Vision-based Sensors for Production Control - The experience gathered in Applications

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Abstract

This contribution summarizes several own developed industrial applications where computer vision-based sensors were used for control and visual appearance check. The knowledge-based systems in manufacturing often lack the on-line information about the production. Cameras as sensors are flexible and mature enough to provide a feedback in very varying tasks. The hope is that the list of specific applications may enable to bridge the gap between the knowledge-based systems in manufacturing community and computer vision people.

Keywords:

Computer vision, digital image processing, industrial applications, non-contact measurements.

1 AIM OF THE PAPER

The aim of this contribution is to demonstrate that computer vision techniques applied in industrial environment can be looked at as sophisticated sensors for production control and 100% visual inspection. Such visual information serves as feedback in traditional control loop or more advanced knowledge-based approach to automation in manufacturing.

In this paper, we overview specific industrial applications that the research oriented university group, the Center for Machine Perception, and its small spin-off company Neovision, Ltd. Developed for industry in the past couple of

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years. We hope that such a survey will persuade the community active in the area of intelligent systems for manufacturing to use vision-based sensors.

The problem with computer-vision based industrial applications is in its enormous variability. The design phase needs highly qualified labor force. Our experience shows that the collaboration between university-based research group and the company oriented to applications (Neovision, Ltd.) is a good trade-off.

2 LIST OF COMPUTER VISION BASED APPLICATIONS

2.1 Dimensions measurement of electronic components cores

The electronic component core sizes (shown on the support bar in Fig. 1 (a)) are measured to adjust encapsulation process. The cores sizes range from 0.5 mm to 5 mm. Their width, height, and length including the wire they are mounted on should be measured. The shape of the core is approximately a parallelepiped. The cores are partly coated by silver and have a rough surface. There are irregularly shaped ledges on the surface. The cores have large deviations in position because the wire is very soft and it is often bended or twisted during manipulation. The required precision of measurement is ± 0.02 mm.

The performance speed is one measured core per second. It is limited mainly by the mechanical subsystem (fixing glass should clasp the core, images are captured, core is released, and next core should move under the fixating glass). The system was extended by the part measuring cores electric parameters.

The system is used for statistical production control. The cores are encapsulated into a plastic in the next manufacturing step. The encapsulation parameters are adjusted according cores sizes. Several cores from each batch are measured and from these statistical data encapsulation parameters are adjusted.

The first attempt to measure core dimensions only visually failed because the cores do not have rectangular shape and they are often slanted in space (see Fig. 1 (c)). The core is mechanically fixed between two glass plates first in the final solution. The distance between the glass plates (i.e. core height) is measured by detecting landmarks on the plate holders by a camera. The length and width of core is measured in back illumination by another camera in a fixed position (see Fig. 1 (d)). This solution (see Fig. 1 (b)) proved to deliver required results even though it becomes mechanically more complicated. It is also sensitive to dust as there are more optical surfaces in the optical path. Some are even in the contact with the dusty cores.

A typical example of a problem appearing in industrial applications is the influence of cores on the glass. Prior to designing the fixing tool we tested

Figure 1 (a) The cores on the tape to be measured. Small and medium size of the manufactured cores are shown. (b) The device for measurement of cores. The fixing bar with cores is placed on the black stick and moved in front of cameras. (c) View of the core on a bent wire (this is an extreme example). Unfortunately, the cores only slightly rotated bias the measurement without the possibility to detect it. (d) Core fixed between two glasses. After the fixation, the remaining degrees of freedom are measurable in the image.

the cores whether they make spots when they slide over glass. The tests in lab showed no problems. When the equipment was delivered to the customer we found that cores taken directly from the process have very soft surface and make the spots exactly in the place where measurement is performed. A mechanical cleaning tool had to be installed to the device.

2.2 Counting of healds and dents

Healds (see Fig. 2 (a)) are specially shaped metal sheets used to lead threads in textile machines. The customer was the company that produces healds and dents for many textile machines manufacturers. The amount of healds packed in one bundle should be one thousand. It is desirable to automate heald counting in order to achieve 1000_{-0}^{+1} pieces in a bundle. Previous human operator heald counting method estimated the number of healds from the width of a thousand pieces on the holding needle. This estimate was not reliable due to the elasticity and slightly varying thickness of the wire the healds are made from. The weighing failed because of differences in the wire thickness. Our customer shipped about 20 healds more than needed to guarantee the amount at least 1000 in the past.

The customer required counting of stacked healds as well as dents on reed (a product similar to healds) which are interlaced with free space. The device should cope with different thickness (0.2 mm to 0.35 mm). A rugged and handheld device was ultimately needed.

We delivered a device (see Fig. 2 (c)) consisting of a handheld sensor and a single board computer control unit. The sensor head illuminates the object perpendicularly and measures the light reflected back (see Fig. 2 (b)). The method relies on the fact that both products counted are flat sheets with sanded edges forming a curved profile. The middle part of the profile reflects light falling perpendicularly to the surface back and the rest of the edge scatters light out from the sensor. The sensor head is moved by hand across healds which forms a sequence of measurements. The sensor itself is a photosensitive differential PIN diode whose signal is amplified and processed. The software in control unit counts the number of significant local maxima in the signal.

The system proved to be reliable in practice and satisfies user requirements. An important part of the solution was careful examination of the properties of the observed surface which leads to the simple solution. A careful design of the sensor electronics was a key point in the implementation phase.

The counting of healds shipped to customer decreased number of customer complaints and on the other hand saved expenses on the healds originally shipped extra.

2.3 High precision measurements of cutting tools

The cutting surface on a multiteeth cutter, the edges on drills, the edges of cutting tools should be measured and adjusted when precise milling, drilling, and cutting are required. Special adjustment machines are manufactured for this purpose. Currently the measurements are usually done by backprojecting the measured shape on a large screen (profile projectors) and then visually compared by a human with the required value. Current technology tends

Figure 2 (a) Several healds on the holding needle. (b) Light impinges on healds/dents; the reflected light is measured. Light is reflected back to the sensor in a flat part of the heald surface, no or little light is reflected towards the sensor on the edges or in gaps. (c) The device for counting healds and dents, the sensor head is shown below, the control unit above.

Figure 3 (a) Optical part of cutting tool adjustment machine. Camera is on the left, illumination unit on the right. (b) User interface. Cutting tool (a camera view) with overlaid required position and error bars.

to replace such human operator dependent measurement by computer vision methods, where the screen is replaced by a camera and the visual comparison is replaced by image analysis. This offers measurement that is independent on the experience of a human operator, it is not as eye straining, and enables to document the adjustment of the tools.

The developed device is shown in Fig. 3. To attain a subpixel accuracy we assume that the measured cutting edges can be described analytically. The edge is typically formed by pieces of straight lines and circular arcs. User specifies the sequence of straight lines and circular arcs by selecting one which

Figure 4 (a) SMD part logo inspection. The characters should be evaluated for readability, and the position and surface defects are checked. The character 7 is unreadable because of the scrape over it. (b) Surface defect of SMD part with protruding silver. (c) Surface defect of SMD component with the crack in plastic encapsulation.

should be measured. The system fits this sequence while ignoring dust and possible defects on the tooth (up to some extent).

We use an ordinary B/W CCD camera with custom optics and back illumination. We found that image radial distortion have to be eliminated in order to achieve the precision over the whole field of view. The first estimate of the edge contour is found by a thresholding. Perpendicular cuts through the edge are constructed in contour points resulting in 1-D edge detection problem for each edge point. The edge is found by a standard zero-crossing method. The detected contour is segmented according to its curvature and the appropriate segment is used. The detected points position is corrected for the camera radial distortion and the projection distortion is obtained by calibration. The parameters of the curve are found from the transformed points by least-squares fitting.

The precision is under $1\mu\text{m}$ within the view field 3.5 by 4.5 mm. 5 to 15 measurements per second are performed depending on the complexity of shape and length of the measured contour. The vision module is incorporated into their products by two different manufacturers of adjustment machines.

2.4 Inspection of labels on SMD components

Labels of SMD components have to be checked in order to guarantee their legibility and correctness (see Fig. 4 (a)). The inspection is boring and eye straining for people who check the products. Human inspection is also unreliable and expensive. The inspected features are the presence of all symbols, legibility, position of the logo, the presence of scrapes and holes on the surface. The time for inspection of one part is limited to 50 ms.

We have proposed a system for label verification based on fast binary correlation. We have proved that the system is feasible and satisfies all requirements.

We have also tackled related problem - the inspection of surface defects. The defects are of various nature. Some of them are formed by protruding inner parts (see Fig. 4 (b)), others are defects of encapsulation (cracks, holes, broken encapsulation) (see Fig. 4 (c)). The part should be inspected from all sides which brings the necessity to evaluate 10 views simultaneously.

3 HARDWARE/SOFTWARE ISSUES

The hardware/software concept we follow is to use ordinary "plain" frame grabbers and to perform image processing by a general purpose CPU in a computer memory. This approach necessarily restricts us in some high speed applications where digital signal processors are necessary. On the other hand, general purpose processor programming is much easier. Re-use of previously developed code is enabled. Consequently the productivity is high and costs are lower. This approach has proven to be a good choice recently as PCI frame grabbers bridged the gap between the frame grabber and the CPU memory communication speed. A gradually growing speed of PC's matches more and more the vision applications needs.

The expensive special purpose hardware development is avoided. Applications written for PC can exploit the progress in technology driven by large companies (Intel, Microsoft, ...). We should also point out that components prices (interfaces, frame grabbers,...) for PC are significantly lower than those for workstations (if available at all). The PC based solution has a drawback too. Top class PC's are usually not manufactured in industrial rack versions. This can cause problems in applications where heavy-duty solution is required.

Currently, one may find a growing offer of tools for visual programming of vision inspections. These tools may significantly decrease the programming costs but their use is still limited to simple tasks. Tasks which are on the edge of the current technology of course require a dedicated software design.

It follows from our experience that design phase (experiments, analysis, design, verification of the image capturing and algorithm performance) is the most expensive part of the process.

The optical design is significant part of the solution. A proper illumination and image capturing conditions are often the key to an easier algorithmic solution. The vision has an important advantage because it leads to non-contact measurement/classification/inspection. On the other hand, optics is sensitive to dirt, dust, and water condensation.

4 CONCLUSIONS

We listed several computer vision applications in its development authors took part. Our aim was to inform people interested in information technology for automation that computer vision is becoming mature enough to provide infor-

mation about controlled production process. The more detailed information about the controlled process allows to gather deeper knowledge and consequently yields better control. The key advantage from the users point of view is a flexibility of vision techniques that dedicated sensors cannot provide.

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6 BIOGRAPHY

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