MACHINE VISION IMPLEMENTATION INTO TECHNOLOGY-ORIENTED OPERATIONS

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DOI: 10.17973/MMSJ.2025_09_2025043

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Machine vision has experienced unprecedented growth in recent years, with its deployment aimed at accelerating inspection, technological and other industrial tasks. By utilising compact camera solutions, we can now meet a wide range of practical and end-customer requirements relatively easily and, above all, effectively. In this article, we, therefore, aim to design and verify a selected camera system that will recognise image data from the running process of the FESTO automated line. The emphasis and added value of the contribution lie in the deployment of an economically advantageous system, the usability of its built-in functions and modules, as well as in the quality control of the scanned objects. In addition, the results and experiments of this paper aim to monitor the transfer of requirements to other (typologically identical) existing operations, where it is necessary to implement a specific type of machine vision without the need for significant and often costly intervention in the existing hardware and software. The monitored parameters of the inspection process include the detection of an object's presence, recognition of the colour scale, and its orientation, with an emphasis on the visualisation requirements of the individual states of the automated workplace.

KEYWORDS

machine vision, PLC controller, detection of the object

1 INTRODUCTION

The use of machine vision in inspection, technological, and other industrial tasks has now become a standard. The main factors influencing the choice and specification of the type of machine vision depend on the importance of the requirements (which arise from the process, the object being monitored, etc.). These factors are often influenced by reliability, cost-effective deployment, quality, software, or individual elements (such as camera systems, lenses, lighting, etc.). Today's compact camera solutions can significantly facilitate and streamline a wide range of (primarily) standard application tasks. They can operate at high speeds, are highly accurate, and their control system can evaluate multiple measurements from a single captured image simultaneously. It is, therefore, no surprise that their deployment is growing and becoming increasingly important [Sobaszek 2019, Vagas 2022, Galajdova 2020]. This paper aims to verify the proposed concept, focusing on the transfer of requirements arising from communication between academia and practice, as well as from optimisation-suitable (and typologically similar) solutions for the given technological process. In many automated operations, it is necessary to innovate or introduce some form of machine vision [Sobrino 2019]. This form is, of course, dependent on quality requirements, economic factors, and the extent (and willingness) to intervene in existing automated operations. Additionally, the compact camera solutions now enable smooth and continuous monitoring of the process without the need to stop the application [Gaspar 2023]. Their built-in functions and modules significantly impact the quality of monitoring, control, and, consequently, the error rate across the monitored process. With increasing demands for speed and reliability, it is becoming apparent that the detection of object properties (presence, colour, dimensions, shape and many others) must take place in real-time (or at least with the least possible delay) [Dado 2016]. Therefore, the results and experiments in this paper monitor and verify the principle and methodology of transferring knowledge, requirements and solutions to other existing automated operations. Machine vision is represented in some form in almost all of them. The need to replace slow and manual methods of monitoring object quality is driving the use of image data processing algorithms, which are now integrated into compact versions. We want to use them to process the acquired image data, digitise it and display and evaluate it using a suitable communication interface. Today's companies are often unwilling to invest large amounts of money in the comprehensive automation of their workplaces. They are increasingly looking for ways to innovate (increase quality and efficiency) their technological processes without the need for a costly replacement of almost all existing equipment (both SW and HW). On the other hand, they require a specific form of visualisation of the automated workplace's status for individual management levels (from operators to management) [Janota 2024].

2 SYSTEM DESCRIPTION

The choice of a compact camera solution depends on several factors that have already been mentioned. However, we will focus (concerning the monitoring of the given technological task) on the presence, colour, and orientation of the scanned object. These factors influence the number of camera sensors (2D versus 3D) and the need for and specification of lighting, as machine vision can be assembled in many ways. At the same time, it is also necessary to ensure that the individual components are interchangeable, integrable, and usable with PC technology (regarding so-called future needs) [Varga 2021, Stejskal 2016].

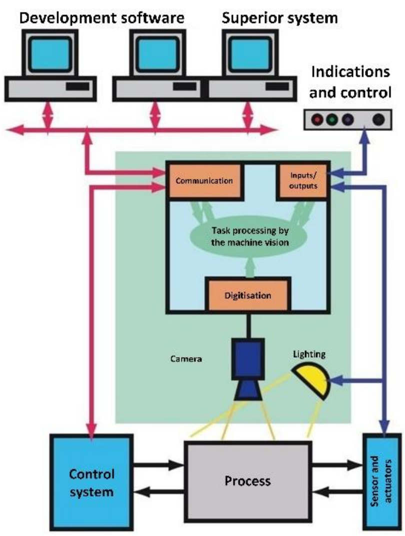

Figure 1. Methodological structure of a compact camera solution based on intelligence and integrability

The methodological structure of a compact camera solution based on intelligence and integrability (Fig. 1) relies on the use of sensors from the surrounding working environment of the automated line. It is essential for monitoring the given technological task, as the combination of sensors (based on inductance, capacitance, etc.) and a camera solution increases the probability of eliminating faults [Simon 2021]. In terms of the internal structure of the selected camera solution, it can be said that it is a unified, compact and integrated CCD system within a single housing (the principle of intelligent camera systems) based on the Ethernet/digital I/O communication interface. However, some technological tasks are more complex and require the connection of several such intelligent camera systems. But this is not the case here. When recognising image data with a compact camera system, many defects and reflections occur. Therefore, the data obtained in this manner must be pre-processed, filtered, and converted into a comprehensible form [Kot 2021, Vagas 2024]. Disturbing influences (variable lighting, but also other factors) distort the result. Therefore, these compact systems have built-in algorithms for removing image noise (Gaussian filtering principle) [Shen 2024]. This algorithm, G (x, y), can be mathematically described in a two-dimensional system as follows:

$$G\,(x,y) = \frac{1}{\sqrt{2\pi\sigma}} exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \tag{1}$$

Where:

x, y - pixel coordination,

σ - the standard deviation of the Gaussian distribution,

Essentially, this algorithm works on the principle of image smoothing, determining the weighted average of neighbouring pixels in the image. The object, its edges and its shape can be detected precisely because the pixel values at the edges of the image under consideration are reduced. By comparing two images, it is possible to obtain the difference (response image) for image1 (g_1) and image2 (g_2).

$$g_1(x,y) = G_{\sigma 1}(x,y) * f(x,y) \tag{2}$$

$$g_2(x,y) = G_{\sigma 2}(x,y) * f(x,y) \tag{3}$$

Where:

g the blurred result of the image,

f value of a specific pixel,

By subtracting g_1 and g_2, we obtain the Gaussian difference function (Gaussian function) G_F.

$$G_F = g_1 - g_2 = \frac{1}{\sqrt{2\pi}}\left(\frac{1}{\sigma_1} e^{\frac{x^2+y^2}{2\sigma_1^2}} - \frac{1}{\sigma_2} e^{\frac{x^2+y^2}{2\sigma_2^2}}\right) * f(x,y) \tag{4}$$

Subsequently, by calculating the gradient of the difference image *(image gradient, $\nabla D\,(x, y)$)*, we determine the strength and direction of the given image edge.

$$\nabla D(x,y) = \left(\frac{\partial D}{\partial x'}\frac{\partial D}{\partial y}\right) \tag{5}$$

x, y represent the pixel directions in the horizontal and vertical axes, and the formulas for calculating gradient magnitude and direction are as follows:

$$M(x,y) = \sqrt{\left(\frac{\partial D}{\partial x'}\right)^2 + \left(\frac{\partial D}{\partial y'}\right)^2} \tag{6}$$

$$\theta(x,y) = arctan\left(\frac{\frac{\partial D}{\partial y}}{\frac{\partial D}{\partial y}}\right) \tag{7}$$

Where $M\,(x, y)$ represents the gradient magnitude of the pixel, and $\theta\,(x, y)$ represents the gradient direction of the pixel.

The control unit of this methodological structure is a standard PLC controller (Siemens SIMATIC S7-1200), which processes output signals from the camera system and sends them to a higher level for further processing (visualisation, evaluation) [Silarski 2023, Miglierini 2006]. The heart of the structure is the BVS-E camera system from BALLUFF, which, in addition to two digital outputs, also has an illuminator. The power supply and peripherals are connected via two proven M12 industrial connectors [Bialy 2019, Peterka 2004, Saga 2018]. The process perspective focuses on monitoring the status of the FESTO automated line (MPS 500), which consists of several modular components. The methodological objective of the paper is to scan an object (and its properties) that moves along the line in a predefined route over time. Communication and evaluation take place during the continuous operation of this line, so this also had to be considered when selecting the camera system (concerning sufficient speed and image data processing).

3 EXPERIMENTAL RESULTS

The basis for conducting tests and experiments was the creation of the entire system in 3D software, connecting and activating individual sub-devices (concerning the compatibility of communication and the flow of collected image data). Specifically, the selected camera system was implemented into the existing environment of an automated line, where its task is to monitor the status of a selected object. At the same time, the modularity and transfer of this principle are based on the use of a PLC device and its communication with an IO-LINK module, which then distributes (and visualises) the resulting values (OK, NOK). Other (typologically and technologically identical) automated operations also strive for seamless integration and communication within their hardware and software devices. Therefore, we decided to test the most frequently requested parameters that occur in practice. It involves verifying the presence of an object and recognising its colour range and orientation, with an emphasis on visualising individual states for both operators and higher-level control forms.

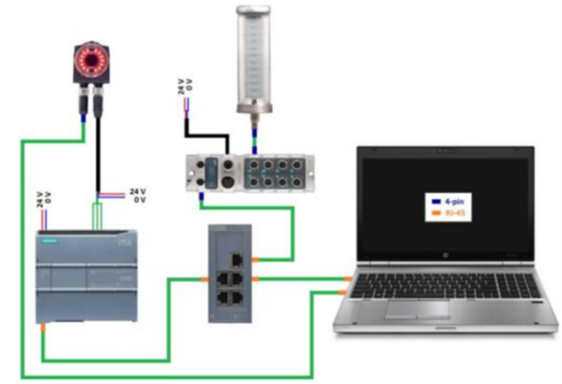

Figure 2. Tested the methodological structure of a compact camera solution

The above test connection of the methodological structure (Fig. 2) clearly illustrates the connection of the camera system using an RJ-45 cable, with control signals sent to the PLC controller via digital outputs. This structure allowed us to easily parameterise and configure the network settings of the camera system (using BVS CONVis software). The subtasks of this activity focused on specifying the IP address, configuring the network adapter, and assigning the hardware itself, i.e., the camera. At the same time, the RJ-45 connector enables us to set up, monitor, and record the created test algorithm for implementing the assigned inspection task. Verification and visualisation of statuses were performed using program blocks (TIA PORTAL) and communication with the IO-LINK module. We evaluated these statuses based on incoming data from the camera system.

3.1 CASE STUDY in the case of object detection

There are, of course, several ways to detect scanned objects. In this case, however, we decided to utilise the built-in functions and modules of the selected camera system to maintain the speed and quality of monitoring, as well as the error rate, across the monitored process. After several tests and configurations, a final test algorithm was created that uses the principle of infinite circular control, specifically the "*360° COUNT CONTOURS*" function. It is interesting in that it detects all contours in the acquired image and compares them with a stored database of learned patterns. The result of the presence is OK provided that the sum of all contours is greater than the specified minimum value (more than *75%*), Fig. 3. The recommended minimum value according to the catalogue sheet is at least *66%*, with *100%* being the maximum identity in the comparison and *0%* meaning that the object is not identical to the maximum extent possible.

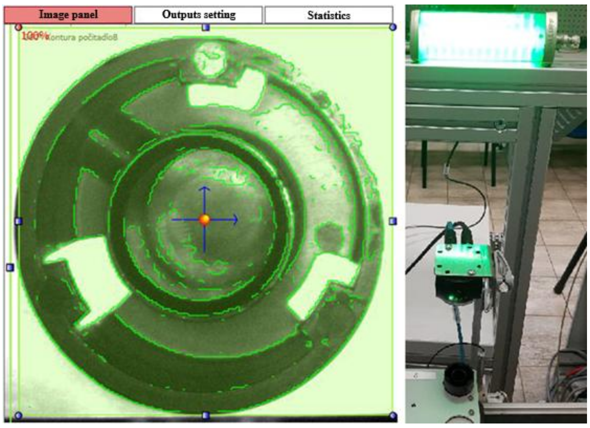

Figure 3. Example of a successful recognised object

Visual conformity or non-conformity (OK, NOK) of the scanned and recognised object is indicated by a segmented light beacon (green colour on the right side of Fig. 3). It can display three colours depending on the activated digital logic output coming from the camera system. At the same time, there is the possibility of combining the display of multiple colours simultaneously in the future. The result of this inspection technology task is thus suitably represented visually.

3.2 CASE STUDY for the colour scale of the object

When recognising the colour range of an object, we assumed that we only had a basic, i.e. monochromatic, image. It made the investigation of this experiment even more interesting. Selecting and choosing the appropriate function in combination with a connection to built-in function blocks proved to be the most effective solution. During testing, we found that the task is challenging to solve in cases where a colour camera system is not available, and the brightness level at the scanning location is variable. We dealt with these problems by detecting the edges of the object as an elliptical shape. Within this ellipse, we then measured the brightness value using the uniform built-in function of the camera system, as shown in Fig. 4.

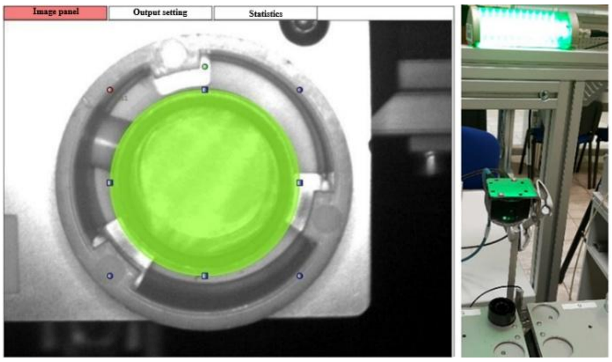

Figure 4. Example of successful colour recognition of the object

During testing of the minimum and maximum brightness values for a black object, a deviation of *±5%* was set so that at the reference value (which was experimentally determined at *65%*), this meant values up to *75%* of the brightness match level. The test of the implemented inspection technology task was successful; however, it is worth noting that a significant factor influencing the quality of the results is the system's susceptibility to changes in lighting within the automated line environment. Of course, light (light sources and reflections) has the most significant impact on brightness.

3.3 CASE STUDY in the case of object detection

This test aimed to experimentally evaluate the cover of the scanned object at various angles of rotation. At the same time, we also wanted to investigate the case where the cover would be absent from the scanned object. The testing showed that scanning the inscription (FESTO) on the cover of the object would be the most advantageous method, Fig. 5. The final testing algorithm uses the principle of contour scanning, considering its rotation, specifically the *"LOCATOR 360° PATTERN DETECT"* function.

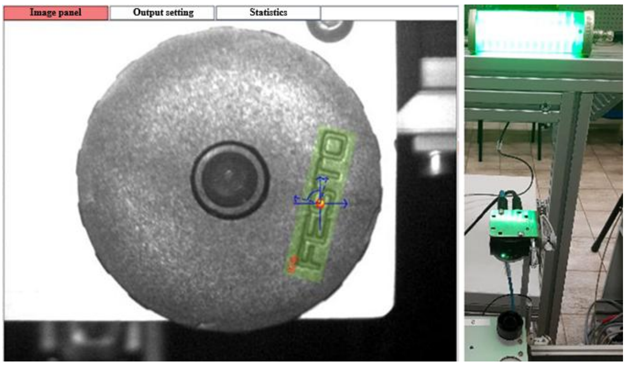

Figure 5. Example of successful orientation of the recognised object

A characteristic feature of this principle is the use of a learned pattern search in the scanned image environment. This environment is defined by a set of points (at least 5 points), in our case, created by an ellipse. The result is evaluated as OK or NOK (found or not found). The settings allow for a range of rotation within specified limits (e.g., from -180 ° to +180°). The image is captured in the form of a frame, and the image is processed in the background.

4 CONCLUSIONS

The boom in machine vision alerted the author of the article to the importance of this field. It was the initial impetus for verifying the above-documented and affordable solution.

The aim is to experimentally document the usability and transferability of this approach to other (technologically similar) automated operations. Today, with the ease of deploying complex camera systems, we can achieve more relevant results.

Efficiency and reliability are at a high level, as documented by a minimum object detection accuracy of over 75%. Colour recognition on the scanned object at a set deviation of ±5% was up to 75%, which can also be considered a satisfactory result. Object orientation, a factor widely used in practice, was tested at a minimum of five points, achieving a 100% result within the range of -180 ° to +180° orientation. Ultimately, the added value of those above and verified research represents the standardisation of the proposed concept, with an emphasis on economic efficiency and deployment in inspection and other industrial tasks.

ACKNOWLEDGMENTS

This work supports the project VEGA 1/0169/22 New methodics approaches to data from automated and robotised workplaces.

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