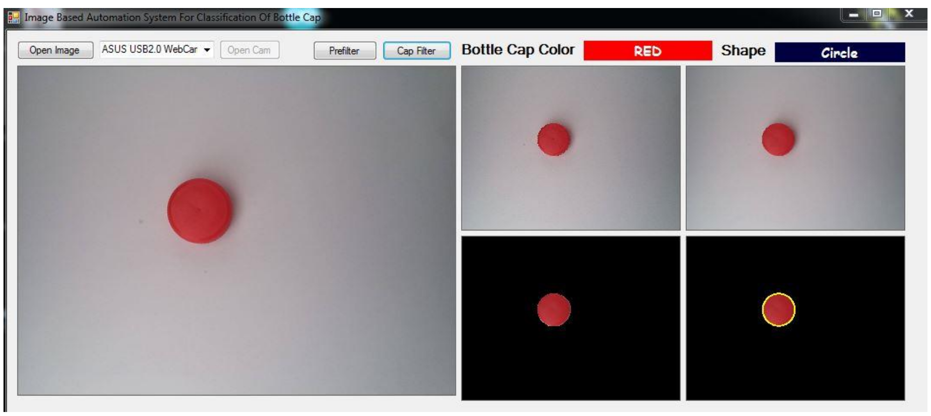


Figure 12. Image processing interface program red color identification

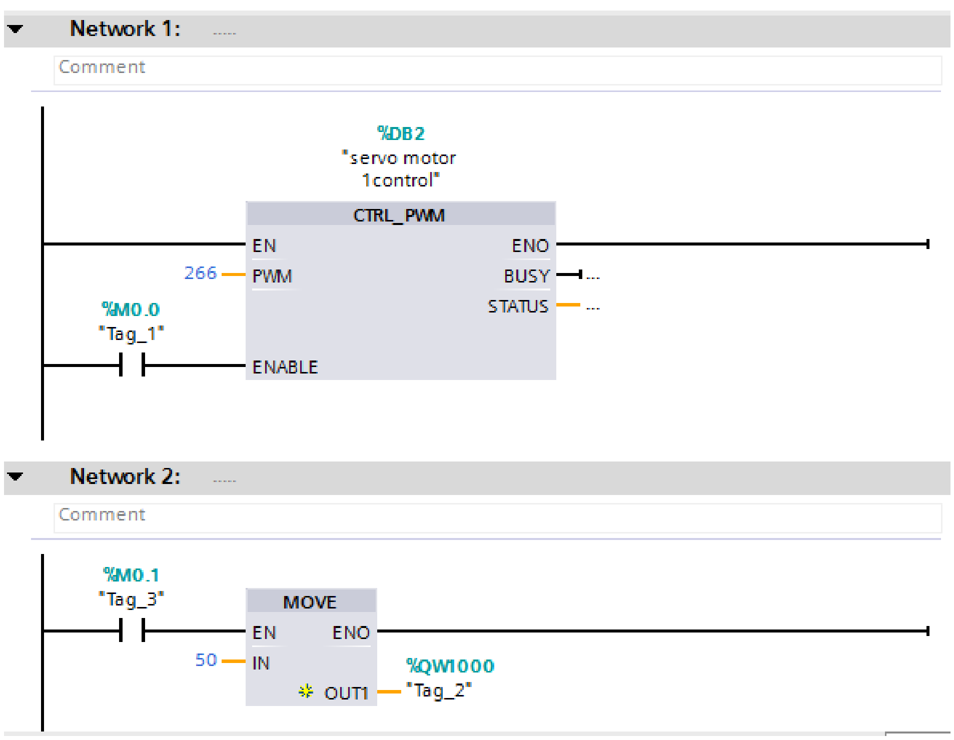
As seen in Figures 10, 11 and 12, the interface program processes the images received from the camera based on the algorithm mentioned above and produces the right output. This output is sent to the Arduino card via USB.

The servo motors in the robotic arm are controlled by the PLC. The robotic arm has 3 motors of type MG 995 and 1 motor of type SG 90. The SG 90 motor facilitates the jaw movements of the robotic arm, while the MG 995 motors lead the axial movements. After detecting the integrity and color of the caps with the camera and the C# program, the data are sent to Arduino, and to the PLC from Arduino. Based on this data received as a digital signal, the PLC runs the servo motors in a way that caps are picked up and placed into the correct boxes. The conveyor belt is stopped when the caps are detected by the second sensor. This point where the caps stop was taken as the reference point for the information on positioning. Movements of the robotic arm are always controlled based on this reference point.

The software for the PLC was constructed in the ladder programming language. The movements of the servo motors are controlled by modification of duty cycle (pulse duration) values of the signals applied onto the motors with the PWM function. The servo motors in the robotic arm are run in a way to drop the caps into the boxes they belong in. The positioning of the reference point where the cap is picked up from and the positioning of the box where the cap should be placed in are constant. Therefore, there are 4 pre-determined routes based on integrity and color of the caps (faulty ones, blue ones, red ones and yellow ones). The robotic arm always moves based on one of these four routes.

SIMATIC HMI Application/WinCC RT Advanced was used as the operator panel. An actual (physical) operator panel was not used.

The system can be monitored via the established SCADA screen. A section of the ladder diagram of the program written in the PLC is seen in Figure 13, while the SCADA screen is seen in Figure 14.



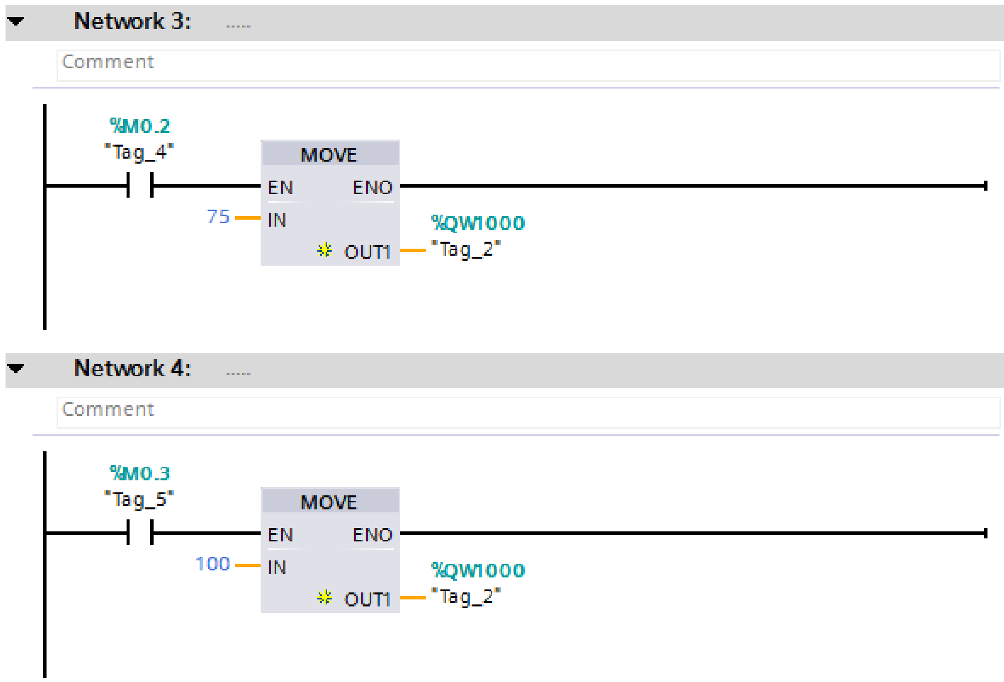


Figure 13. Part of the ladder diagram

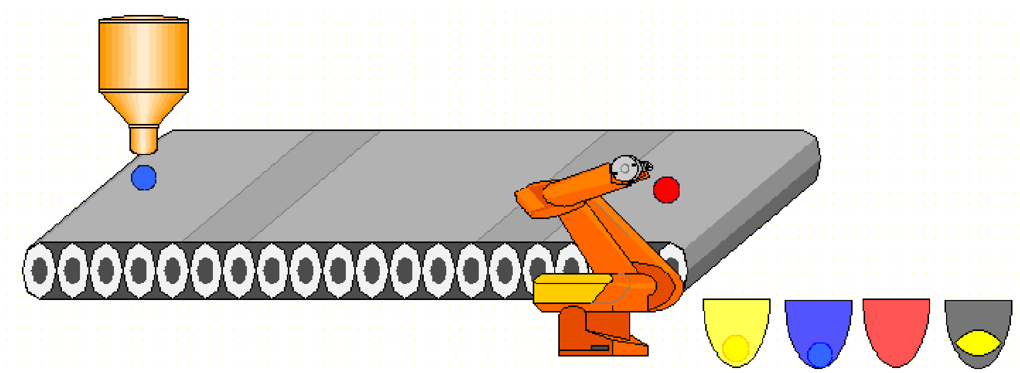


Figure 14. SCADA screen

Conclusions

An industrial automation system prototype was constructed in this study. In the operation of the system, C# software was used for image processing, and Arduino and PLC microcontrollers were used for hardware and software purposes in other controls. The reason for using both Arduino and the PLC as microcontrollers is that the constructed prototype will be used as educational material. The purpose is to provide students with an opportunity to compare the two systems by combining the Arduino embedded system popular among students and the PLC system, therefore presenting a different point of view for them. It was seen that determining the operating scenario and the algorithm in the optimal way is highly important in the fast and efficient operation of industrial automation systems.

This project, by usage in universities and schools that provide professional and technical training, will contribute to the laboratory education of students who will have the chance to observe the operation logic of an industrial automation system. The prototype may be used as educational material for courses like, Industrial Automation Systems, Special Electrical Machines, etc.

The constructed prototype is open to physical and software improvements. It is aimed to reduce the limitations of the system in further studies. Different image processing procedures will be tried and results will be observed.

Acknowledgements
This work was supported by Research Fund of the Karabuk University. Project Number: KBÜ-BAP-16/1-YL-172

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