TARGET – a flexible installation for inspection of industrial objects

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ABSTRACT

Keywords: Industrial metrology, image processing, image analysis, moldmaking, inspection

A solution for industrial inspection purposes will be shown. The conception is based on digital colour images taken from numerous perspectives around the object to be controlled. The process of image orientation is simplified and improved by the use of spatial reference objects. In contrast to conventional planar targets they are visible from all views and allow a better concatenation of the images. In addition, they can introduce a scale information what simplifies preparatory actions to be done within object space and can contribute with their spatial shape. For the inspection the object will be marked by a laser projection system with point or line patterns. The main aspects of the solution will be shown together with first test results.

1. INTRODUCTION

Within most industrial applications aimed at the construction of physical objects we have an increasing importance to precisely know the exact geometry of the objects produced. This might be due to demands from the customer or because of internal controlling processes. The later ones might not only be predestined to control the final geometry but are used to monitor the geometric shape throughout the whole construction process. This construction may consist of several individual steps which have to be passed starting with the raw material and ending at the final object.

During such a production process the object passes different geometric shapes which have to fit within certain boundaries. If once a boundary is exceeded the piece either has to be thrown out or costly additional work steps have to be applied. This is especially of importance if the objects are large, expensive or pass several time consuming steps before the final shape is reached. Such a scenario holds for the applications within moldmaking and tooling, for example.

These problems only will be avoided, when an appropriate monitoring and controlling system is available allowing to test the actual geometry and to compare it with a given ideal shape. Such a system needs to be as accurate as necessary to meet the quality aspects, has to be fast, flexible, simply to use and should be affordable. High flexibility would allow to control the object under varying conditions as they appear during the production cycle. In addition, it should be possible to control the object when it sits in a tooling machine in order to avoid transport to a stationary control installation.

Such a flexibility, combined with the potential of high accuracy will be achieved by the image based measuring conception presented here. The object will be monitored by means of several digital metric images arranged around it, which are automatically oriented and evaluated using projection technique and special spatial control targets.

2. EXISTING TECHNIQUES

Inspection of industrial objects has a long tradition as the geometry of such objects in general is predefined and has to be exactly met in the final stage of production. The number of control steps and the demands in terms of accuracy, speed and amount of control data, for example, are depending upon the production process and its practical and organizational conditions and may vary strongly. Consequently, there exists not one best strategy but numerous conceptions allowing to collect geometrical object information (cf. Fig.1).

From the users point of view several aspects may be considered looking for most appropriate measurement strategy. Of interest are, for example /6/:

- accuracy
- point density
- mobility
- measurement speed

- preparatory effort
- size of measurement volume
- allowed object shapes
- usability
- interaction with the object
- costs

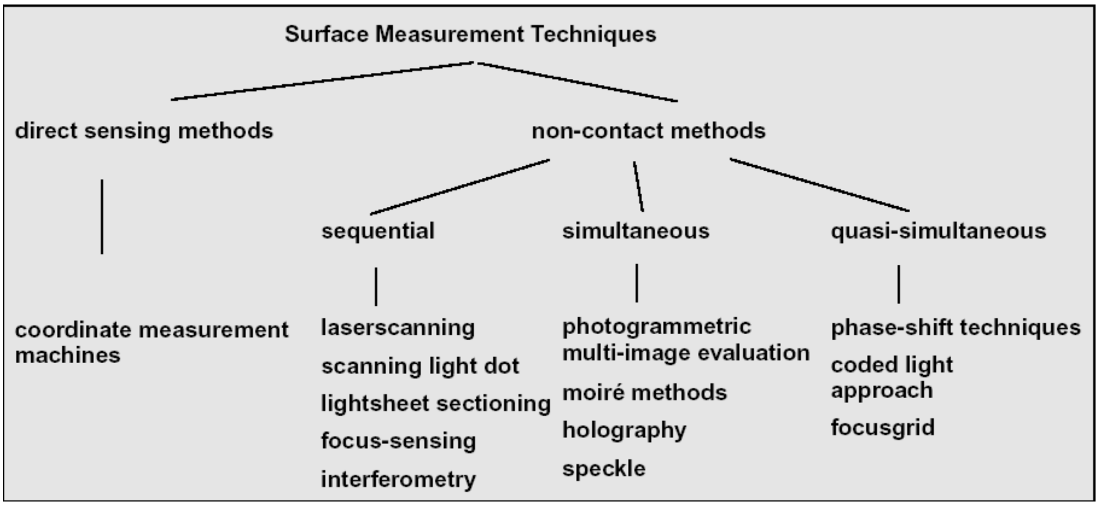


Figure 1: Surface measurement techniques /7/

With respect to the most important parameters the user has individually to decide which way to go for his metrology task. As the characteristics of the techniques are partly excluding each other it's sometimes inevitable for a user to purchase more than one system, if the demands are differing strongly. In such cases it might be of interest, to have a scalable system, being able to be adopted to different situations.

Looking at the systems listed above it is obvious, for example, that direct sensing systems like coordinate measurement machines are very accurate. However, they are very inflexible, need a stationary set up and cannot be used for measurement tasks to be applied onto objects having to be checked in their tooling machine.

Non contact methods not necessarily need a special stationary set up and provide much more flexibility. They can be distinguished by measurement speed, for example. Sequential systems need much more time for data capture at the object, than simultaneous systems. Furthermore they may have restrictions, because each individual data capture is tied to one viewpoint. The generation of a complete 3D geometry, therefore needs to move the object or the viewpoint and the combination of all views.

Simultaneous and quasi-simultaneous methods use one or multiple digital images and are much faster. After data capture they need further time for data evaluation and the generation of the object geometry. However, this might be accomplished within several minutes and must not be far away from real-time applications. Limitations could come from interactions with the object, which are necessary to prepare it for the measurement process /4/. This conflicts with an application, if it is forbidden to touch the object or if the time spent for the preparation exceeds the period for which it is accessible. Nevertheless image based measurement techniques provide a higher degree of flexibility, although effort and cost may be considerable, if high accuracy is desired.

3. A FLEXIBLE APPROACH

3.1. GENERAL ASPECTS

In the field of moldmaking and tooling the user may have permanently changing tasks, as the objects to be built often are single pieces, passing through numerous production steps. They pass stages, which may lead from a rough model made from polystrene to a final precise one made from aluminum, steel or other solid materials. During this process it would be ideal to monitor each stage in order to control the next production step starting from the well known actual geometry. Such a procedure results in very different demands to a measurement process. Characteristics to be handled could be:

- range of accuracy from low to high
- size of objects from small to several cubic meter

- varying surface types (roughness, reflectivity, firmness)
- varying data density, ranging from local to global information
- mobility, allowing to check objects within tooling machines
- high measurement speed at the object
- no interaction with the object, if possible
- moderate costs
- integration into the manufacturing process

It is obvious, that solutions found in automotive industry, which use specialized measurement stations within production lines cannot be transferred to this applications. Instead, only a very flexible system, which might be adopted to each individual aspect can solve all tasks. An image based solution seems therefore be the most promising, because of:

- fast data capture at the object, with shortest possible interruption of the production process
- high flexibility
  - as images can be taken anywhere
  - because images can be individually combined as appropriate for accuracy and for geometry elements to be captured
  - because the object not necessarily needs to be touched or interacted with
- potential to be as accurate as necessary

In addition, the use of one single system simplifies the use for the personnel being responsible for quality control. They only need to know one user interface, although opposed to that, they have to know precisely how to apply the system for different tasks in order to get the desired result.

3.2. CONCEPTION

On this background a solution has been designed, which uses digital images for the data capture, a special set up for the introduction of metric reference information, an optical system for the generation of patterns to be used for digitization and a software package for all necessary algorithmic steps.

The capture of all images will be achieved by use of digital camera systems, which are widely available. It is up to the user to decide about the camera being well suited for his purposes. However, this decision is strongly determined by the price/accuracy relation. There exist high accurate systems /1/ ranging far above 100.000 EUR, which in general are only used for special applications requiring highest accuracy. At the opposite low price segment, digital cameras are offered for 1000 EUR having the potential to meet the accuracy needed, if their internal geometry will be treated correctly.

Using one or several camera systems the object will be photographed where necessary. Prior to the image taking some elementary preparations have to made. This comprises

- to introduce sufficient metric reference information into the object space
- to prepare the object space for the determination of orientation values for all images
- to make the object visible for the evaluation algorithms

For first the two actions special cubic reference objects are used. They serve as targets for the image analysis and provide scale information as their shape is calibrated. This set up follows a new conception for the automatic orientation of images /2/ and is explained below. The visibility of the object is assured by a projection system allowing to generate appropriate patterns like points or grids, for example. This projection has to assure sufficient contrast on the object surface, what needs a powerful light source, because of the varying surface types.

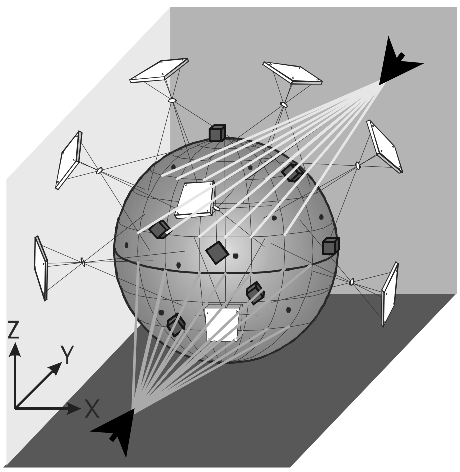


Figure 2: Arrangement of images around an object

Based on this preparation the object is monitored with the camera system from many positions around. This has to be done in accordance to the requirements of accuracy, point density and surface regions to be checked. Here the user has flexibility to take as much images as necessary comprising variations in image scales in order to get the information help needs.

Based on all images taken, the evaluation process follows. First, the images have to be oriented and second, the objects points signalized have to be determined. Both processes should be done completely automatically. Furthermore, the conception allows to complete an already generated object model with additional measurements as long as the geometry of the situation remains unchanged and the reference object have been kept at their positions.

Finally some additional steps are planned. First, a conversion of the final object model into the data structure of the CAD software used for design and construction should be possible and second, the software should be able to check the measured object geometry against the pre defined geometry in order to control the next production step. This would speed up the construction process considerably, because the machines could be driven in a way allowing to restrict their actions at those object regions where deviations between ideal and real shape make it necessary.

4. SOLUTION

4.1. IMAGE ORIENTATION

4.1.1. BASIC IDEA

The process of image orientation is the first and very basic step of a surveying process. It decides upon the final quality of the results and has to be prepared carefully. In addition, some actions have to beal completed allowing real time processing.

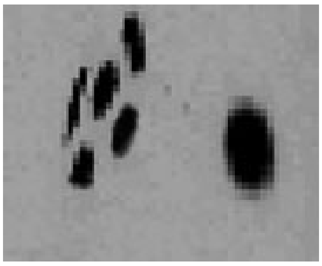


Figure 3: Variations of geometry within planar targets

This in general comprises the preparation of the object by coded and non-coded planar targets (cf. Fig. 3) being attached to the object surface and the distribution of scale bars at and around the object. The targets provide the image rays needed for the orientation process and coded ones give additional information allowing to solve the correspondence problem for an automatic processing. Finally the scale bars contribute with their precisely defined length and introduce the scale information needed for accurate results.

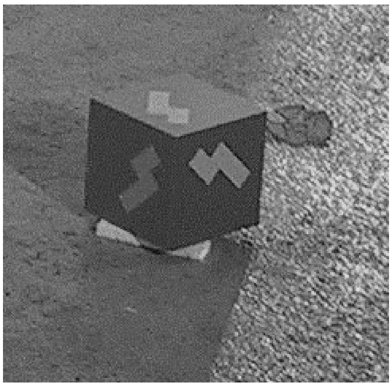


Figure 4: Cube example

However, in industrial applications often the complete spatial shape of objects has to be determined, what requires a surveying with images taken from all sides around. As consequence images may look from very different views onto the surface resulting in distortions for those targets having a large inclination to the image plane. Such targets will not be used because they won't pass successfully through the image analysis. So, the number of image rays will be reduced what leads to a

- weakening of the geometry within the block
- problems with the establishment of a complete block
- higher effort for calculations

These problems can be avoided by spatial targets (cf. Fig.4). This is because spatial targets show either one surface directly to the camera or up to three with moderate inclination. So, it is possible to detect such a target in all images having sight to it, what allows a maximal concatenation between the images taken. As further aspect, it is possible to use such spatial targets as scale targets. If they have a body with edges, these edges introduce a distance information which may be used instead of external scale bars. However, several targets have to be used because their edges are shorter than distances on scale bars. On the other hand, each target may provide several distances, oriented in all three directions of space, what simplifies a solution.
The use of spatial targets therefore has some advantages:

- the whole object with all surfaces is usable for the image analysis, avoiding problems arising from oblique views
- provides maximal concatenations between all images
- allows the combination of images from opposite views (inner and outer part of an object)
- combines target and scale information
- needs no attachment to object

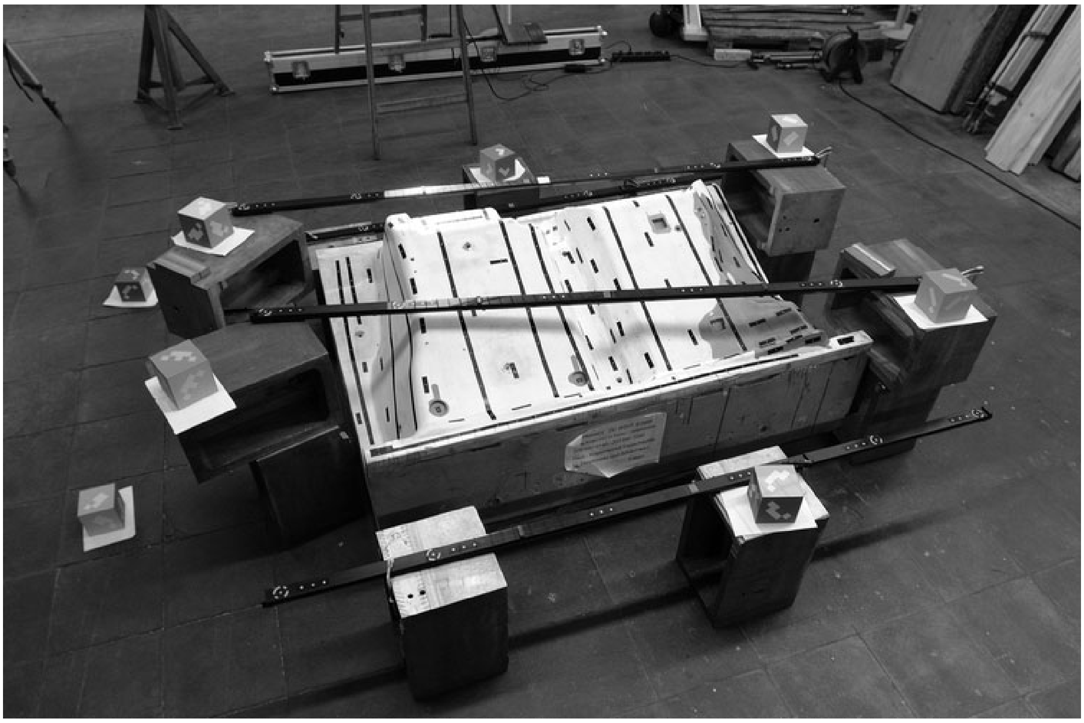


Figure 5: Test situation

These advantages help to solve problems which may arise when objects have to be measured under varying conditions with changing demands, because there are no general limits for the arrangement of images. One simply has to choose an adequate distribution of the targets within object space, allowing to connect the images as needed.

In addition, spatial targets are physically stable. This avoids problems, which may arise from difficulties with the attachment to a certain surface. They might be simply placed on the object if allowed but also can be scattered around if it is not permitted to touch the object for any reason.

4.1.2. ALGORTIHM

The use of cubic tie objects results in some additional efforts having to be invested into the image analysis, because of their higher complexity compared to planar targets:

- multiple surfaces have to be detected
  As the whole tie object has to be known for the orientation procedure the algorithm has to detect all surfaces of the target, being projected into a particular image
- each surfaces has to be uniquely identified
  Giving the freedom of connecting arbitrarily arranged images the images may observe completely different parts of the object. This has to be recognised, because otherwise wrong constellations would be assumed.
- The tie objects need to have a fix and known topology, which has to be observed and used, because they might be arbitrarily oriented within space. This has impact onto the sides presented to the different images and must be handled by the algorithm.

The overall procedure has three steps, which are applied sequentially.

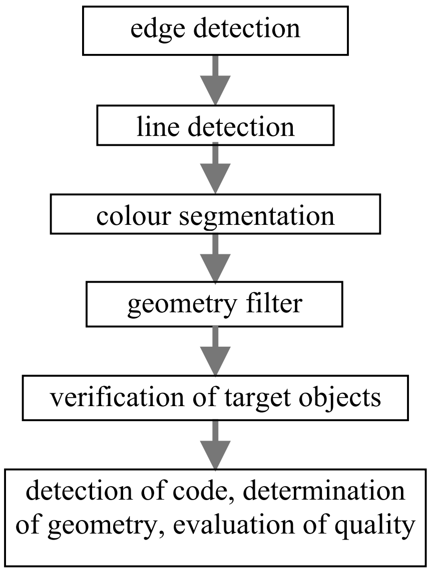


Fig. 6: structure of target detection

First, all images of a block are individually analysed, looking for the occurrence of targets (cf. Fig. 6). This is the most important part of all steps, because it has to assure, that the targets distributed in the object space will be successfully detected.

The second part analyses the correspondence of the images and calculates first estimates for the orientation values and the object coordinates, then, as last step, a conventional orientation procedure on the base of image bundles is applied.

The first step is based on a combined use of shape and colour information. Colour might be introduced in an active and a passive way. Passive coloured cubes are simply painted with well known colours in a predefined relation between all sides. However, this solution is sensible to changes within incoming light and needs higher efforts for calibration purposes. A solution with active light elements on each side (cf. Fig.7) representing a unique code for each cube side is more robust and practical and is preferred for industrial applications.

Figure 7: Cube with LED code

Based on this colour image analysis target candidates are identified in each image followed by an edge detection process which is continued by a geometry check using the well known and calibrated shape of the targets and will be terminated by final tests onto the exact shape.

The image analysis produces a list of cube objects for each image, from which the correspondence of all images is derived. As we have chosen cubes as targets each element gives 8 image points and an ID if it was prepared as coded target (cf. fig. 4, 7). The solution of the correspondence problem has some simplifications allowing to reduce the amount of calculations and to introduce some rigorous controls. They originate from the spatial shape of the targets allowing to group all points belonging to it. This reduces the amount of search steps due to less combinations possible. Second, the geometry of the cubes is well known permitting to rigorously control the hypotheses for image pairs, because the produced model geometry has exactly to correspond with the cube geometry. By this, systematic deformations will be detected immediately.

For the final calculation of the orientation values an existing software solution has been integrated /5/, which is well-tried in the field of industrial applications, allowing to get optimal results for the orientation values.

In general, the orientation should be as accurate as necessary, when all preparations within object space (number and distribution of targets) have been made carefully. However, those rays coming from the signals projected onto the surface used for the process of digitization will further improve the results. Therefore, the final result of the measurement process will be received using all image rays available in a last triangulation process.

4.2. OBJECT DIGITIZATION

4.2.1. PROJECTION

With the orientation values for all images taken the base for the real process of measurement is founded. The digitization process is founded on numerous objects points which must be visible and clearly defined. As it should be possible to treat objects without touching, points have to be made visible by means of a projection technique. According to the desired flexibility several demands have to be met by a usable projection system:

- the projection has to be invariant for the period of image collection
- the projector must have a high resolution to get the desired point density
- the projection should have a high field of depth
- the transmitted light should be rich of energy
- the projected pattern should be also appear in a bright environment
- the projected pattern should be visible on different backgrounds
- the system should be portable, easy and fast to install in the environment
- it would be helpful to project different patterns with different symbols and colors in order to simplify the image analysis (cf. Fig 8)

There are different techniques available, however, only a laser-projector will meet most of the criteria mentioned above. The best laser light is green light, because it is very intensive and provides a higher contrast than other colours. Green light is also visible in bright environments as will be found in most production halls.

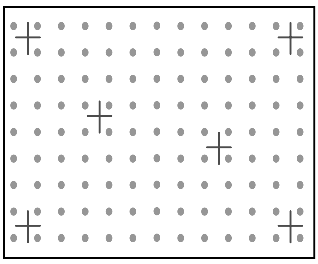


Figure 8: pattern sample

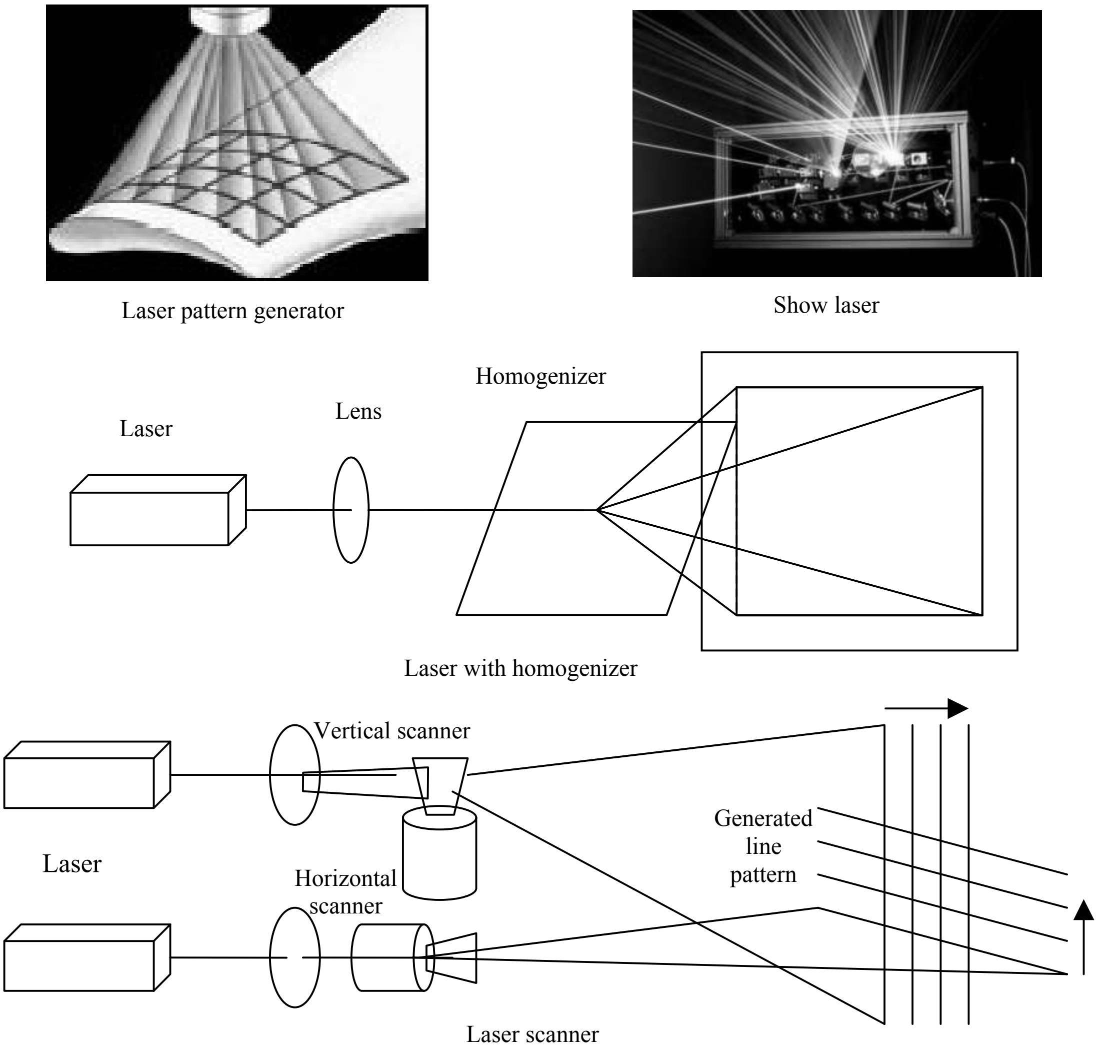


Figure 9: Different laser projection techniques

The most demanding criterion is to meet high point density together with an invariant and fast projection. In principle, this is supported by (cf. Fig. 9):

- show-laser-systems
- laser pattern generator
- laser with homogenizer
- laser scanner

Show-laser-system have problems to focus the beam in order to get fine and clearly defined points and therefore are only useful for small surfaces. Laser pattern generator allow to project fine points, however, they have restrictions in terms of point density. Available shaping optics generate arrays of not more than 99*99 lines and need to be combined, when large objects have to be digitized with high density.

Laser with a homogenizer are based on a monolithic array of cross-cylindrical lenses. They are used to generate a homogeneous rectangular spot. Changing the arrangement of this optical system, the homogenizer generates lines or points. However, some practical problems may arise from the fact, that the optical system individually has to be arranged with varying distances to get the desired pattern.

The most promising technology provide laser scanner. They use a small mirror being is controlled by a computer to deflect the laser beams in X- or Y-direction. For a grid pattern one needs a horizontal and a vertical deflecting system. It is possible to generate points or lines, with high optical and mechanical precision. The projection of 360000 needs not more than 0.1sec and in principle is in the range of usable exposure times.

Alternatives to laser systems are offered by video projection. However, they have a small field of depth and lower energy. Different types of video projectors exist differing in resolution and luminosity. Best results will be achieved by a DLP, DMD or D-ILA systems, although their use has to be restricted to small volumes and/or low point densities.

4.2.2. ALGORTIHM

The conception of the algorithm is shown in figure 10 and corresponds in principle to other strategies known. However, some additional aspects should be mentioned here.

Role of colour: At the moment colour images have to be used, because the shape of the targets uses colour information. So, colour can also be used to simplify the correspondence problem. This is strongly determined by number and density of points found. Using colour it is possible to project coarse and fine patterns of different color in parallel allowing to apply a hierarchical strategy for the detection of corresponding image points.

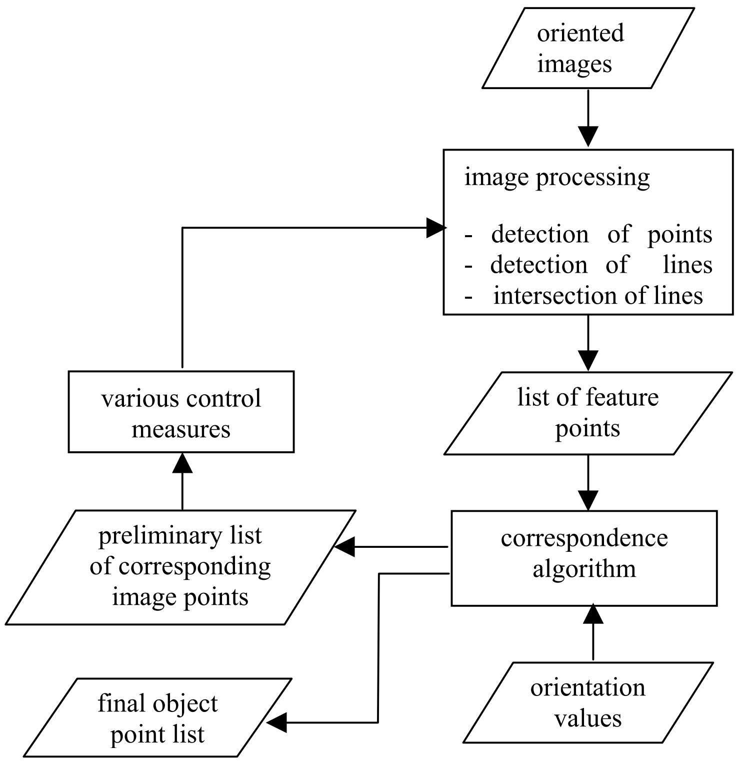


Figure 10: Flowchart for detection of object points

Image processing: Depending on equipment and application varying patterns will be used. Each pattern type needs its own processing logic, what requires a flexible operation of different analysis concepts. As image analysis and correspondence algorithm are separated it is simple to change between different mathematical allowing to change patterns as wanted.

Adopted image handling: Accuracy requirements will vary between different problems and objects. For high accuracy it is inevitable to use all images simultaneously and to combine all image rays existing there. Simple and/or local measurements which can be realized with lower accuracy don't need the whole data. They can be handled with some images allowing to reduce the amount of calculations.

Global to local processing: The conception allows to combine local and global data capture, what is useful, when not the complete object has to be digitized with high density. Then a hierarchical strategy might be applied. First, the complete object has to be illuminated and measured with a certain density followed by a second process of illumination, image taking and evaluation with a modified possibly higher point density. This is possible as long as the reference targets have been kept in their positions.

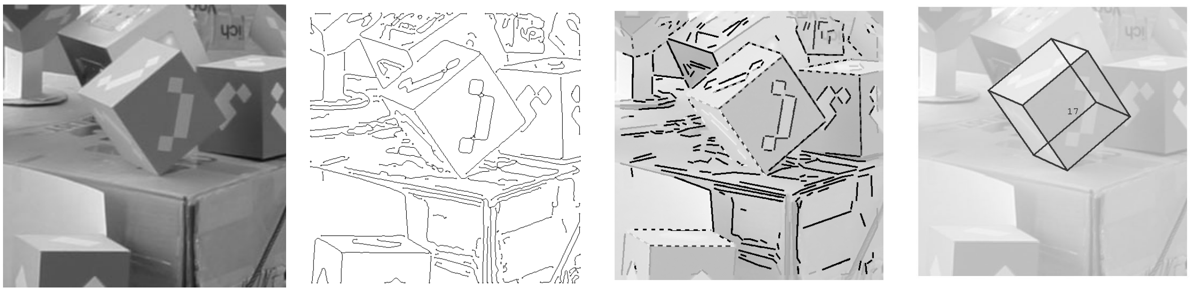
Control measures: The problem to find corresponding points is a function of point density, image quality, quality of orientation values, number of images, distinctness of points and complexity of object shape. Here simplifications can be used as the generation of the projected pattern may assure sufficient distinctness, the use of several images allows to introduce geometric restrictions like those based on epipolar lines and their intersections /8/ and, in addition, the available and good orientation values reduce ambiguities.

5. TESTS

5.1. IMAGE ANALYSIS

Some phases of a typical analysis are shown in fig. 11 documenting the major steps. This example presents results from a passive target. The conception of active targets shows fig. 7, their implementation is just ongoing.

Actually the success rate for the detection of passive targets reaches 80%. It must be below 100% because the geometric model for the targets is restricted to those imaged with 3 sides. Some problems are induced by interactions between targets, composition of incoming light and characteristics of the CCD chips in the cameras.



part of original image | Detected edges | Color edges | detected target

Figure 11: image analysis

These interactions lead to partly strong changes in quality and distinctness of colour data resulting in misinterpretations by the colour image analysis. If it is a global effect it can be compensated by a new color calibration for individual images, if only single targets are affected a compensation is more complicated. In both cases additional effort and partly manual interaction has to be invested, what cannot be accepted for an automatic procedure. Therefore the use of actively marked targets is essential for industrial applications.

5.2. ACCURACY

In order to check the accuracy some simulations have been calculated. Several situations have been examined. One of these used an object of about 4 m^3 (2 * 2 * 1 m^3). Numerous constellations of reference targets scattered around this object have been tested. It could be shown, that with almost all constellations the accuracy level of about 0.1 mm for the standard deviation in all coordinate directions was attained. As base served an accuracy for image coordinates of about 0.2 pixel, a value which is in the range of standard image analysis algorithms.

Practical tests had to be restricted to passively coloured targets, because the image analysis for the targets coded with LED have still to be completed. Results therefore are non optimal due to the impact of illumination conditions onto the results of the image analysis and leads to partly imperfect connections between images and to lower quality of detected cubes. The latter problems are forced by degradations of image quality due to compression algorithms applied within the digital cameras used.

Expressed in numbers, this means for the test situation shown in fig. 5 a point quality for object points of 0.3 mm. The quality of the image coordinates was about 0.5 pixel and has further potential for improvements. Although these practical results are not as good as desired, they show where the solution has to be improved. It can be expected, that with actively marked targets several problems will be avoided and the gap to the accuracy theoretically will be closed considerably.

6. CONCLUSION

A flexible solution for the inspection of industrial objects has been presented, showing some new aspects compared to other known strategies. Essential is the use of spatial targets and a projection system allowing to illuminate objects of limited size with various patterns. This conception offers some advantages which are useful for inspection purposes:

- the concatenations of images is improved due to the extended visibility of the targets allowing to reduce the amount of images necessary or to simply connections between images
- a higher flexibility
  - as images can be taken anywhere
  - images can be individually combined as appropriate for inspection
  - the object not necessarily needs to be touched
- allows the combination of images from opposite views (inner and outer part of an object)
- provides scale information directly with the reference targets

Theoretical investigations have shown, that an accuracy interesting for many inspection purposes can be attained. Practical tests show however, that further modifications have to be made, which are already ongoing.

7. ACKNOWLEDGEMENT

The paper presents results of a research project funded by the German Department of Trade and Industry and is conducted in Co-operation with Grunewald GmbH, a leading german enterprise in the field of tooling. The authors cordially appreciate the support and co-operation.

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