

Advances in Automated Inspection Using Contactless Head Height and Countersink Measurement Techniques

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ABSTRACT

For decades optical camera systems have been used by Broetje-Automation to locate pilot holes and find product orientation on NC-controlled positioner systems.

Measurement tolerance requirements were and are in the range of ± 0.2 mm. Recent developments enhance the sensor technology function from pure hole detection to new features like Fastener Head Height Measurement and Countersink Diameter Measurement. While head height measurement has to go 3D by enhancing the planar sensors to head protrusion measurement, the Countersink measuring tolerances are much smaller than "simple" hole detection, in fact require more than a magnitude tighter tolerances.

This paper will present how Broetje-Automation solved the issue of a 20 plus fold accuracy increase, the 3D capability of the one eyed camera and all accompanied by a more robust evaluation software.

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INTRODUCTION

Countersink diameter and head height of mounted fasteners are important metric traits to describe and ensure the quality of the product assembled with Broetje-Automation technique. The measurement of countersink diameter as an indicator for countersink depth gives a more direct possibility to control the process of drilling and fastening. The result of head height measurement is a quality measure used to report quality.

Usually the head height tolerance of the mounted fastener is less than ± 0.1 Millimeter. That defines the necessary measurement precision of 0.01 Millimeter for the head height measurement system, 10 times finer than the tolerance. Countersink diameter has to be measured with a precision of 0.02 Millimeters as there is a factor of about two between countersink diameter and countersink depth, 0.02 Millimeter difference in diameter leading to 0.01 Millimeter in depth at a countersink angle of 100° .

Measurement must be precise but not time consuming; time for measurement should be less than 200 milliseconds for a reading. The faster the measurement is the more values can be collected to ensure quality.

And the measurement has to be robust. The readings must be reliable even if the surface is dirty or sealing is close by or even on the fastener head.

In order to fulfill customer requirements regarding speed, robustness and precision a new optical measurement system was developed by Broetje-Automation.

SYSTEM COMPONENTS

Overall Design and Optical Resolution

The vision system consists of two main hardware components, camera and structured light projector

The so called measurement camera (MCam) is mounted in the upper part of the machine head. Working distance is about 700 Millimeters, and the viewing area frame can be up to 24 Millimeters. Two different lens combinations are available. The camera uses the Sony ICX445 Standard 1.3 Megapixel CCD Sensor, high resolution macro lens allow an optical resolution of 0.018 Millimeter per Pixel. The measurement camera is also used as so called position sensor to measure the current position of objects (PSEN).

In order to be able to measure local height differences between the upper surface of the fastener and the work piece, structured light has to be sent through a hole in the pressure foot bushing. The angle between the two optical axis is about

60°. That means a height difference of 0.01 Millimeters moves the projected template about 0,017 Millimeters, which is nearly 1 Pixel of the sensor.

The pixel resolution of about 0.02 Millimeter can be enhanced using interpolation between neighbored pixels on signal level and mathematical modeling of objects in high level processing.

So called sub pixel algorithms are used to enhance system resolution up to 1/10 of a pixel at clearly defined edges [Steger, 2008]. Under practical conditions 1/3 of a pixel is within easy reach, leading to a system pixel resolution on signal level of about 0.007 millimeter or 7 micrometer.

In order to make measurement robust and even more precise, mathematical models of the objects to measure are included into the software. Least squares adjustment is used to compute object parameter from pixel positions, so called observations. In principle, least squares adjustment computes “mean values” for object parameters from observations. If all observations fit to the model, i.e. are a part of the circle or plane, the precision of the parameter is better than precision of a single individual observation. With realistic field conditions, least squares adjustment enhances precision in consequence of noise reduction with factor from 3 up to 5. That means, if pixel observations deliver a precision of 7 micrometer, object parameter can be computed with a precision of 2 micrometer.

Table 1. Exemplary results from practical acceptance tests. Every line in the table shows one countersink, measured five times, mean value is given in col number six, RMS (root mean square) in col number seven. All values in millimeter except RMS value in micrometer.

1	2	3	4	5	Mean Value	RMS Value
6,3540	6,3530	6,3530	6,3550	6,3540	6,354	0,8
6,3670	6,3660	6,3670	6,3650	6,3650	6,366	1,0
6,3590	6,3640	6,3610	6,3630	6,3630	6,362	2,0
6,3710	6,3720	6,3740	6,3720	6,3730	6,372	1,1
6,3740	6,3750	6,3730	6,3750	6,3760	6,375	1,1

Exemplary results from acceptance tests (refer table 1) show that overall system design with optical resolution of 0.02 Millimeter together with sub pixel algorithms on signal level and least squares adjustment lead to the expected repeatability of 0.002 millimeter.

But repeatability is not precision. System components have to be adjusted and calibrated on pixel level with precision of 2 micrometer in order to deliver correct and precise results. Therefore, adjustment and calibration of system components mounted in the machine is an important issue.

Head Height Measurement

Head height measurement is mainly depth or height measurement using triangulation techniques. Structured light is used to project a pattern with known geometry onto the surface to measure.

Usually a laser projector is used together with a camera. If the angle between laser and optical axis of the camera is known, height differences can be computed as the line position changes its position in the image as a function of distance to the object. So called laser profile sensors are using this principle. Laser triangulation is robust against other lighting sources in the industrial surrounding. On the other hand speckle effects limit the precision, interaction between surface and coherent laser light leads to less sharp edges.

Non-coherent light sources do not have this limitation stemming from speckle effects; projected structures deliver very sharp edges in the images. That is one of the reasons why high precision optical 3D scanners are using non-coherent light sources. On the downside, these classes of sensors are less robust against other lighting sources.

We decided to use non-coherent white light for our structured light projecting device together with the color sensor in the camera. The main reason for white light decision was that the lack of speckle leading to sharp edges gives higher precision.

But white light has even more advantages regarding the information content of the images. The additional color information in the images can be used to detect additional features, for example the coverage of sealant. Furthermore the measurement itself is not influenced by the color of work piece surface and fastener.



Figure 1. Detail of an image used for head height measurement. The black stripe visible in the right part of the figure has a width of about 1 Millimeter. It consists of about 50 pixels. Upper part of the figure shows the surface of the work piece, lower part the fastener.

Compared to laser triangulation the image processing becomes more complex if white light is used. For example different contrast in different regions of the image requires