Chapter 9
Presence Verification

Viewed from the perspective of the problem to be solved, presence verification appears easily grasped and structurally rather simple. This is the reason why presence verification is often used as an introductory example to image processing. In reality, the concept of presence verification is quite difficult to define precisely: is it simply counting objects or are properties of these objects of importance? Are these properties simple features or is the entire appearance of the object to be considered? Do properties relate to individual objects only or do we have to take relationships between objects into account, for example, when doing assembly verification.

The methods used in this area are as varied as the questions above. Often methods from other application areas, like classification and gauging, are used as tools for presence verification. Another reason why presence verification was not chosen as the starting point of our introduction to image processing was that this field is characterized less by particular methods and algorithms than by the way questions are asked. If gauging is used as a tool for assembly verification, it is typically less important to verify that specific dimensions are within narrow tolerances than to check certain relationships between objects. Classification in the framework of presence verification is less concerned with *what* objects are present—which is the ultimate goal of character recognition—than whether the *right* object is there.

Because of the variety of questions asked and methods used, presence verification problems are typically rather difficult to approach. Solutions to gauging and classification tasks are usually rather similar to each other and also similar to the way a human would intuitively describe the task. The basic approach to presence verification applications is often more difficult to find and less intuitive.

In this chapter's examples we want to give an impression of the diversity of the field of presence verification and also of the fundamental way of thinking in this type of inspection problem.

C. Demant et al., *Industrial Image Processing*,
DOI: 10.1007/978-3-642-33905-9_9, © Springer-Verlag Berlin Heidelberg 2013

9.1 Presence Verification Using PTZ Cameras

The first example for presence verification is a rather simple one since only the presence of objects and their correct fitting is checked. The inspection object is a car engine where the correct fitting of a number of sensors, clamps and clips needs to be checked. All in all, about 60 extremely different inspection features need to be checked. In many cases the inspection features cannot be separated from the background by thresholding, or can hardly be distinguished from reflections using the binary contour. Therefore, all inspection features are searched for using template matching and fitting is checked using the matching results. We selected this example less because of the relatively simple inspection strategy but to show how to capture images of so many independent inspection features efficiently.

9.1.1 Inspection Part Geometry

The most obvious difficulty of this inspection task is the size of the engine over which the rather small sensors, clamps and clips are distributed. When capturing the entire engine, the sensors measure merely a few pixels. When objects are this small, one can only check whether a bright spot is present or not. The differences between a correct and a faulty fitting measure less than one pixel and thus cannot be checked. It is also not possible to determine whether the bright spot is indeed the sensor in question or a light reflection. The conclusion could be drawn that individual cameras are needed for inspecting individual sensors and components resulting in a large number of hardware items.

Indeed it is possible to use considerably fewer cameras if special ones are used. Applications like this one call for pan/tilt/zoom (PTZ) cameras. They consist of a camera head mounted on a stand in such a way that it can be turned both horizontally and vertically by built-in motors. Thus the line of sight of the CCD camera integrated into the camera head can be changed while the size of the captured field of view can be manipulated simultaneously using the integrated zoom lens. These cameras are usually used for video conferences and surveillance tasks but can also be used in machine vision. This example presents a typical application for this type of camera where a sequence of detail views of the engine are captured in succession. The complex shape of the engine and the large number of inspection features necessitate a total of five PTZ cameras capturing the engine from different angles and heights.

As useful as PTZ cameras are, their use causes several difficulties. First of all, the camera position must be carefully selected. The camera must have an unobstructed field of view of all inspection features it is supposed to capture.

Also the camera's line of sight is not without difficulty. Only rarely will it be possible to capture all inspection features with an optimal angle. In most cases the

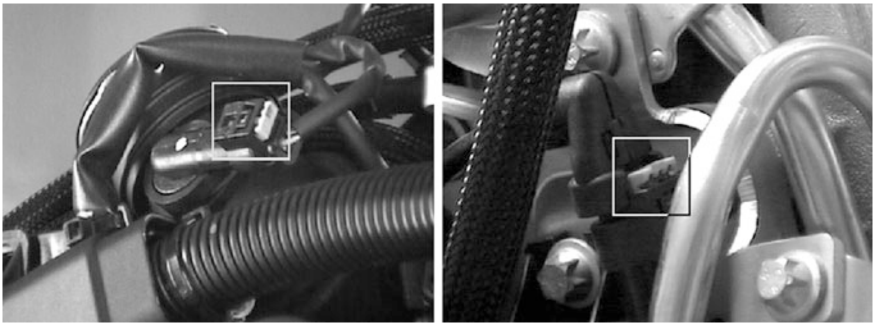


Fig. 9.1 Adverse angle of view and nearly obscured inspection feature

view will be slantwise. Therefore one has to make sure early on whether all inspection features can be checked from the planned position. In this example this does pose a problem for some inspection features. Some parts are partly obscured by other components while with others, the difference between correct and faulty fitting is almost parallel to the line of sight and therefore hardly visible. In Fig. 9.1, the sensor to be checked on the left side is hard to see because of the angle of sight, and on the right side one feature is almost obscured by a pipe.

When selecting the camera position, another aspect must be considered: the potential of the zoom lens. Since the lens is firmly integrated into the camera, it cannot be replaced with one having a different focal length. Thus both the maximum angle of view and maximum zoom are determined. Small inspection features must be close enough to the camera for the camera's resolution to be sufficient for inspection. Of course, an extension tube cannot be inserted behind the lens to shorten the minimum working distance. Therefore, the distance between the inspection features and camera must not be too short.

9.1.2 Illumination

The surface of the engine is curved in all directions and its components and the many inspection features tucked away necessitate illumination that is very diffuse coming from as many angles as possible. Individual illumination of each inspection feature would result in considerable effort because of their number. With a number of large-area light elements with fluorescent tubes, the engine can be illuminated diffusely from all angles so that almost all inspection features can be checked. For a few inspections it is better to switch off some elements of the illumination to improve contrast or avoid disturbing reflections.

9.1.3 Positioning

The engine is fastened in the inspection station so its position is fixed. However, it can be tilted around two axes. This results in position deviations in the images that also change from one perspective to the next. The rotation in the images can be neglected because of the engine's size, but even small angles can result in significant position changes of inspection features in the image. Since position changes are the larger the farther away the captured engine section is from the fixture, global position adjustment cannot be used but the deviation must be calculated for each image.

Since the inspection features are searched using template matching, one could try to look for the inspection feature directly within a sufficiently large region of interest without prior positioning. Unfortunately, even in detail view the size of the inspection features is still rather small. This necessitates a search with extremely small step sizes, which requires a lot of time. Furthermore, reflections occur on the engine's surface and that of its components that, in the worst case, can lead to matches with template matching thus to wrong segmentation.

Therefore, the position is adjusted. Searching for the reference for position adjustment also uses template matching with a large and uniquely shaped reference being selected such as the screw in Fig. 9.2 left. However, it does not necessarily have to be an individual component like a screw. A bended pipe can also be used as a reference as can be seen in Fig. 9.2 right. Naturally, the reference should be an object with a rather large area and little detail to allow for a large step size in the search.

9.1.4 Object Detection

As described above, the inspection objects are found using template matching. An obvious approach is to use the correctly fitted inspection object as the only

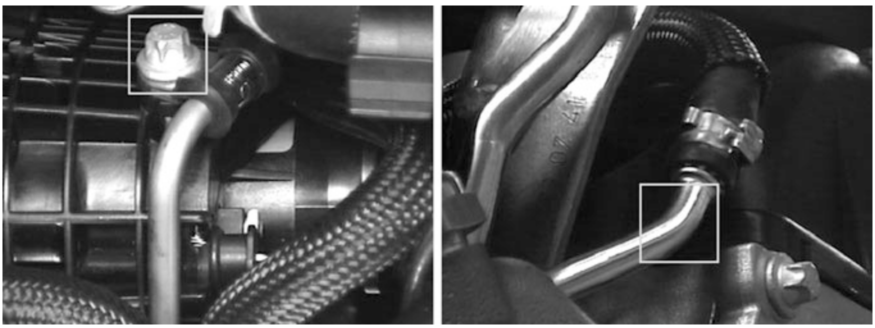


Fig. 9.2 Various position references

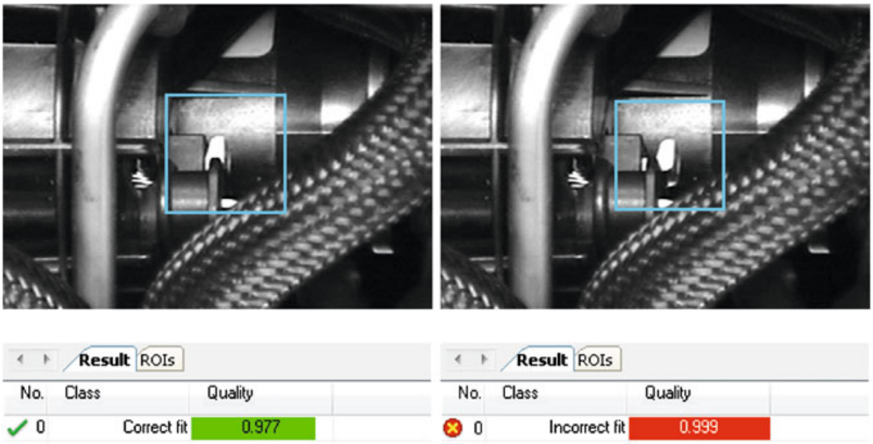


Fig. 9.3 Correctly and incorrectly fitted sensor

template. When these are found in the image, the degree of agreement between the template and the found object determines whether the inspection feature has been fitted correctly or not. This method works very well in a number of cases but there are inspection details where the difference between correct and faulty fitting causes only minor differences in correlation values. In these cases the search is extended by using not only the correctly fitted inspection object as a template but also the template of an incorrectly fitted one. Figure 9.3 shows a "correctly" fitted sensor on the left, and an "incorrectly" fitted one on the right. In both cases the object is found with sufficient correlation. Because of the template with which the sensor is found, we can clearly distinguish between correct and incorrect fitting; i.e. it is checked that the sensor is found with the "correct" template and a sufficiently high correlation. Else an error occurred since either the object is missing completely or incorrectly fitted.

Program hint: To remove objects because of their classification, NeuroCheck provides the check function *Evaluate Classes*. If *Verify target value* is enabled, you can specify a list of classes that will be accepted. All regions of interest (ROIs) of classes that are not on this list result in an error. In this case, the not OK class must not be in the list of acceptable classes so that regions of interest found with the not OK template are considered an error. *Delete pattern* causes ROIs determined as errors to be removed from the ROI list without causing the check function to be terminated with a target value error.

9.1.5 Verification of Results

Actually the inspection is already completed but let us imagine a case where the search for an inspection feature yielded a reflection. One way to prevent this is to

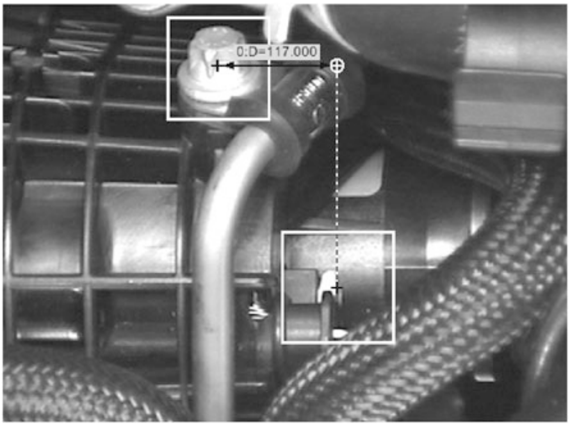


Fig. 9.4 Verification of gauging results

require higher quality for template matching. However, this can result in properly fitted sensors not being found. Therefore, we will take a different approach. To adjust the position, we have already looked for a reference in the image. The distance between this reference and the inspection feature is usually fixed with small tolerances. If the search for the inspection feature engages in a completely wrong spot, the distances between the inspection feature and position reference will deviate considerably from the normal values. Therefore, the distances in X and Y direction between position reference and inspection feature offer a good possibility to check the template matching results for plausibility. Basically, this will also check whether the position reference has engaged in the correct spot since this can also lead to an alteration of the distances between the inspection feature and position reference.

Since the screw head and sensor have already been found, this result verification merely consists of computing the distances of the two objects along the coordinate axes and comparing them to the usual distances; hence verification necessitates hardly any additional effort. Since we only have to verify that the correct objects have been found, neither gauging nor allowance check require high accuracy. An example for result verification can be seen in Fig. 9.4 where the distance in X direction between the sensor and the screw head—which incidentally is the position reference—is checked.

Table 9.1 shows the complete inspection program for one inspection feature with position adjustment, object search and result verification.

9.2 Simple Gauging for Assembly Verification

The example in this section demonstrates how to use methods from dimensional checking as a tool for presence verification. This is a typical method used in applications where the objective is to verify that a product has been assembled

Table 9.1 The following table summarizes the example from Sect. 9.1

Category	Description
Directory	\Examples\Presence
Illumination	Diffuse, large-area lighting
Functions	The example uses the following check function sequence: 1. *Image capture* 2. *Define ROIs*, sets a region of interest in the surrounding area of the screw head 3. *Template matching,* searches for the screw head as reference for positioning the ROIs 4. *Determine position,* the found screw is used as position reference to compensate shifts because of engine tilts 5. *Define ROIs,* sets the ROI for the sensor search 6. *Position ROIs*, shifts these regions according to the position of the screw head 7. *Template matching,* searches the sensor with templates of correct and incorrect fitting 8. *Evaluate classes,* removes the found object if it was found because of using a template with an incorrect fitting or if the correlation quality between template and image is too low 9. *Count ROIs,* makes sure that an ROI exists, i.e. that a correctly fitted sensor was found 10. *Combine ROIs,* combines the position reference and sensor in one ROI list for gauging and verifying the result 11. *Gauge ROIs,* measures the distances between the reference and sensor in X and Y direction 12. *Check allowances,* verifies that the distances between reference and inspection object are correct and no faulty segmentation occurred

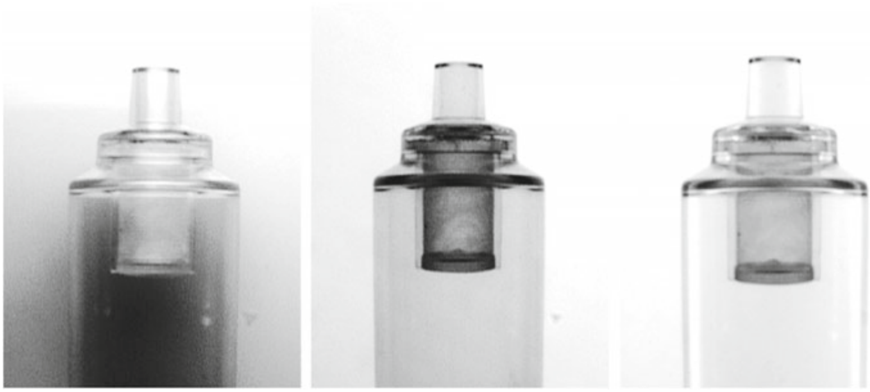
Fig. 9.5 Drip chamber for dialysis device

correctly, as in this example. The test piece shown in Fig. 9.5 is an IV drip chamber that is used as a blood filter in dialysis devices. Correct assembly of the blood filter behind the outflow of the chamber is of critical importance for function and safety of the product.

9.2.1 Illumination

Figure 9.6 shows the drip chamber under different lighting conditions. Obviously, inspection is possible only in transmitted light. Polarization improves definition of the edges. For the final realization, the area permitting light through the test piece was limited to the actually relevant inspection area to minimize problems caused by lateral illumination. Figure 9.8 shows the result.

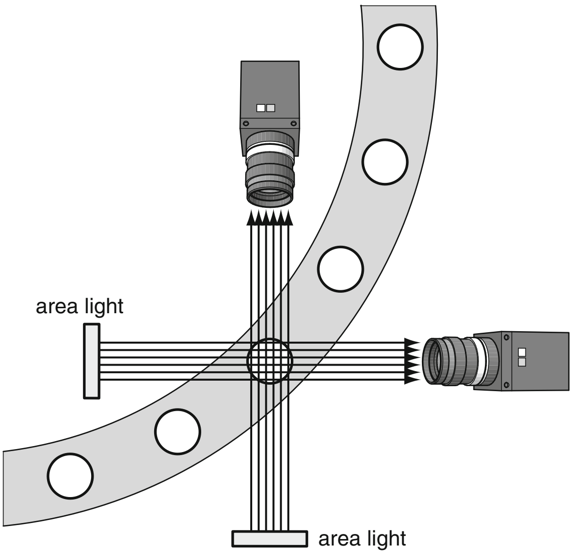
The basic setup of the inspection system follows from the illumination requirements and the necessity to inspect the part from two different directions, which we will explain in the next section. Figure 9.7 shows a schematic top view



Front lighting Back lighting Polarized back lighting

Fig. 9.6 Drip chamber in front light, backlight and polarized backlight

Fig. 9.7 Schematic structure of station for inspecting blood filter



of the setup. The drip chambers are transported upright on a conveyor belt through camera/light source combinations oriented at right angles so that an inclination of the filter can be detected independent of its direction.

9.2.2 Inspection Criteria

The most difficult stage in assembly verification in applications is often the specification of the criteria to be used for verifying correct assembly of a test piece. The intuitive human answer—“the part has to look right”—is unfortunately not very helpful. First, it has to be clarified what kind of assembly faults are possible and how they change properties of the test piece *in a quantifiable manner*.

In this example, incorrect assembly of the filter can manifest itself in the following ways:

- Skewed filter mesh, possibly causing a gap at the top edge of the filter.
- Deformation of the filter, leading to holes due to tensions in the material.

Figure 9.8 shows two images of a damaged filter captured at right angles. It can be seen that a deformation shortens the filter so that the distance between the bottom of the filter and the outflow of the drip chamber is changed. The skew of the filter causes the distances from the outer edges of the drip chamber to be different.

Figure 9.8 also explains why two images taken at right angles are required: taking only a single image, the system would miss a deformation or inclination of the filter in the direction of the optical axis of the camera.

From the possible defects of the filter listed above it follows that the following criteria have to be checked:

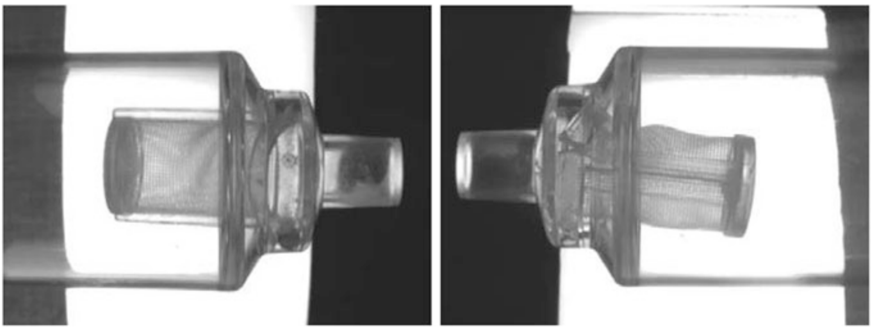


Fig. 9.8 Defective filter from two lines of sight with right angle offset

- length of the filter,
- centering within the drip chamber,
- diameter of the filter neck.

In the following we will show how to determine these properties.

Length of the filter: The length of the filter, i.e. the distance between filter bottom and outflow of the drip chamber, can simply be measured by segmenting the bottom part of the filter as one object, the top edge of the outflow as another. Figure 9.8 clearly shows that this edge is well defined by reflections inside the transparent plastic in front of the dark background. The edge as well as the filter bottom can be easily segmented by thresholding with individual thresholds for each object. Figure 9.9 shows the regions of interest used in the image from the first camera: a search line is used to probe the edge, whereas the filter bottom is segmented within a rectangular region of interest.

Centering: The subtask of checking whether the filter has been skewed during assembly might suggest measuring the direction of the outer edges of the filter. The angle of these edges may be altered by small irregularities in the outer contour due to inevitable—and acceptable—slight deformations of the filter. This is therefore not a suitable measure for the alignment of the filter. A much more reliable method for checking whether the filter has been skewed or bent is to measure the distances of the filter edges to the outer edges of the drip chamber. Since the objective is to determine correct centering, it is preferable not to test the individual distances against a specific tolerance, but instead to compare the difference of the distance in both directions to zero. This measurement is very stable and robust with respect to position and lighting variations. To determine the distance in both directions, four search lines can be used. Their arrangement is shown in Fig. 9.10. Along each search line a light–dark-edge is determined. The distances between corresponding pairs of edges are computed.

Diameter: In addition to these search lines, Fig. 9.10 shows two search areas used for measuring the diameter of the filter neck. Since the filter neck can in

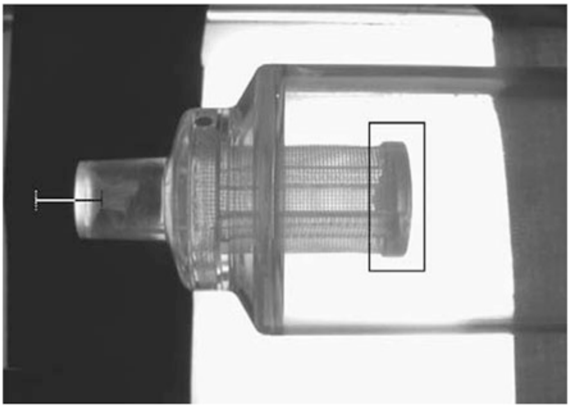
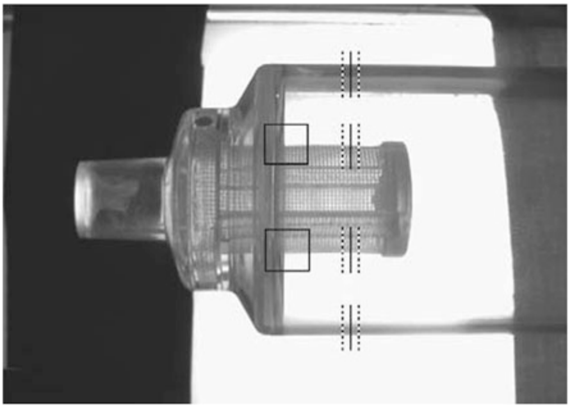


Fig. 9.9 Search areas for creating filter bottom and outflow edge

Fig. 9.10 Search lines for measuring filter orientation



practice not be separated visually from the body of the drip chamber, this diameter is measured indirectly by creating objects from the background areas limiting the filter neck on both sides. The distance of these background areas is equal to the diameter of the filter neck. One could call this a "negative measurement": instead of measuring the width of the actual real-world object, the width of the interruption caused by the object in the background is measured.

9.2.3 Object Creation and Measurement Computation

All objects required to measure the criteria described in Sect. 9.2.2 can be segmented in one go. Because of the different brightness levels of the various object edges individual thresholds are needed in each region of interest for robust thresholding. Figure 9.11 shows the separately thresholded regions of interest within the otherwise unchanged gray level image on the one side, the segmented

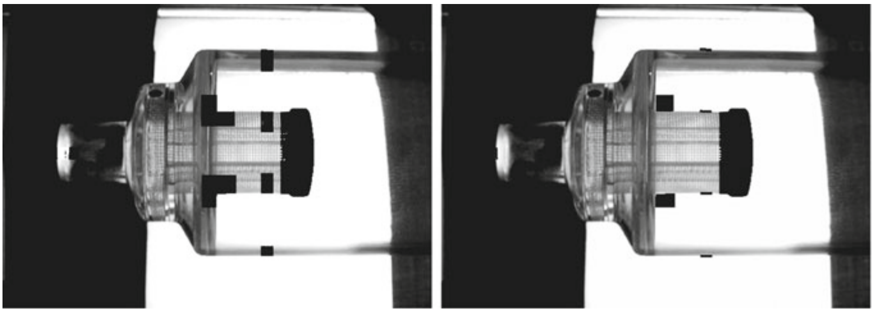
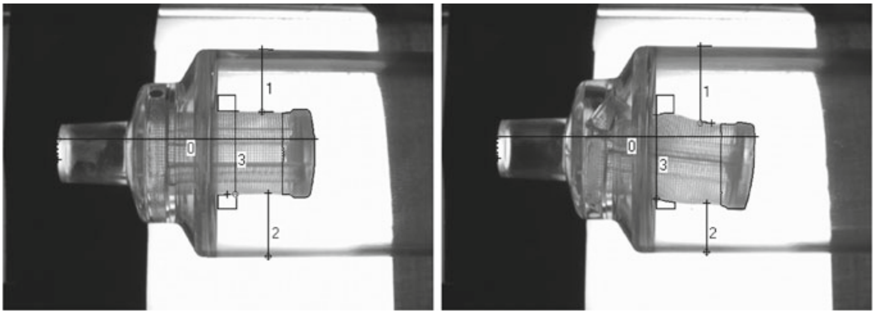


Fig. 9.11 Individually thresholded ROIs and segmented objects



Good test piece Faulty test piece

Fig. 9.12 Measurements necessary for inspecting a filter

objects drawn black into the gray level image on the other side (edge objects have been thickened for better visibility). Note the bright background areas created as objects above and below the neck of the filter.

In Fig. 9.12 the measurements used for the inspection have been drawn onto the images of a good test piece and a faulty one. The distance between the outflow and the filter bottom is measured in 0°-direction and is denoted by 0. All other measurements are taken in 90°-direction. It is important to specify the direction of the measurements to avoid measuring errors due to irregularities of the contours of deformed filters. Please note that the distances are measured in different places of the objects. This is because the minimum or maximum distances are measured. For the width of the filter (measurement 3) the minimum value is important, for the full length (measurement 0) the maximum value has to be taken to measure down to the filter bottom.

Finally the difference between the distances from the filter to the respective drip chamber edges labeled 1 and 2 in Fig. 9.12 has to be computed and compared with the pertaining nominal values. It is this measurement which leads to the rejection of the faulty piece shown in Fig. 9.12. It is larger by a factor of 25 than for a good piece.

9.2.4 Position Adjustment

We have left out one important aspect so far in this application. The test pieces are mounted on holders fixed on the conveyor belt. Due to the elasticity of the plastic, it frequently occurs that a test piece will not be precisely vertical on the holder. The inclinations will only amount to a few degrees, making an adjustment of the measuring directions of 0 or 90° unnecessary. They do have an effect, however, on the positioning of search regions. This is especially true for the search line creating the edge at the upper end of the drip chamber since, with a total length of 15 cm of

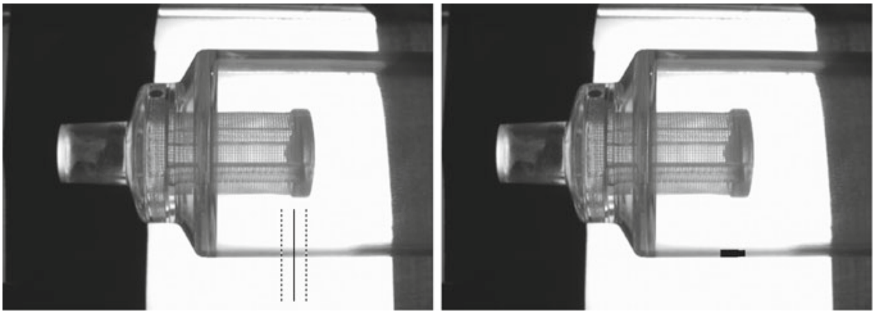


Fig. 9.13 Search area and reference object for position adjustment

the inspection part, a tilt of three degrees causes a deviation of 8 mm. Since the section to be inspected is rather short compared with the length of the inspection piece, rotation adjustment is not necessary, the ROIs can be repositioned using the position of a side edge. A prerequisite is the sufficient length of this search line. Figure 9.13 shows the search line and the generated reference object. We use the bottom edge as the reference object here because it is a very smooth edge which can be reliably detected.

Table 9.2 summarizes the entire inspection procedure for one of the two cameras. Apart from the different arrangement of regions of interest the checks for the two aspects are precisely identical.

9.3 Presence Verification Using Classifiers

The next example is taken from the automotive industry. We have clamping flanges that are secured on a shaft using a crimped nut. The application described in this section performs type identification and assembly verification on this test piece combining methods from basic presence verification, gauging and classification (Fig. 9.14).

The visual inspection of this test piece serves two purposes:

1. Ascertaining assembly of the correct flange type; the various types of flanges differ in the number of arms and in their length or in the distance of the bore holes from the center of the flange.
2. Verification of the crimping of the collared nut in the center of the flange. The crimping fixes the flange in a certain position on the shaft. If the nut is crimped incorrectly—for example because the crimping tool slipped—or not at all, the flange will not be fixed on the shaft.

Table 9.2 The following table summarizes the example from Sect. 9.2

Category	Description
Directory	\Examples\Presence
Illumination	Polarized back lighting with shields to avoid lateral illumination and diffraction effects
Check functions	The example uses the following check function sequence: 1. *Image capture* 2. *Define ROIs*, sets a search line for the front edge of the test piece (with respect to the movement of the conveyor) 3. *Determine threshold*, optimizes the threshold using a histogram analysis of the region of interest 4. *Create ROIs by thresholding*, segments a portion of the side of the drip chamber 5. *Determine position*, uses the bottom (or top, depending on the camera) coordinate of this section as position reference 6. *Define ROIs*, sets the regions of interest depicted in Figs. 9.9 and 9.10 7. *Position ROIs*, moves these regions according to the position of the edge of the drip chamber 8. *Determine threshold*, computes individual thresholds for each of the positioned regions of interest 9. *Create ROIs by thresholding*, segments the individual edges and sections 10. *Gauge ROIs*, computes the following measurements: • 0°-distance between outflow and filter bottom • 90°-distance between top edge of the drip chamber and top edge of the filter • 90°-distance between bottom edge of the drip chamber and bottom edge of the filter • Minimum 90°-distance between the background portions above and below the filter neck 11. *Derive measurements*, computes the difference between top and bottom distances between filter and chamber wall 12. *Check allowances*, compares the computed measurements with the nominal values

Fig. 9.14 Clamping flange with uncrimped nut

9.3.1 Illumination

As usual, the first question is that of suitable illumination. The decisive factor is rendering the crimping visible because the flange arms and the bore holes are much easier to find and identify than the crimping. Viewing the collared nut from the top, a human can easily discern crimped, uncrimped and incorrectly crimped nuts, but a reliable automatic identification requires much better contrast in order to have an existing crimping stand out clearly.

Correct crimping creates a surface area which is neither horizontal nor vertical in contrast to all other surface portions on the collared nut. This means that an illumination is needed which emphasizes differences in the inclination of surface areas, i.e. a directed illumination. It is clear that the crimping cannot be separated equally well from vertical and horizontal surface areas at the same time, but a good starting point for further inspection is the clear distinction of the horizontal areas on the one hand and the vertical areas together with the crimping.

Another requirement on the illumination follows from the rotational symmetry of the test piece and the fact that the location of the crimping along the perimeter of the test piece is unknown. It is therefore necessary to inspect the entire perimeter. This means that lighting also has to be rotationally uniform. Both requirements can be fulfilled by a large ring light illuminating the test piece obliquely from all sides. All horizontal areas appear extremely bright in the image, whereas the vertical edges of the nut as well as the crimping cast clearly defined shadows. Figure 9.15 shows the illumination effect schematically. The effect of the illumination is depicted extremely simplified to make the principle clear; the actual conditions are of course more complex due to the surface structure of the material and the rotational symmetry of part and lighting. For clarity's sake, reflected rays have only been drawn for three significant locations. The fanning out into several rays indicates that the surface is not an ideal mirror but scatters the light with a certain predominant direction. It can be seen that

- light from horizontal surfaces is reflected primarily in the direction of the camera. These areas appear bright;
- almost no light falling on rising, vertical edges is reflected towards the camera. These edges therefore appear dark;
- shadows appear behind falling vertical edges;
- only little light is reflected towards the camera from the inclined surface of the crimping, with the inclination presenting more working surface to the light than a vertical edge. This dark area therefore appears wider.

The effects of the lighting setup described above can be easily seen in the camera image. Figure 9.16 shows images of a crimped and an uncrimped nut. Because of the overexposure, the horizontal areas appear pure white, the vertical edges are visibly darker. However, they are disrupted in several places by the overexposure. The image of the crimped nut clearly shows the wide dark area of

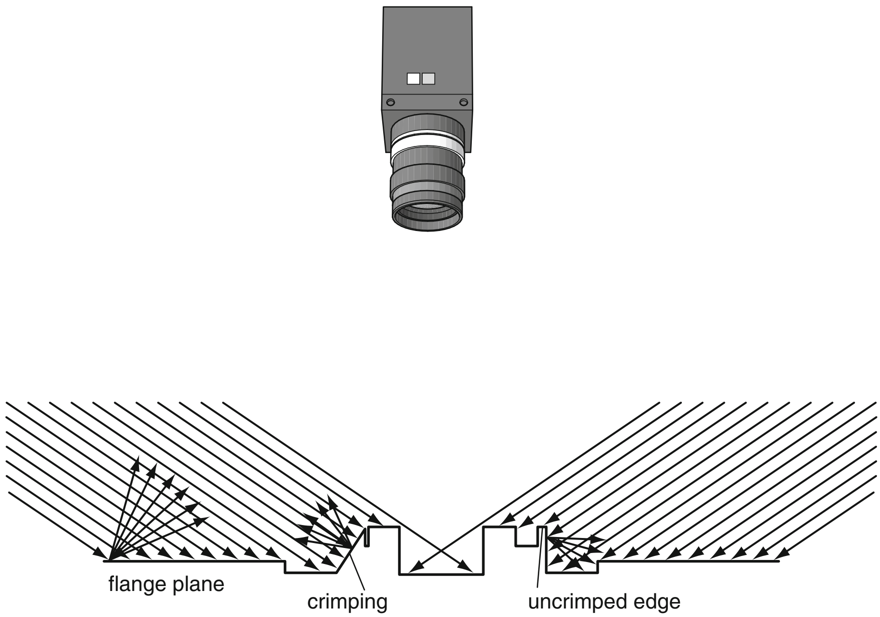
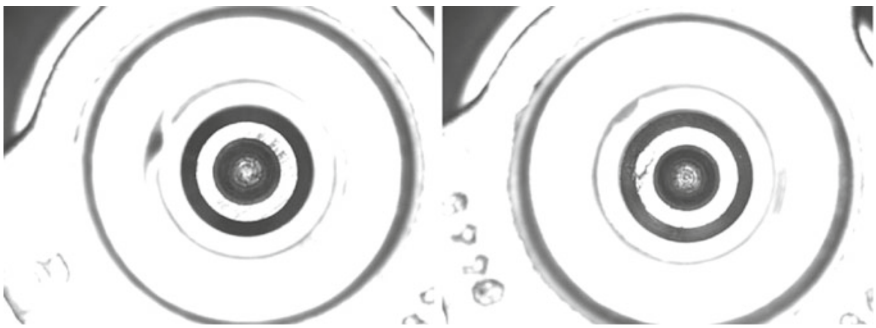


Fig. 9.15 Illumination of nut



Crimped Uncrimped

Fig. 9.16 Nut under ring light illumination

the crimping tapering out in correspondence to the shape of the crimping, whereas in the image of the uncrimped nut the edge appears only slightly thicker at the point where the crimping tool is applied. Incidentally, the illumination creates a wide shadowed ring, which is a very stable image feature that can be put to good use for positioning purposes.

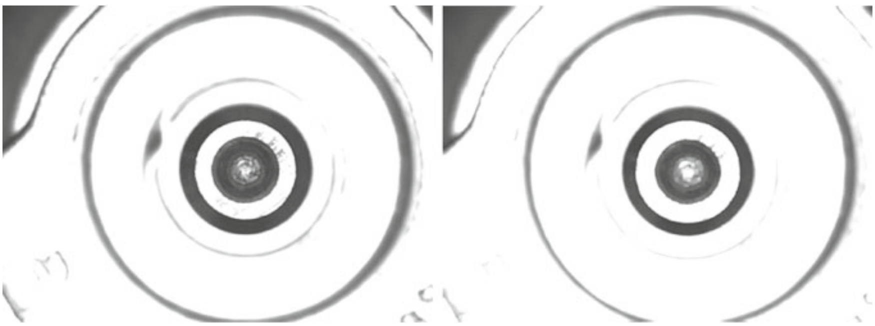
This application is another striking example of the importance of illumination for image processing solutions. On the other hand, it also shows that the design of a suitable illumination setup requires at least some idea of how to realize the inspection itself, because the algorithmic solution affects which features have to be visible in what way within the scene. We will later see that position adjustment is very important in this application. It is therefore very fortunate that the selected illumination method also creates a stable reference object for positioning in the image.

A word on the technical realization of the ring light: there are large ring-shaped fluorescent lights available but their fixed diameters limit flexibility and they do not produce entirely uniform all-around lighting because there has to be a starter at some place. For these reasons, a ring light was constructed from separate LED spots, which have the additional advantages of great durability and high yield at wavelengths for which CCD sensors are especially sensitive.

9.3.2 Check of Crimping

Preprocessing: The vertical edges, which appear as thin dark lines in the camera image, cannot be used for positioning or other evaluation purposes because they may be partly interrupted due to the overexposure. The exact location of these interruptions cannot be determined beforehand because the test piece may not be positioned precisely in the center of the ring light. For the inspection they are therefore a disturbance whose influence can be reduced by preprocessing with a dilation filter as can be seen in Fig. 9.17.

Determining of position reference: The next step is the definition of a region of interest within the outer borders of the collared nut. Within these limits, thresholding based on a histogram analysis can be performed easily, taking into account that a considerable portion of the pixels is concentrated at gray level 255 due to the overexposure. The suppression of artifacts by removing extreme gray levels from the calculation described in Sect. 4.2.3 is therefore not recommended in this application. Fig. 9.18 shows the defined ROI and the corresponding



Original image   Result of dilation

Fig. 9.17 Nut before and after gray level dilation

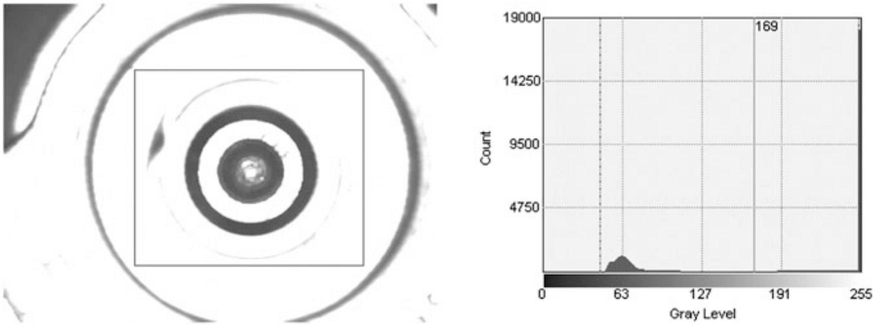


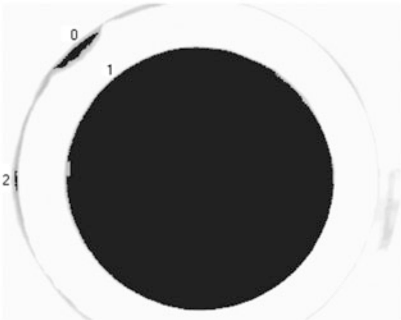
Fig. 9.18 Region of interest for positioning around nut (black rectangle) and corresponding histogram

histogram. As is customary for applications with position variations, the first region of interest has to be large enough to find the relevant objects for the maximum position variation. On the other hand, one will choose the smallest region possible in order to reduce the time required for the segmentation and the number of additional objects which would have to be screened out later. The wide shadow ring in the middle of the nut can be easily segmented as reference object for the position determination. Parts of the vertical edges not suppressed by the dilation as well as the crimping itself may be detected as additional objects. The object sizes are sufficiently different to suppress these spurious objects already during segmentation. For safety reasons, a validation using features significantly different for the spurious objects and the shadow ring like perimeter, area, form factor and ratio of width to height is recommended. Figure 9.19 shows this on the example of an uncrimped nut where all objects have been detected. Perimeter and area are much larger for the shadow ring than for the spurious objects, as is the form factor; the ratio of this almost perfectly circular object is always close to one.

It turns out that the inner border of the shadow ring is smoother and more stable than the outer one; therefore, another segmentation is performed inside the circular object for a bright object. After another validation stage similar to the one described above, this inner circle is used as the position reference.

Unrolling: What is the purpose of this complex procedure of determining a reference object? The main issue of this inspection task is the insecurity when it comes to the angle position in which to find the crimping. Thus the entire perimeter has to be searched.

On the other hand, Fig. 9.19 shows that there can be several spurious objects at almost equal distances from the center of the nut which are very difficult to distinguish from the crimping using simple features. This means that one should immediately search for an object of the appropriate shape, which suggests using template matching. The object's pixel shape is changed depending on the angular position of the crimping, leaving two possible methods:



Display: Features

No.	Ratio	Perimeter	Form factor	Area
0	0.816	106.125	0.263	236.000
1	0.987	769.392	0.843	39695.000
2	8.500	36.107	0.202	21.000

Fig. 9.19 Shadow ring with spurious objects and corresponding features

- Creating (or internally computing) separate templates for a multitude of angular positions. On the down side, the computational effort for correlation increases significantly with the number of templates. It has to be taken into account that several templates are necessary since the crimping does not always have the same shape.
- The circular ring inside of which the crimping has to be located can be converted to a rectangular image. Thanks to the large radius of the circle, discrete effects are limited and the computation effort is restricted to a single conversion.

To perform such a conversion of a ring into a rectangle, a circle line is defined around the center of the ring. At certain angular increments the normal on this circle is computed. Then the gray levels to both sides of the circle are interpolated parallel to this normal direction and written column-wise into a new, rectangular image. Figure 9.20 shows the definition of a circle along the shadow border of the collared nut and the result of the unrolling (to enhance visibility, contrast has been improved and the overexposed background has been shaded in gray).

This method can in principle be applied to arbitrary contours, but it is advantageous to use a manually defined circle because then size and shape are exactly specified. It is of special importance to position the circle very accurately. Figure 9.21 shows the effect of unrolling when the center of the defined circle and center of the collared nut do not coincide. The unrolled image shows a noticeable wave which may change the shape of a correct crimping as to be unrecognizable.

There is one other problem with the unrolling process: in contrast to a circle, unrolling requires a defined starting and end point. If this falls in the middle of the crimping, unrolling will cut it in two parts whose shapes differ from the original unbroken shape making further segmentation impossible. It is immediately obvious that this can be avoided by "over-unrolling" the circle by 50 %. This means that the first 180° are appended a second time to the end of the image. It is then absolutely certain that the unbroken crimping will be present at least once in the unrolled image.

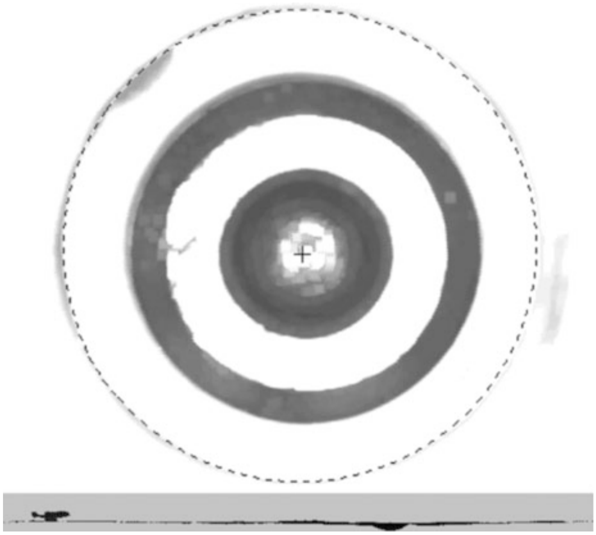


Fig. 9.20 Definition of a circle and result of unrolling

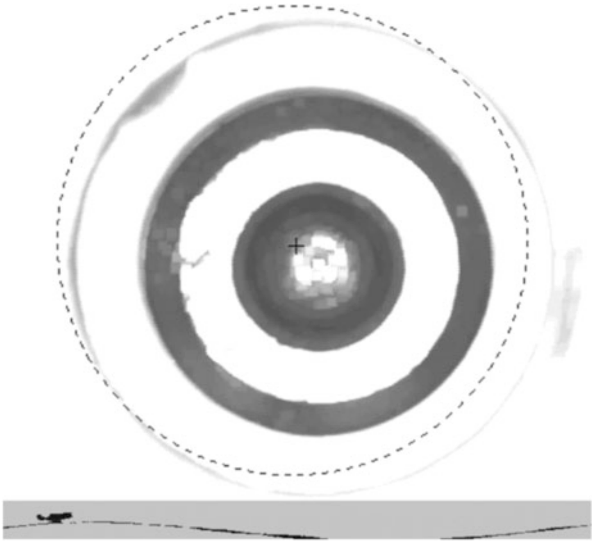


Fig. 9.21 Definition of a circle and result of unrolling with incorrect positioning

Segmentation and evaluation of the crimping: Because of its compact shape, the crimping can be segmented easily and reliably using template matching. It is recommended, however, to include images of incorrect and missing crimping in the template set and to optimize the positions of the correlation points according to the shape of the crimping. Figure 9.22 shows some templates.

But the inspection task is not solved after finding the crimping using template matching. The main capabilities of template matching are in the area of segmentation, not classification. It is therefore quite easy to locate a good crimping,

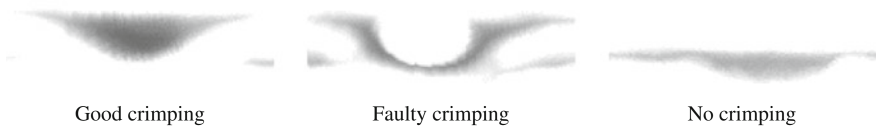


Fig. 9.22 Templates for searching the crimping

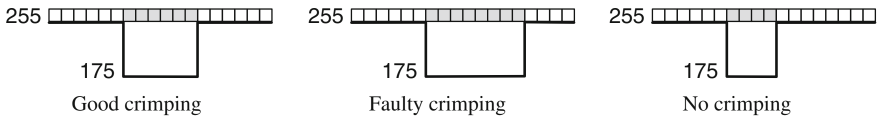


Fig. 9.23 Distinction problems with template matching

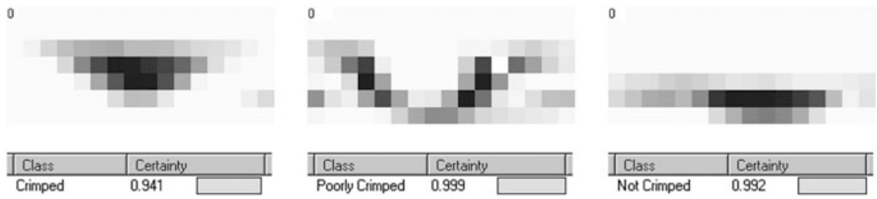


Fig. 9.24 Resampled and classified crimping

but it is much more difficult to distinguish it from a faulty crimping or the point where the tool is applied. A one-dimensional example may help to illustrate this problem. Figure 9.23 shows schematic cross sections of the crimping. For simplicity reasons let us assume that there are only two gray levels: 255 and 175. The narrow dark area with a width of only four pixels corresponds to the point where a tool is applied, which is a bit wider than normal, whereas the wide dark area represents a faulty crimping.

When computing the correlation between the good crimping and the other two cases in the sample profile, one obtains a correlation coefficient of 0.79 with the faulty crimping and of 0.76 with the uncrimped point where the tool is applied. In reality, cross sections will not be quite so similar. But because of the considerable variation in the shape of the crimping, it is not possible to require high minimum correlation coefficients, so it will be difficult to distinguish good, faulty and missing crimping on the basis of the correlation coefficient alone. It is therefore necessary to evaluate the detected object again, for example by presenting its appearance to a classifier. Figure 9.24 shows the result of such a classification using a resampled image of 16 × 7 pixels and the average gray level inside the bounding rectangle of the object. This average gray level will be significantly lower for correctly crimped parts because the dark area of a correct crimping is much larger than that of a faulty or missing one.

Table 9.3 The following table summarizes the example from Sect. 9.3.2

Category	Description
Directory	\Examples\Presence
Illumination	Low, incident ring lighting from LED lights with strong overexposure
Check functions	The example uses the following check function sequence: 1. *Image capture* 2. *Filter image*, performs a dilation to remove thin edges 3. *Define ROIs*, sets a rectangle in the approximate center of the flange 4. *Determine threshold*, optimizes the threshold using a histogram analysis of the region of interest 5. *Create ROIs by thresholding*, segments the shadow circle in the center of the flange. The object can be validated by check functions Compute features and Screen ROIs 6. *Create ROIs by thresholding*, segments the bright inner area of the shadow circle, which is better suited as position reference because of its more stable contour. Again the object can be validated by check functions Compute features and Screen ROIs 7. *Determine position*, uses the centroid of the bright inner area as position reference 8. *Define ROIs*, creates a circle with the exact diameter of the edge where the crimping is located 9. *Position ROIs*, centers this circle according to the centroid of the bright inner area 10. *Unroll ROI*, transforms a strip to both sides of the positioned circle into a long, rectangular image 11. *Define ROIs*, declares the entire unrolled image as the search area 12. *Template matching*, scans the unrolled image for the crimping 13. *Compute features*, calculates the average gray level inside the bounding rectangle of the detected crimping 14. *Resample ROIs*, creates an input image for the classifier from the detected crimping 15. *Classify ROIs*, determines whether the detected candidate is a good crimping from the average gray level and the resampled image

This solves the first part of the inspection task, the verification of the crimping. Table 9.3 summarizes the example. We can see that it is a rather time-consuming inspection. Decisive factors for the inspection time are the functions *Filter Image* with the computational intensive dilation, *Unroll ROI* with the interpolation along the circle and *Template Matching*, which has to use a small step size here to allow for a sufficiently reliable detection of the varying and rather ill-defined shape of the crimping.

9.3.3 Type Verification of the Flange

Now we turn to the second part of the inspection task, checking the type of the flange. The various types of flanges differ in the number of arms and their length.

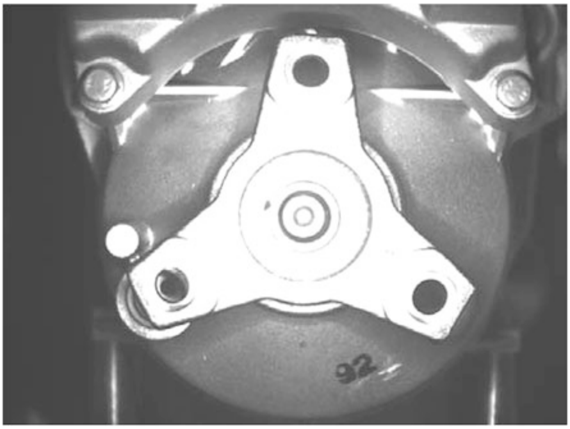


Fig. 9.25 Three-armed flange

Figure 9.25 shows a complete three-armed flange. We can see a correctly crimped nut in the middle. It can be seen that the flange can be inspected using the same illumination as for the crimping. Only the camera has to be switched because a much larger field of view is required for this part of the inspection.

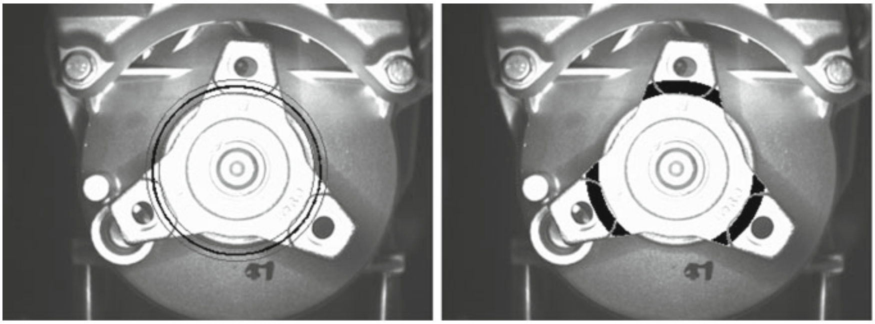
The entire flange is difficult to segment as it can merge with background areas, depending on its angular orientation. It is much simpler and more reliable to segment sections from the flange arms, count these, and gauge the distance between the center of the collared nut and the bore holes in the flange arms to check the length of the arms. A high level of accuracy is not necessary in this application since only a type distinction is required.

The inspection starts in almost the same way as that of the crimping in Sect. 9.3.2, with the following alterations:

- Small spurious objects from the edges of the nut are not important in this inspection; the computation intensive dilation filtering can therefore be left out.
- The inspection is less position-sensitive, therefore the slightly less smooth and stable outer contour of the shadow circle suffices as reference object.

The final configuration is almost identical to that in Sect. 9.3.2 before unrolling. Again, a circle is defined running through the roots of the flange arms slightly outside the base of the flange itself, as Fig. 9.26 shows. A binary thresholding along this circle that restricts contour tracing to a narrow area on both sides of the circle segments a section from each arm without the time-consuming unrolling. For the correct flange this results in three objects also shown in Fig. 9.26.

As usual, several features are computed for each of these objects to ascertain that they are actually sections from the flange arms and not undefined objects from the background. These features have to be independent of the angular direction of the flange arms. Some suitable features are, for example, the area and the maximum radius, i.e. the maximum distance between the centroid of the object and its contour. After all objects have been removed which do not comply with the criteria



Positioned circle Segmented sections

Fig. 9.26 Flange with positioned circle and segmented sections of the arms

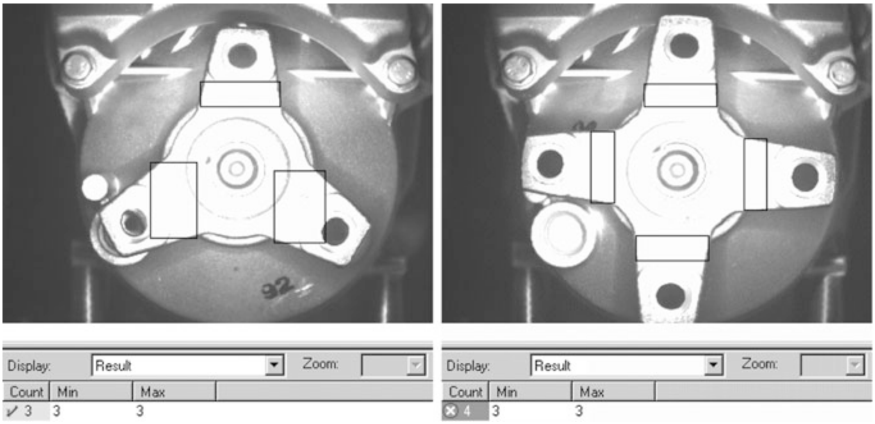


Fig. 9.27 Flange with three and four arms

for flange arm sections, the remaining objects are counted. If the number of objects does not equal three at this point, the check is aborted immediately because it cannot be the correct flange. Figure 9.27 shows both cases, a correct three-armed flange and a flange for which the sections of the arms meet all criteria—except for the fact that four arms are present.

Presence of the correct number of arms does not necessarily mean that the correct type of flange is also present. For this to be true, the length of the arms also has to be correct. This is determined by measuring the distance between the center of the flange and the bore holes since the bore holes can be segmented more reliably than the far edges of the arms, which may merge with bright background areas depending on the angular orientation of the flange. The bore holes are such clearly defined objects that they can easily be found by template matching without

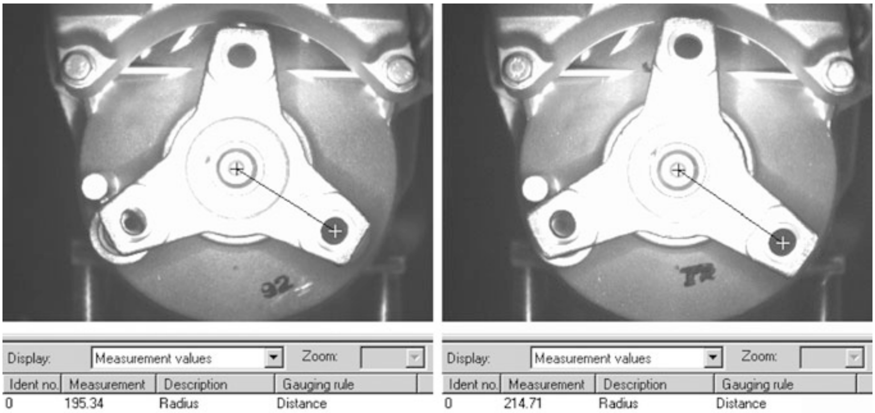


Fig. 9.28 Flanges with varying arm lengths

particular regard to the region of interest. The search area can simply be defined as a square encompassing the entire flange. It is also not necessary to restrict the template search to a circle defined around the center of the flange. Although this would limit the area to be searched, the computational complexity would be increased due to the more complex addressing of the positions to be searched so that there would be no significant increase in speed.

Since this application does not require particularly accurate gauging but only a relatively coarse distinction between various types, one can simply search for a single bore hole and measure its distance to the center. For the same reason, no calibration to metrical measurements is required. The scale will be identical for each flange, so one can directly relate the pixel-based measurement values. Figure 9.28 again shows two cases. Both flanges are three-armed—else the check would have stopped before this point—but the arms of the right flange are too long.

Finally it should be noted that a precise measuring of the flange diameter would be done a little differently. In this case all three bore holes should be detected by template matching, then the exact contours of the bore holes created by thresholding inside the template areas. As we know from Sect. 7.2.1, these centroids are subpixel-accurate. A model circle can then be computed according to Sect. 7.5.1—which for the three defining points in this case is an exact circle but still subpixel-accurate because it is based on the subpixel-accurate centroids. The radius of this model circle is a very accurate and stable measurement for the radius of the circle of bore holes. Prerequisite for this method is that all bore holes are visible as complete, unbroken circles without irregularities in their contours. Table 9.4 summarizes the example.

Table 9.4 The following table summarizes the example from Sect. 9.3.3

Category	Description
Directory	\Examples\Presence
Illumination	Low, incident ring lighting from LED lights with strong overexposure
Check functions	The example uses the following check function sequence: 1. *Image capture* 2. *Define ROIs*, sets a rectangle in the approximate center of the flange 3. *Determine threshold*, optimizes the threshold using a histogram analysis of the region of interest 4. *Create ROIs by thresholding*, segments the shadow circle in the center of the flange as position reference. The object can be validated by check functions Compute features and Screen ROIs 5. *Determine position*, uses the centroid of the shadow circle as position reference 6. *Define ROIs*, creates a circle running through the bases of the flange arms 7. *Position ROIs*, centers this circle according to the centroid of the shadow circle 8. *Create ROIs by thresholding*, cuts out sections from the flange arms along this circle as new objects 9. *Compute features*, computes characteristic data (area and maximum radius) from the sections of the flange arms 10. *Screen ROIs*, removes all objects with invalid feature values leaving only actual flange arm sections 11. *Count ROIs*, determines whether the flange has the required number of arms 12. *Define ROIs*, sets a search area encompassing the entire flange 13. *Position ROIs*, positions the search area again according to the centroid of the shadow ring 14. *Template matching*, searches for a single bore hole 15. *Gauge ROIs*, measures the distance between the centers of bore hole and flange 16. *Check allowances*, verifies the compliance of the measured distance with the prescribed size of the required flange type

9.4 Contrast-Free Presence Verification

This section is about inspecting the tube holder of an air-conditioning unit in Fig. 9.29. Rubber tubes are wedged between the individual noses during assembly. It can happen that some noses are not molded correctly or break off later. The main difficulty with this subtask is that the noses are molded together with the part from

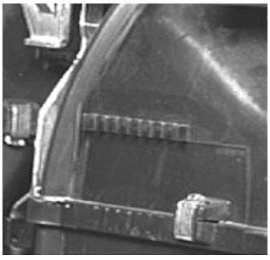


Fig. 9.29 Tube holder on air-conditioning unit

Fig. 9.30 Proper and faulty tube-holder with laser line illumination

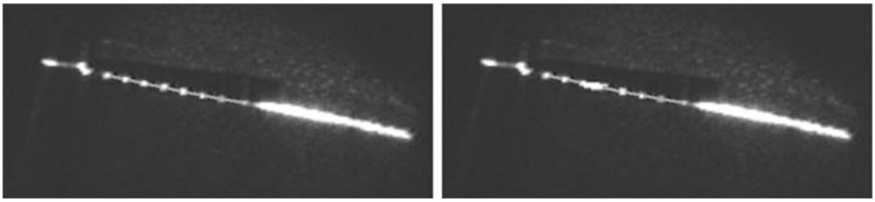


Fig. 9.31 Interspace objects for interval check at hose holder

the same dark plastic. It is therefore practically impossible to design an illumination yielding reliable and sufficient contrast.

Such a problem can be solved by structured lighting. Figure 9.30 shows the effect of projecting a laser line onto a good tube-holder and a tube-holder with a missing nose. It can be clearly seen that in the second case one of the required shadows is missing.

To inspect the tube-holder, all bright objects, i.e. the reflections of the laser line on the dark plastic, are first created using thresholding. All objects are screened out which do not correspond to the typical appearance of such a reflection. Since the reflections are small, almost circular objects, features like area, maximum radius and form factor, i.e. the normalized ratio between area and perimeter, can be used. Then the remaining objects can be counted.

In addition to directly counting the objects one can also check the spatial frequency, for example by connecting the center points of the objects with a line and performing another segmentation along this line, this time for dark objects. By restricting this segmentation to the line connecting the center points the dark gaps between the bright reflections are created as objects. These can be checked again for their length and counted. Both checks together determine the presence of the correct number of objects in the correct intervals, thus preventing an additional reflection outside of the area of the tube-holder to convey the impression that an actually missing nose was present. The objects created in this interval check are indicated in bright gray between the reflections in Fig. 9.31.

Program hint: A line connecting the center points of objects is automatically created in **NeuroCheck** when a model line is created for the entire group of objects using check function *Compute Model Geometries*. The check function creates a virtual object from the control points as an intermediate step for the calculation of the regression line. These are just the centroids of the objects in question. The complete check can be found in the download in directory \Examples\Presence\Airco.

Finally, it should be noted that such structured lighting using laser lines also allows for actual gauging—sufficient resolution provided—as shown in Sect. 8.6.2.

9.5 Presence Verification Using Line-Scan Cameras

All examples from the previous sections used an area-scan camera image for inspection, i.e. a rectangular image that was captured at once at a certain time. This method reaches its limits with certain types of inspection pieces. This is the case, for example, with very large objects where the fixed sensor resolution of an area-scan camera usually doesn't allow for sufficiently detailed images. Another very common example is cylindrical parts that occur in a great variety in all parts of industry. We are first going to comment on when the inspection of lathe parts is possible using area-scan cameras and what difficulties can be encountered.

9.5.1 Inspection of Cylindrical Parts with Area-Scan Cameras

In the previous examples we've already dealt with some visual inspections of rotation-symmetric parts. Section 7.6 shows gauging of the outside contour of a thread flange, Sect. 9.2 the assembly inspection of a drip chamber. The film rolls from Sect. 5.4 and the spark plug from Sect. 1.6 are further examples for inspections of cylindrical parts.

In all these examples the inspection features either referred to the cross-section of the inspection parts (as with the thread gauging) or had to be determined through individual images of certain sections of the part surface (as with character recognition on the spark plug or block code recognition on film rolls). Such inspection tasks involving round parts can be solved using the "ordinary" image of an area-scan camera. However, if the inspection task involves capturing the entire surface of a round inspection part, using an area-scan camera poses several problems.

Shortening of projection: The main difficulty is that the part's surface is curved away from the object. When projecting the curved surface onto the sensor plane, more or less distinctive shortenings occur outside the image center. The broader the section of the part captured in the image, the more pronounced the shortening. In the extreme case that the entire part is captured in the image, the shortening on the outermost edges is infinite, i.e. each arc length on the surface shrinks to a length of zero in the image. Figure 9.32 shows the effect of this projection with the

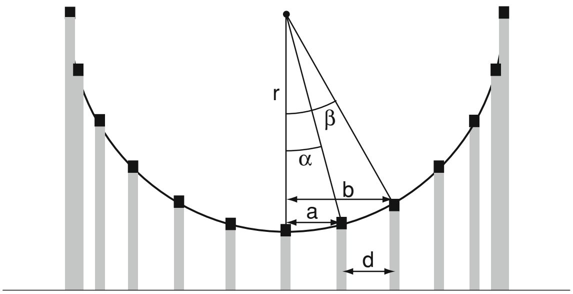


Fig. 9.32 Shortening of objects along a circle line when projected onto a sensor plane

assumption that the camera is focused on the axis of a lathe part. On the circumference of this part, objects are arranged with a 15° distance. One can see that when projecting onto a planar sensor, the distance of the objects to each other gets smaller to the outside. The outermost objects even fuse together. If, for example, the objects are lines of a bar code, this code wouldn't be legible.

If two objects on the circumference of a cylindrical part are located at the angle positions α and β, according to Fig. 9.32, their distance d in the projection onto the sensor plane is:

$$d = b - a = r(\sin \beta - \sin \alpha). \tag{9.1}$$

The (not depicted) distance d_k of objects on the circumference of the circular cross section is just equal to the arc length between the two angle positions:

$$d_k = 2\pi r \frac{\beta - \alpha}{360^\circ}, \tag{9.2}$$

with the angles in degrees. Table 9.5 gives an impression of the degree of shortening occurring with growing distance from the central view direction. Between 90° and 75°, an arc length of 26.18 mm is shortened to 3.41 mm in projection from an object with 100 mm radius.

Task types: An essential criteria for being able to solve an inspection task involving a cylindrical part with an area-scan camera is how far the area to be inspected covers the circumference of the part, and whether it is possible to present the relevant areas directly, if possible, in the line of sight of the camera.

Table 9.5 Shortening of distances when projecting the circumference of the circle onto a planar sensor

Radius	Alpha (°)	Beta (°)	Arc	Projection	Remaining length (%)
100	0	15	26.18	25.88	98.86
100	15	30	26.18	24.12	92.12
100	30	45	26.18	20.71	79.11
100	45	60	26.18	15.89	60.70
100	60	75	26.18	09.99	38.16
100	75	90	26.18	03.41	13.02

A perspective shortening can already be seen in the introductory example character recognition in Sect. 1.6, Fig. 1.9 but which was rather limited so close to the middle of the projection.

Also of importance is whether the inspection feature is axial or radial oriented. The bar code on the film rolls in Fig. 5.29 is far away from the middle of the projection, the scanning, however, is done at a right angle so the shortening is of no importance for reading the bar code.

Basically, inspecting a cylindrical object with an area-scan camera is thus possible if one of the following conditions is met:

- The inspection features only refer to the contour or cross-section of the object (as with the thread gauging in Sect. 7.6 and assembly inspection in Sect. 9.2).
- In the projection on the sensor plane, the inspection features are so close to the part's axis that the shortening because of the curvature is very small (as with the digits on the spark plug in Sect. 1.6).
- The inspection features are prominently axial oriented so the radial shortening is of no great importance (as with the bar code on the film roll in Sect. 5.4).

Furthermore, fluctuations in the orientation of the inspection piece in front of the camera (that lead to varying optical shortening of inspection features) have to be limited to a range that is permissible for each inspection task. Even when the characters are along the axis, character recognition would certainly be difficult or impossible if the inspection piece is turned so far that the characters are only visible along the edge.

Gauging tasks: Special problems pose themselves when gauging on the surface of cylindrical objects since the shortening changes the geometric resolution of the image and thus calibration and accuracy depending on the angle position. Table 9.5 shows that already in a range of $\pm 15°$ on both sides of the direct line of sight of the camera, distortions of more than one percent occur. With increasing distance from the optical axis, this distortion grows rapidly because of the nonlinearity of the angle function. Strictly speaking, measuring such a piece with an area-scan image is only possible with the part's contour or along the axis, not along the circumference.

Inspecting the complete circumference: When the inspection features cover the entire circumference of the inspection piece and an area-scan camera is to be used, several images have to be captured. The number of images depends on the required resolution and permissible distortion. If, for example, a shortening of a maximum of ten percent is permissible, then no more than $\pm 30°$ of the part's circumference can be captured in one image according to Table 9.5. Thus six images are necessary for each part. These six images can be captured in various ways:

- Several cameras are arranged around the part. This way is rather expensive (because of the required number of cameras) and also poses illumination problems since the illumination for one camera can blind other cameras.

- The part is turned and captured cyclically, i.e. in each of the desired angle positions, in front of the camera. This solution requires a high mechanical effort and complex control for the step motor and trigger signals. Since the part is again and again stopped and set back in motion, image capturing takes a lot of time which is aggravated by vibrations that can occur and for whose quieting down one has to wait.
- The part is continuously rotated in front of the camera. This is mechanically more simple than a clocked rotation, but poses even more serious synchronization problems since the individual image captures have to be triggered in specific angle positions. Since the part is captured in motion, exposure can only be very short to avoid blurring. This, in turn, results in the problem to get enough light onto the curved surface in the moment of image capture.

One can see that an inspection covering the entire circumference of a cylindrical part cannot be solved satisfactorily using an area-scan camera. The inspection of lathe parts is a typical line-scan camera application.

9.5.2 Inspection of a Valve Body

Figure 9.33 shows a section of a valve body used to control the oil flow in automotive hydraulics. This image shows the illumination problems posed by these parts. Under a certain angle, the curved, polished surface reflects so strongly that a homogeneous illumination over a large area is rather difficult.

Let us take a closer look at two of the inspection criteria for these components:

- The bore holes in the lathed cut-ins of the part are vital for the proper oil flow. Their number and size have to be checked.
- The raised contact surface between the lathed cut-ins must be free of cavities since they have to seal the oil flow.

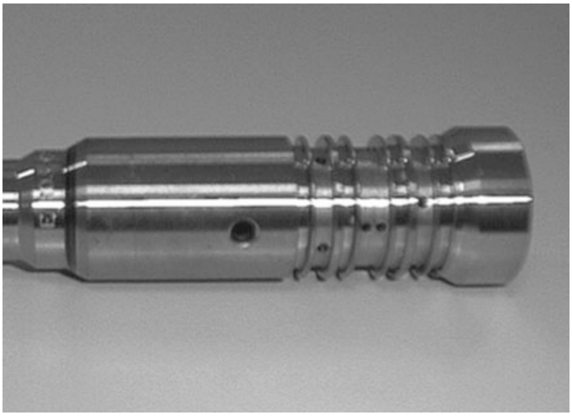


Fig. 9.33 Valve body from automotive hydraulics

Image capture: A line-scan camera is used for inspection. As described in detail in Sect. 8.4, image capturing with a line-scan camera always necessitates relative movement between inspection object and camera. Figure 8.15 shows the image capturing situation for capturing the surface of a cylindrical component using a line-scan camera. The component surface is scanned line by line with the camera, i.e. unrolled into a rectangular image.

The capturing method is fundamentally different from capturing a rotating component using an area-scan camera.

Rotation: Since the line-scan camera scans the component surface continuously line by line, the component is continuously rotated and not stopped.

Synchronization: If the rotation is sufficiently even, the image processing system or the camera only need a trigger signal for the start of the rotation. Only when very high accuracy with regard to gauging and geometry is required, synchronization of rotation and image capturing via rotary encoder according to Sect. 8.4.4 is necessary.

Distortion: Since the camera only captures one line at a time along the component axis, the camera always looks down on the part's surface at a right angle so there are no curvature distortions.

This way we can obtain a distortion-free unrolling of the component surface. The necessary time for such image capturing results from the required geometric resolution (see Sect. 8.4.2), the required exposure time (see Sect. 8.4.3), and the mechanical conditions that determine the speed with which the component can be rotated. For the application described here, image capturing takes about 3 s.

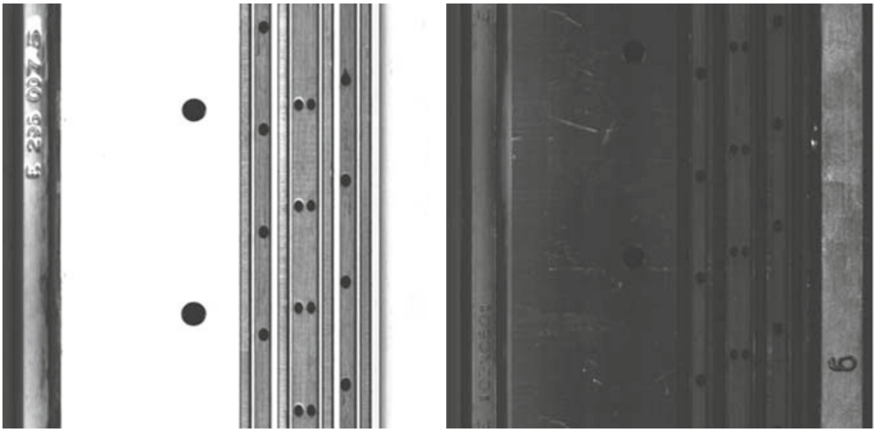
Illumination: The inspection tasks mentioned above, bore hole and surface inspection, require different illuminations:

Bore hole inspection: For the inspection of the oil flow openings, a diffuse bright field illumination is used. The polished surface strongly reflects the light so the dark bore holes contrast sharply.

Surface inspection: Spurious cavities in the contact surfaces can be detected with a directed dark field illumination. The principle of the illumination is shown in Fig. 5.26. The even, smooth surface reflects the directed incident light past the camera while cavities on the surface disperse the light in the direction of the camera. For the illumination a cold light source with line projector was used. Capturing and illumination angle must be adjusted to each other.

Figure 9.34 shows the line-scan camera images of the inspection part with the described illumination conditions. All in all, two captured images are necessary for the inspection with different illuminations. It is advantageous to capture both images in sequence at the beginning of the inspection routine instead of capturing first one image and processing it completely. The images can be buffered and processed while the component is leaving the inspection station. This way, part of the handling time can be used for inspection.

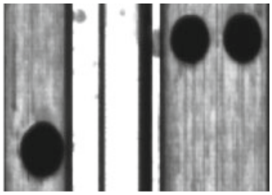
Bore hole inspection: Because of the good contrast in the bright field image, the bore holes can be easily detected using thresholding. However, accurate positioning is important to narrow down the search for the bore holes to a restricted area. This can reduce the risk to find the edges of the cut-ins that also appear dark in the image.



Bright field illumination Dark field illumination

Fig. 9.34 Line-scan camera images of the valve body with various illumination conditions

Fig. 9.35 Reference template for position determination in bright field



This way, there are also less spurious objects that need to be filtered; the more artifacts are present, the more difficult it can be to find good filter criteria. Also, it is quicker to search a smaller area. The characteristic group of three holes depicted in Fig. 9.35 offers itself as a reference object for position determination.

Further inspection takes place in the following steps:

Search areas: Depending on the position of the first bore hole group found, the search areas for the bore holes are set. Please note that we are only concerned with the horizontal position. The vertical position is undetermined anyway since no information is available concerning the angle position of the component with which the line-scan camera started capturing. A full revolution of the part is captured starting from the position of the part when it enters the station.[1]

Segmentation: The bore holes are segmented within these search areas using a threshold. Template matching as for positioning wouldn't suffice. For the

[1] Actually more than 360° are unrolled to avoid cutting off a bore hole in the image because it is at the starting point of the revolution. With line-scan camera applications it's a common approach to capture slightly more than a full revolution.

Table 9.6 The following table summarizes the example from Sect. 9.5.2

Category	Description
Directory	\Examples\Presence
Illumination	Diffuse front lighting, bright field
Check functions	The example uses the following check function sequence: 1. *Image capture* 2. *Define ROIs,* sets a search area for detecting the reference position 3. *Template matching,* detects characteristic bore hole group as position reference 4. *Determine position of ROIs,* measures the offset from the reference position 5. *Define ROIs,* sets a search area for segmenting the bore holes 6. *Position ROIs,* adjusts the search areas according to the determined deviation 7. *Determine threshold*, optimizes the bright/dark-threshold using a histogram analysis of the search areas 8. *Create ROIs by thresholding,* segments dark objects within the search areas 9. *Compute features,* computes characteristic values of found objects 10. *Screen ROIs,* eliminates spurious objects 11. *Screen ROIs,* checks agreement of remaining objects with characteristic features of bore holes 12. *Count ROIs,* checks whether the correct number of bore holes is present 13. *Gauge ROIs,* computes the distances of neighboring bore holes within a cut-in 14. *Calibrate measurements,* converts pixel measurements into metric ones 15. *Check allowances,* checks the distances between neighboring bore holes

subsequent inspection of the bore holes' sizes, it is necessary to determine the actually visible contour.

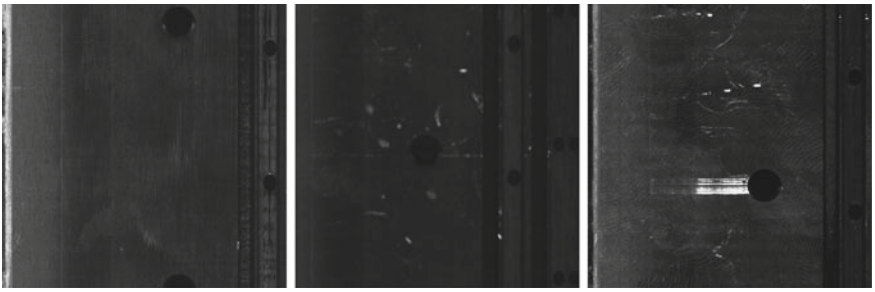
Removal of artifacts: After thresholding the spurious objects are removed that may result, among others, from surface structures and the edges of the cut-ins. For this reason all objects are removed that are not sufficiently circular (measured using the height-width ratio and form factor; see Sect. 10.1.2) and whose area is not within certain limits.

Inspection of bore hole size: Subsequently, the inspection checks whether each cut-in shows the required number of objects of the proper size. Since the component is rotated more than 360° in front of the camera, one object more is admitted than bore holes are present.

Inspection of geometric arrangement: Finally, the distance between two neighboring bore holes in the same cut-in is checked to make sure there is no bore hole in the wrong spot; this would, after all, not manifest itself in a faulty number.

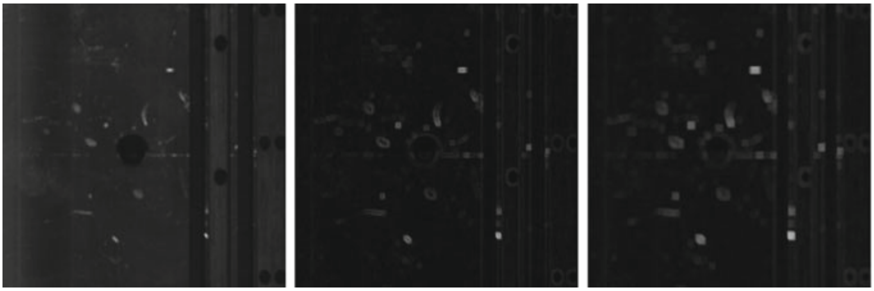
Table 9.6 summarizes the check routine for the bore hole inspection.

Inspection of contact surfaces: Please note that the example in this section is highly simplified. Especially with applications dealing with surface inspection, time-consuming and elaborate experimental runs are necessary to capture the variety of possible error types, and also the variety of appearances of faultless surfaces. It's not unusual for an application engineer to have to "think outside the box" to achieve a reliable distinction between OK and not OK parts using preprocessing, masking known surface effects and so on.



Perfect surface | Small defects | Large-area damages

Fig. 9.36 Various valve bodies with dark field illumination



Mean value filter | Contrast filter | Dilation

Fig. 9.37 Valve body with damaged contact surface after preprocessing

Figure 9.36 shows segments of the surface of three different valve bodies. The inspection part in the left image has a perfect contact surface; the part in the middle has a number of small defects while the part on the right has large-area damages. A surface inspection of this type where certain individual defects are searched can be compared to presence verification except you're checking for the absence of defects.

Here, the defects need to be enhanced first so they can be reliably detected. For this, the image is filtered three times:

Mean value filter: This low-pass filter is used to smooth tiny machining artifacts that could be confusing in the subsequent screening stage.

Contrast filter: This non-linear filter improves the inhomogeneous nature of the gray level distribution caused by the defects.

Dilation: To improve detection, the bright defects are thickened.

Figure 9.37 shows the middle image from Fig. 9.36 after the three filtering stages.

After preprocessing, the bright defects are searched for in the contact surface area. They are evaluated according to area and brightness. Finally, the remaining bright objects are counted. If no objects remain that were determined to be defects,

Table 9.7 The following table summarizes the contact surface inspection from Sect. 9.5.2

Category	Description
Directory	\Examples\Presence
Illumination	Directional front lighting, dark field
Check functions	The example uses the following check function sequence: 1. *Image capture* 2. *Define ROIs,* sets a search area over the entire contact surface 3. *Filter image,* mean value filter for smoothing machining artifacts 4. *Filter image,* contrast filter for enhancing defects 5. *Filter image,* dilation to thicken bright objects 6. *Determine threshold*, optimizes the bright/dark-threshold using a histogram analysis of the search areas 7. *Create ROIs by thresholding,* segments bright objects within the search area 8. *Compute features,* computes characteristic values of found objects, in this case the maximum brightness and the area 9. *Screen ROIs,* leaves objects fulfilling the criteria for a defect according to size and brightness 10. *Count ROIs,* determines the inspection piece as "not OK" if an object, i.e. a defect, remains after object filtering

the entire inspection piece is deemed correct. Table 9.7 summarizes the check routine for the contact surface inspection.

9.5.3 Notes

In conclusion we would like to make a few remarks on the basic properties of line-scan camera applications.

Image size: Usually, line-scan camera applications deal with very large images. In the above examples we have images of merely 1,000 × 1,000 pixels that could also be captured using an area-scan camera. However, image sizes of more than 50 million pixels are not unusual.

Necessary time: Line-scan inspection of components usually require a lot of inspection time. This is caused on the one hand by the processing time for large line-scan camera images; on the other hand by the necessity to move camera or inspection part to get a contiguous image. The necessary time can be reduced by capturing the next image while the previous one is being evaluated; thus, these two time-consuming steps can be executed in parallel.

Surface inspection: This is a very typical application area for line-scan cameras. In the present example, the surface was inspected using presence verification after appropriate preprocessing. This is a method that can often be used, especially if it's important that a surface is free of certain defects.

If, however, the surface is required to have a certain structure, methods from texture analysis need to be used that are much more computation-intensive than the preprocessing filters employed here. Protracted optimization processes for a large number of inspection parts—and especially from batch production—are typical for applications of the surface inspection type since the appearance of technical surfaces and the possible defects are manifold. It is therefore advantageous if the image processing system used allows for a fast, interactive optimization of the running application.

Illumination: Like area-scan camera applications, line-scan camera inspections depend on adapted illumination. Since the camera only captures a very small section of the image scene, a single line, line-scan camera applications are very sensitive to adjustments in illumination and camera. On the other hand, the areas that need to be illuminated are so small that homogeneous lighting is easier to achieve.

Geometry: For line-scan camera applications that depend on the unrolling of the surface of a cylindrical part, the vertical position of objects in the image is usually undetermined. It depends on the angular position of the inspection part with which the image capture was started. An appropriate position compensation has therefore be taken into account.

Program hint: In **NeuroCheck** the check function *Adjust Line-Scan Image* can be used utilizing a determined position in the image to make sure that the image structure is always identical.

9.6 Summary

The following list summarizes some general properties of presence verification problems. Since this application area is rather heterogeneous, inspection routines can seldom be built according to predefined structures. Hardware setups (illumination, number of cameras…) are correspondingly varied. It did not seem useful to include such special aspects of the applications described above in this summary.

Presence verification problems: This is a very heterogeneous application area, ranging from simple object counting to validation of basic features and recognition of objects using classifiers to assembly verification with gauging methods.

Simple presence verification: In this type of application the validity of the objects to be inspected can usually be checked using simple feature screening. By this, we mean checking features of individual objects using numerical limit values. The typical procedure is as follows: after segmentation, basic features are computed such as size, brightness, etc., invalid objects are removed, remaining objects are counted. If the segmentation is performed by template matching, the correlation coefficient is already a first measure for the validity of detected objects.

Assembly verification with gauging: In this type of application, validity of objects follows from gauging results; i.e. in addition to basic features, relationships between objects, e.g. distances, angles, circle similarity, etc. are important. It is usually more important how the measurements relate to reference objects than achieving particularly high accuracy.

Presence verification using classifiers: If complex interdependencies between features have to be checked to determine the validity of objects, or if the entire appearance of the objects is important, classifiers can be used for object screening which have been trained to distinguish appearance and features of valid and invalid objects.

Contrast-free presence verification: Structured lighting, for example laser lines, can be used to segment relevant objects under conditions where no visual contrast can be achieved—for example in the case that the foreground, i.e. relevant objects, and background are made out of the same material.

Relevant properties: The main difficulty in most presence verification tasks is translating the quality criteria into measurable, computable quantities. Example: the requirement that a filter must not be mounted askew can be checked most reliably by measuring symmetrical distances.

http://www.springer.com/978-3-642-33904-2

Industrial Image Processing
Visual Quality Control in Manufacturing
Demant, C.; Streicher-Abel, B.; Garnica, C.
2013, XVII, 369 p. 252 illus., 20 illus. in color. With
online files/update., Hardcover
ISBN: 978-3-642-33904-2