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Preparation of a Machine Vision System's Environment for an Automotive Manufacturing Technology Research

Attila Trohák, Zsófia Forgács

Institute of Automation and Infocommunication,University of Miskolc, Miskolc, Hungary
Institute of Automation and Infocommunication, University of Miskolc, Miskolc, Hungary
trohak.attila@uni-miskolc.hu, autforzs@uni-miskolc.hu

***Abstract*—This article presents a machine vision system that is part of an experimental system that follows Industry 4.0 directives. The main task of the equipment is to determine the orientation of a plastic part on the equipment's working plane and to move the part to the target location. For preparing the environment of the machine vision system, the authors had to make considerations about the camera, the sensor types and the lighting features of the system. This is an important step for making decisions when choosing the devices for the development.**

***Keywords*—machine vision; Industry 4.0; camera interfaces; lighting techniques;**

I. INTRODUCTION

In recent years, the authors have met a number of industrial challenges, where increasing the level of automation of the assembly processes could provide the solution in automotive manufacturing technology developments. The test results so far show that certain part of the manual assembly process can be replaced by automated assembly, but for designing a technology that can be used economically, further studies and simulations are required. As a result of this research a systemwill be developed which may be able to automate the assembly process of an entire production cell.

Within the New National Excellence Program our research plan won support, where our task is to examine the grabbing method of the manually assembled parts which are mounted by the operators and the tolerance of moving the object to the target location. This requires the development of an experimental, high resolution and high-precision equipment, which has the ability to take off parts from arranged sections and storages and then to place them in position by applying a manipulator and using machine vision.

The measurement of the accuracy of the parts' position, the implementation of the control algorithm and the other control engineering tasks will be carried out later, this article presents the requirements arising during the design of the machine vision system. By fulfilling these requirements we can build up the environment that is appropriate for our system.

II. REQUIREMENTS

Nowadays Industry 4.0, or the fourth industrial revolution is a closely related concept of the development of manufacturing and logistics systems, that creates new opportunities for continuous improvement and development of advanced manufacturing technologies and logistics processes. The three key components of Industry 4.0 are the Internet of Things (IoT) which provides access to a variety of devices over a network, the cyber-physical systems which are devices connected to a network and can realize control functions by using data collected by sensors and the third element is the "Big Data" concept for predictions of large amount of data by applying mathematical methods. [1]

The machine vision system presented in this article is a part of a pilot system which contributes to the development of an intelligent automotive manufacturing technology research. As part of the research we have to develop an equipment as a component of an automotive production line that replaces the manual assembly to automated assembly process. As a result of the research and development it may realize complex automation tasks of a complete production cell's assembly process by following the Industry 4.0 directives. According to the requirements of the pilot system, the orientation of the part placed on the working plane must be determined by using machine vision and then the part must be placed to the target coordinates by applying a manipulator.

III. CONSIDERATIONS FOR SELECTING THE CAMERA

The camera is a key element of our system, so by selecting the device many aspect must be considered. First of all, through the imaging system parameters we have to determine the required sensor resolution and size and the appropriate focal length as a function of the working distance, the scan type related to the application and finally, by examining the possible camera types and interfaces we will be able to choose the potential device type that fits best to our application.

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A. The imaging system parameters

For choosing the camera we determine firstly the imaging system parameters which are the sensor resolution, sensor size and the focal length. Figure 1. is for understanding the meaning of these parameters

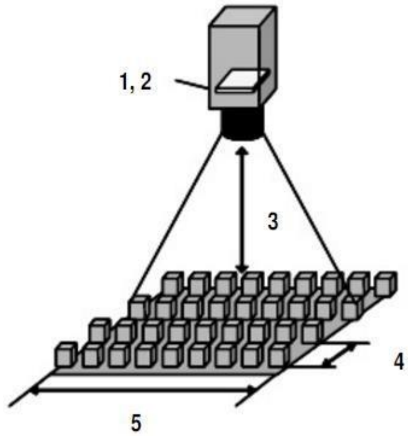


Fig. 1. The imaging system parameters [2]

Sensor resolution (1) represents the number of pixel rows and pixel columns in the camera sensor, the sensor size (2) means the physical area of the sensor array. The working distance (3) is the distance between the lens of the camera and the workpiece under investigation. Feature resolution (4) shows the amount of smallest object detail that can be distinguished and reproduced by the imaging system. The field of view (FOV) is the size of the area under investigation by the camera, which is determined by the horizontal and vertical dimensions of the area. [2]

Camera sensors contain two-dimensional arrays of pixels which detect the intensity of light, after these measurement data can be transmitted serially or parallel through an output register to the processing unit. We can determine the necessary sensor resolution by using the measured smallest feature size of the observed object and the field of view. By using the same measurement unit for the two parameters and by selecting the largest value of the horizontal and vertical dimensions we can use the following formula to determine the necessary sensor resolution [2]:

$$minimum\ sensor\ resolution = \frac{FOV}{feature\ re3solution} \qquad (1)$$

In our case the greater dimension of the field of view will be adjusted to 500 mm, the smallest feature size of the observed object is 2.5 mm, so the larger component of the necessary sensor resolution’s size is 400 pixels. Among the products that we checked the smallest sensor resolution was 640x480 pixels, that is appropriate for our application. The working distance, the sensor size and the field of view also affect the focal length, according to the following formula.

$$focal\ length = sensor\ size * \frac{working\ distance}{FOV} \qquad (2)$$

For determining the focal length of the lens and the sensor size helps Figure 2.

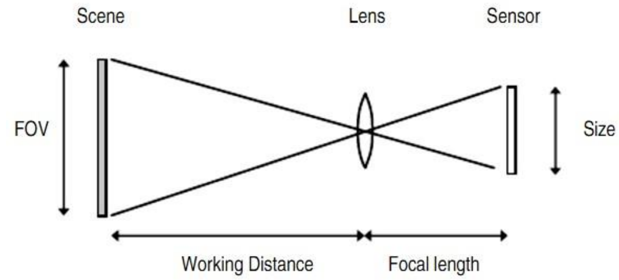


Fig. 2. Determining focal length and sensor size [2]

Since the lenses are only available with certain standard focal length (e.g. 6 mm, 9 mm, 12,5 mm), so after choosing the device we will have to adjust the working distance to get the part under inspection in focus. As the lens with short focal length can cause high distortion, if the application is sensitive to image distortion, increasing the working distance and applying cameras containing lens with higher focal length may eliminate this problem. [2] The sensor size also will be known after selecting the device, so the tuning of the parameters above of the system will be realized later, by considering the equation (2).

B. Methods of image recording

After determining the imaging system parameters, it is worth examining the typical scan types to make the ideal choice of the different image recording methods. There are basically two different technologies, the area scan and the line scan cameras. The area scan cameras acquire an area, so multiple rows and columns of pixels at one time. In case of line scan cameras the scanning method works line by line, so only one line of pixels will be scanned at a time, providing by this a faster acquisition. Of course, this method requires further processing tasks for fitting together the pixel rows, so for building the whole image. The line scan cameras proved useful in applications where the object under investigation performs movement in the system (e.g. on conveyor belts). Summarizing, the disadvantage of the area scan cameras compared with the line scan devices is that slower scanning speed is available to them, however, they cost less and their use requires less processing tasks than the other technology. Although line scan cameras are more expensive and by using them further processing required for building the image, but they provide faster acquisition and can be applied for recording object at higher speeds too. [2] In case of the application developed by us, the investigated parts do not move during the observation period, furthermore, our application is not time- critical, so the area scan technology fulfills our needs.

C. Camera interfaces and sensor types

Two types of camera interfaces can be distinguished: analog and digital interfaces. The output video signals of the analog cameras are continuously variable voltage signals. Most common standard formats of the analog cameras are RS-170, NTSC, CCIR and PAL.

Most low-end analog cameras has the quality limitation of interlaced scanning, where the image is split into odd and even lines of fields, then the scanning method follows among them alternately, with some time delay, and finally, the two sides will be put together, thereby displaying the image appears to be continuous. The disadvantage of this technology that in case of fast-moving object there is a smaller delay between the two image scanning processes, which blurs the captured image. The progressive scan method can eliminate this problem, where instead of scanning and concatenating separate parts of the image, the entire image will be scanned. Progressive scan using devices are typically used in applications where the object under investigation performs motion. [3, 4] Although the progressive scan technology is not typical of standard analog cameras, but there are solutions where the full-frame scanning is adjustable via software instead of part by part scanning, thereby eliminating the blurring of the image. [2]

Most cameras of machine vision systems use digital interface. These devices transmit the image as digital data to the processing unit. [5] The most common digital camera interfaces are Camera Link and the IEEE 1394 (FireWire) standards, furthermore, it is worth to mention the non-standard parallel interface. The parallel interface provides a wide range of acquisition speeds, image sizes and pixel depths, but the cabling of the devices supported this interface may represents a very complex task. The IEEE 1394 standard provides a simple daisy cabling, but offers slower data transfer rate. The Camera Link standard was developed by a consortium of several companies. This standard provides high data transfer rate, uniform cables and interface, but not more than 10 meters of cable length can be applied with it. [2]

Overall, by comparing the two camera types it can be stated that the analog cameras are cheaper and allow simpler cabling, but their product range of market is much poorer and also potentially lower image quality can be achieved by applying them. In addition, digital cameras can be used in imaging applications with the requirement of high speed, high pixel depth and large image sizes, they can be controlled programmable and using them leads less image noise compared to analog cameras. [2] The observable parts in our pilot system are black colored plastic buttons with white captions included by dashboard panels shown in Figure 3.

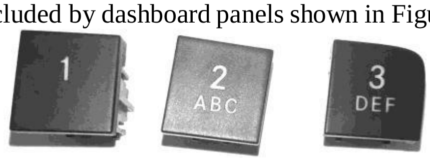


Fig. 3. The investigated parts in the experiments

A low-cost, monochrome analog camera could be an appropriate choice for most beginner machine vision applications, as well as in our case, since the investigation of the colors are not necessary for us, and because we observe the part with the camera after it has arrived to the working plane, so it will no longer perform high-speed motion.

Basically there are two technologies of sensors which is worth to mention, the CCD (Charge-Coupled Device) and the CMOS (Complementary Metal Oxide Semiconductor) sensors. In most machine vision systems cameras with CCD sensors are used. [5] In this case the sensor is a silicon chip that contains photodiodes which are suitable for charge storing and its surface is divided into pixels. To each pixels connects a single electrode. An external clock signal generator circuit shifts the charge packets down the line, pixel by pixel and row by row. Finally, perpendicular to the shift's direction, the packages converted to voltage signal get to the input of the image processing unit through an external amplifier and an analog/digital converter circuit. CCD cameras are available in many different formats, resolution and sensitivity. [6]

In case of CMOS sensors there is no need for charge coupling, each picture element has an amplifier to amplify the charges pixel by pixel, rather than line by line. This may be useful for time-critical applications, where only a certain part of the image becomes relevant. The advantages of CMOS sensors against CCD sensors are the lower production costs and lower power consumption, which have replaced charge- coupled devices in most applications. [6]

IV. LIGHTING FEATURES OF THE MACHINE VISION SYSTEM

The critical first step of each machine vision application is to set up the appropriate environment. After examining the parameters of the imaging device, we must carefully consider the light source and lighting technique to use in our system, because lighting poses the developer to a critical decision by any machine vision application.

A. Types of the light source

The illumination is a critical issue for all camera-based application. At the most basic level, generally it can be stated that we will have "enough" light for recording a good quality image, but we need to think about the orientation, geometry and light color in order to highlight the relevant details and minimize those parts of the image that restrict the image processing (e.g. glares). [5] The light sources commonly used in machine vision are fluorescent, quartz halogen, LED (Light Emitting Diode), metal halide (mercury), and xenon. Fluorescent, quartz halogen, and LED light sources are used the most widely, especially in small and medium-sized machine vision systems. Metal halide and xenon are more typically used in large-scale applications where there is need of a very bright light source. Figure 4. shows the advantages and disadvantages of fluorescent, quartz halogen, and LED lighting source types. [7]

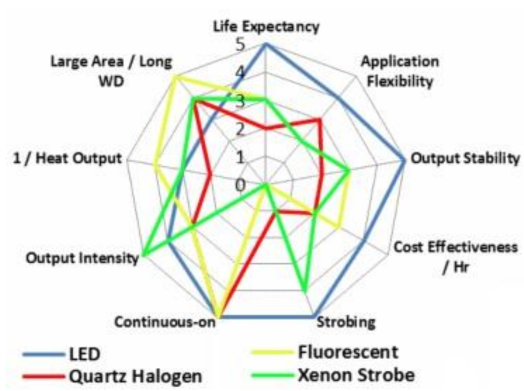
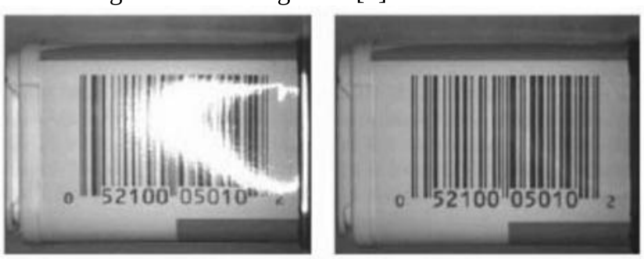


Fig. 4. Comparing lighting sources [7]

In recent years LED technology improved in stability, intensity, and cost-effectiveness, however, it is still not as cost- effective for lighting large areas, especially compared with fluorescent sources. If the application flexibility, output stability and longevity are important parameters, then LED lighting might be the appropriate choice.[7] Since for LED- based systems, most manufacturers products supporting the use of different lighting techniques on the same lighting device so during the research LED light source could be appropriate for us.

B. Lightning techniques

We examined the ring lighting, backlighting, diffused lighting and the strobe lighting of the illumination geometries and techniques. In case of ring lighting the light covers the camera lens around, thereby resulting an intensive shadow-free light along the axis of the camera. It is often used in combination with polarizer to filter the glares generated by illuminating bright objects. Strobe lights turn on and off very rapidly in order to illuminate objects under inspection at very specific points in time. A great advantage of the technique is that it reduces blurring of the recorded object. Since the object is illuminated only briefly, it is sometimes necessary to apply a gain to the image so that the pixels do not appear too dark in the image. By using backlighting the observed object placed between the camera and the light source. This technique is useful when our application is only about to examine the shape of the object. Its advantage, that it creates a sharp contrast that makes finding edges and measuring distances easy, but a disadvantage, that curved objects can diffract light. Some objects reflect light due to their surface texture or curvature. For eliminating this glittering, reflective effect we can use diffused lighting. The effect of applying diffused light shown in Figure 5. [2]



On the left part of the image the barcode image was acquired using highly directional light and the barcode on the right side was acquired using diffused lighting to reduce glare. [2]

As the system developed by us primarily examines plastic parts with a label, the backlight is not appropriate for us. By determining the orientation, the parts will not perform movement on the working plane, so applying strobe light is not necessary, however later, if the image recording device or the lighting control unit supports the strobe lighting control, we should examine its application methods also. Since on the parts there are small white signs which in case of a smaller light reflection can cause problems in image processing also, therefore, diffused light illumination technique is recommended in our system.

V. SUMMARY

As part of a program we have to develop an experimental system which is able to determine the orientation of a part arrived onto the working plane by using machine vision and then by applying a manipulator it can move the part to the target coordinates. By development of machine vision applications the primary task is to prepare a suitable environment for the system. For this we examined the issues arising by selecting the image recording unit, including the imaging system parameters, scan types, camera interfaces and sensor types and then we examined the possible work area illumination techniques and light sources. Many parameters will only be known after the physical system tuning, but by taking into account the formulas and technological features described in this article, selecting the platform and integrating it into the system will be a part of awell-prepared process. Our next step, after the investigations presented in this article, is to obtain the appropriate device, perform its calibration and finally, implement the machine vision application.

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