CONFIGURATION OPTIMIZATION AND OPERATING RANGE ENLARGEMENT OF CCD-VIDEO-CAMERAS

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ABSTRACT:

In the field of industrial quality control the object measurement with CCD-video-cameras gains increasing importance. In contrast to conventional photogrammetry there are other possibilities, but also other boundaries, depending on hardware. Especially the lower relative image resolution and the resulting small operating range in object space influence the configuration possibilities. Under this point of view different layout aspects of CCD-video measurement systems are discussed in the following. Solutions for special problems are proposed. The difficulty of the selection and evaluation of systems is described.

KURZFASSUNG:

Im Bereich der industriellen Qualitätskontrolle gewinnt die Objektvermessung mit CCD-Video-Kameras zunehmend an Bedeutung. Gegenüber der konventionellen Photogrammetrie ergeben sich gerätebedingt andere Möglichkeiten, aber auch andere Grenzen. Besonders die geringere relative Bildauflösung und der damit einhergehende kleine Arbeitsbereich im Objekt wirken sich nachteilig auf die Konfigurationsmöglichkeiten aus. Unter diesem Gesichtspunkt werden im folgenden verschiedene Aspekte der Auslegung von CCD-Video-Vermessungssystemen diskutiert. Für einige Detailprobleme werden Lösungsmöglichkeiten vorgeschlagen. Es wird desweiteren auf die Schwierigkeit der Auswahl und Beurteilung von Systemen eingegangen.

1. INTRODUCTION

Planning a photogrammetric measurement system for industrial quality control purposes is a very complex task. Several aspects have to be taken into account which are not known when using conventional cameras. Examples are statically installed online-systems, real-time ability and automatic evaluation. The objects to be measured vary in form and size in a wide range. Many special conditions are given in an industrial environment. A large palette of hardware is available.
In the following some considerations are made concerning the configuration of static online photogrammetric systems based on standard video techniques.

1.1 Basic requirements

A measurement task is described by the:

- size of object
- accuracy of results
- available time for image acquisition and evaluation
- industrial environment
- economic considerations

The object size together with the required accuracy define the number of cameras, which also depends on the image resolution. The available image aquisition and evaluation time is mainly a factor for hardware layout and software automation. Beside this it possibly limits the use of moving components which are discussed below. The industrial environment can cause a lot of difficulties resulting from dirty conditions, reduced operating space, production activities and traffic.
While optimizing a system for the above mentioned criteria one has to consider the costs of hardware and software in order to achieve an economic solution.

1.2 Status quo of video hardware

Hardware availability has grown while prices were reduced rapidly in the last few years. This affects mainly standard video products compatible with TV-norms like CCIR in Europe or RS170 in the USA. Cameras of this type have an image resolution of up to 800 by 600 pixel at a rate of 25 or 30 frames per second. Several available features like shutter modes, automatic gain control, gamma adjust, different synchronisation methods and separated heads make the difference between low-cost and high-end. In the context of this paper an idealized camera of this category is used as base for all considerations.

1.3 Resulting aspects of block configuration

A static online video system needs a different block layout compared to conventional photogrammetry for the following reasons:

- The relative image resolution is lower, which results in a smaller object area covering and therefore leads to a greater number of cameras. The effort to be made for orientation and calibration increases.

- In most cases every image is taken with a unique camera. This reduces the field calibration capability. Also every additional image is quite expensive. Therefore redundancy is often poor.

- Orientation elements for online system checks must be provided.

- Limitations in the positioning of cameras and controller hardware are given by cabling.

A good optimization has to be done in order to come to efficient systems.

1.4 The problem of system evaluation

For the quality control manager who has to decide if a photogrammetric video system fits to his requirements arises the problem of correctly evaluating the available solutions. A formalism with a set of comparable parameters does not exist. The dependence on individual configuration aspects is very high. Some suggestions will be made at the end of this paper.

2. CONFIGURATION AND ORIENTATION

Determinating the orientation of an image is a basic photogrammetric operation and necessary for most of the evaluation methods. It can be done online with additional object information, offline by calibration or indirectly with special hardware. It influences configuration considerations heavily.

2.1 Online-orientation versus calibration

In a static measurement system it is possible to calibrate fixed camera positions in a seperate step instead of orienting every new image. It depends on the mechanical and electronical stability of cameras and fittings relative to environment conditions, how long uncontrolled operation is guaranteed to be errorfree. The advantages are:

- no additional targets neccessary
- better independence from object variation
- higher accuracy of orientation
- faster evaluation

The combination of both orientation methods where the separate calibration is periodically controlled online possibly with a reduced set of parameters is of course the best solution.

2.2 Aspects of accuracy, speed and economy

The accuracy of measurement results influences the configuration through the image scale, which together with the camera resolution defines the object area covered by one image. It is important to clarify very precisely which accuracy is really needed, because every additional image may become expensive, because in static online measurement systems with fixed camera positions this will require a new camera and possibly new or extended controller hardware. For this reason it depends much more on the block configuration whether a system is economical or not than in conventional photogrammetry. Another factor for costs is the speed of image acquisition and evaluation at the point where the job cannot be done in time by standard hardware. Concerning the camera configuration it may limit the use of moving components which are discussed more detailed below.

2.3 Flexibility

In most cases a static video measurement system is designed for exactly one well defined task. Nevertheless the requirements given by the industrial production process may change or the system has to be placed to another location or it has to be adapted to different objects. In these cases a very specialized and optimized configuration shows low flexibility. This has to be taken into account when reducing camera numbers and using unconventional orientation methods which are described below.

2.4 Configuration types

A video measurment system may have the following principal camera constellations:

a) 1 camera
b) 2 cameras
c) several cameras in block configuration
d) several independently oriented cameras

a) One single camera can be used to determine object coordinates in a plane.

b) Using two cameras with overlapping image areas is the simplest way to obtain three-dimensional object coordinates. There is no redundancy for error control and the object size is limited if high accuracy is needed.

c) The block configuration, that means several overlapping images which cover the whole object, is the most accurate constellation, supposed that a bundle block adjustment with sufficient redundancy is used. It is very flexible, but it needs a great number of tie points which in most cases have to be signalized on the object surface. The number of required cameras is high. If an object has only a few points of interest with long distances between them it may occur that several images only act as block connections, which is very ineffectiv and expensive.

d) Independently oriented cameras can concentrate on the important parts of the object. It has to be considered that every target must be measurable in at least two images, which leads to a pair or better a triple of cameras for each interesting object region. This method is discussed in detail below.

2.5 Conventional orientation methods

A simple way of determining an orientation is to provide enough control points in the image and calculate a spatial resection. In a block arrangement the images can be oriented relatively, whereby it is necessary to have identical points which do not need to have known coordinates. This operation can be performed by a bundle block adjustment. In both cases additional targets have to be placed in object space, in the case of control points they have to be determined in a separate calibration step. The positions of such targets of course must also be covered by the images, which may sometimes lead to additional cameras. If point signalization on the surface or in front of the object is not possible and an offline system calibration does not come into consideration, a different orientation approach has to be done.

2.7 Special demands in industrial environments

The limit for configuration layouts given by the industrial production process is mainly that the optimal camera positions are not accessible. The consequences can be small object regions covered by images for short distances between camera and object and in most cases unfavourable ray intersections which lead to reduced accuracy. Important for the stability of camera positions and control points are production activities or traffic, possibly causing that orientations have to be controlled permanently.

3. OPERATING RANGE ENLARGEMENT

Operating range enlargement in this context means to optimize extensive configurations with the goal of a minimum of cameras and a maximum of object size. It is mainly a problem of camera orientation.

3.1 Object coverage

As mentioned before it is not always necessary to cover the whole object with images. An example is the determination of profiles of a railway waggon of 18 m length, which are only required in the middle and at both ends. A complete coverage with a usual close range block configuration would only be possible with a lot of cameras, when an accuracy of 1 mm has to be achieved. As already pointed out many of these cameras only have the task to build the block structure and do not show any really interresting object point. When such cameras are eliminated, the block becomes instable or unusable. The remaining cameras have to be oriented independently. This can be done in the same coordinate system for all parts which is represented for example by a field of control points determined in a special calibration. The possibilities and advantages of block adjustment are reduced for this type of configuration because of lower redundance and slighter connections between the block parts. Also the elimination of tie cameras can result in remaining images that have no orientation information. These images have to be oriented by a calibration, or in unstable conditions with alternative methods described below.

3.2 Moving cameras

Camera movement in an otherwise static measurement system can be used to obtain more images without additional video hardware. This is the same idea as the macro scanning used in some digital photogrammetric cameras. There are two principal movement types which have different effects: the rotation and the shifting.
Rotating cameras simulate a greater field angle. They can cover a larger object region. Depending on layout and precision of the fitting the images taken in different directions have none or up to five identical orientation parameters. The rotation parameters are given by the the movement itself, whereby the cameras normally do not roll around their optical axis. Position shifts are caused by different locations of the rotation and the projection center. This is a mechanical problem, but the effects can be calibrated. Two different shots taken from an only rotating camera of course cannot be used alone for a three-dimensional evaluation because of the missing image base.
Shifted cameras deliver fully independent images. Orientation parameters may still be partly identical, suitable mechanics presupposed.
A combined movement system with rotations and shifts can be very flexible, but loses the advantage of identical orientation parameters.
The disadvantages of moving cameras are the additional time consumption, the sensitivity for disturbance and the mechanical wear.

4. ALTERNATIVE ORIENTATION METHODS

Standard methods use their own image information for the orientation process. The disadvantage is that additional targets have to be placed in object space, which can be difficult, instable or simply impossible. In these cases the orientation of cameras can be performed by alternative methods which will be described in detail below.

4.1 Laser

To obtain all orientation parameters with a laser system is possible but very complicated and inefficient. The advantages lie in rotation control and determination. A laser attached to the camera body can point to a far target outside of the object space, where displacements of the beam are equivalent to certain rotations of the camera. The check can be performed manually, for example with a scale, or an additional camera can be used for the automation of this step. Another possibility to control the beam movement is given by PSD's (PSD = Position Sensitive Device). These elements have a size of 10-30 mm^2 and can register the position of a light point in one ore two dimensions with high accuracy.

4.2 Orientation cameras

The fact that two cameras fixed together have sets of orientation parameters, which are directly dependent from each other, can be used to place control points far

away from the object. One camera has the task of orientation, the second has to measure the desired targets. Many configuration variants can be realized. Of course the orientation camera can additionaly be used for object measurements and one camera can control the positions of a set of several cameras. It may also be possible to optimize the image scale for the control points and use cheap hardware for the orientation task.
A variation of this method can be used to determine the angles of rotating cameras. In this case the field of control points can be very small and near the camera.

4.3 Beam splitter techniques

Instead of using additional cameras it is possible to use beam splitters in order to get two different viewing directions with the same camera, one on the control points and one on the object. This is a much cheaper solution compared to additional cameras. The disadvantages are reduced flexibility and lower image quality together with illumination difficulties because of overlayed images.

4.4 Video theodolites

Photo theodolites are used in conventional terrestrial photogrammetry for the purpose of obtaining photographs with known orientations. The optical axis of the camera is combined with the angle measurement facilities of a theodolite. With known position coordinates all orientation parameters are given for every viewing direction. Modern theodolites have features that allow remote or automatic operations. They have interfaces for data transfer and device control and they can perform a remote controlled positioning with built-in servo motors. Combined with a CCD-camera they can operate as a very flexible online system. The main disadvantage are the very expensive theodolite components, which consist of precise mechanical and electronical parts. For many applications the full flexibility is not really neccessary.

4.5 Reproducible camera positions

For moving cameras it is possible to build fittings with several predefined positions. The simplest way is to have two viewing directions represented by two limiters, where the camera moves against. Intermediate stops can be realised with mechanical centering devices. All camera positions have to be calibrated. The main problem is that the rotation angles have to be known with high accuracy, which requires very precise mechanical parts. They have to be protected against bad environment conditions like dirt and shock and they may loose stability by wear.

5. DATA TRANSMISSION

An online measurement system has more or less demands on transferring data between the different components, depending on distances and configuration complexity. Limits are given by cabling possibilities, cable length and transmission speed. They reduce the layout flexibility of a system and can lead to serious problems.

5.1 Data types

Three principal data types can be distinguished:

- video data
- controlling data
- resulting measurement data

Analog video data has to be transferred between camera and frame grabber, which is the device for analog-to-digital converting. In digital cameras the frame grabber is built-in and therefore the image information has to be sent digitally to the controlling computer. This data type requires the highest transferring rates.
Controlling data is needed to remotely handle camera functions and movement. The information amount is low and there are usually no transmitting difficulties, excepte the cabling itself in some cases.
Resulting measurement data mainly consists of coordinate sets and accuracy information. The transport is usually done via printout or floppy disk. A connection to an existing computer network is possible and has several organizational advantages.

5.2 Influence on system configuration

The configuration of an online video measurement system can be affected by data transfer problems. The worst case is that for environmental reasons it is not possible to find cabling paths anywhere. One solution might be to place the controlling computer nearby each camera, another could be found in wireless systems described below. Limited cable length can have the same effect. In most cases this will have the effect on the configuration that certain good camera positions cannot be used, which reduces accurracy and may complicate the orientation process.

5.3 Standard video

Standard video means the analog signal transmission as defined in the common TV-norms. For this type of connections the cable length should be under 10-30 m, which depends on electronical disturbance potentials in the environment. The data rate is normally 25 images per second (30 for USA), which at usual sensor resolutions leads to a bandwith of about 4-5 Mhz. The speed of measurement and evaluation is given by the controlling computer.

5.4 Digital video

Digital video means in common that the camera has a built-in frame grabber as mentioned above. Data rates and permitted cable lenghts between camera and computer depend on the interface type used, which may be for example the serial RS422 interface or an SCSI-Bus. The transmission speed of analog video is not reached in usual systems. Data quality is high because of the digital character.

5.5 Computer network

The usual computer network techniques can be used for data transfer. Errorfree connections over long distances can be established. But the speed e.g. of the common ethernet with 10 MBits/s is not high enough for live video. Another disadvantage for image transfer is that a computer is needed on the camera side for converting the data formats. There are so called PC-cameras available with a complete computer built-in, but they are quite expensive.
In complex configurations with more than one controlling computer a network can be used for coordination of operations and collecting results, even over long distances. It is also possible to link the whole system into an existing network so that access to data and functions of the measurement system is available in the administration area.

5.6 Wireless connections

As mentioned before, certain camera positions that are very useful for a configuration cannot be reached with cables. One example is a type of crane found very often in industrial halls, which may be the only possibility to get upper views of an object. Because of its motion a wired connection to cameras mounted on it cannot be realized. A wireless data transmission can solve this problem.
The following carriers come into consideration:

- ultrasound
- infra red light
- laser
- radio

Acoustic data transmission seems to be not usable for the desired purposes, because the realizable bandwidth is to small for efficient video data transmission. It also can be assumed that it is very sensitiv against noise in industrial environments.
Data transmission with modulated light is used for example for wireless network links. The main disadvantage is that a direct sight connection is needed and that the beam adjustment has to be very precise, especially when a laser is used. This fact reduces the flexibility of such a system.
A radio wave based system appears to be the optimal solution. The positions of transmitter and receiver are nearly free and the operating range is mainly a question of output power. Several distant stations can be switched to send their data alternately, or parallel when using different channels.
Video transmission devices are available at acceptable prices for security systems or home video. The main problem is to receive geometrical correct images, while the industrial environment produces disturbing electromagnetical fields and interferences. The Institute for Photogrammetry in Hannover has started an investigation, which deals with different methods of transmissions as well as hard- and software-based error corrections.

6. MEASUREMENT SYSTEM EVALUATION

The market of video equipment is steadily growing, and the number of available photogrammetric video measurement systems is increasing. Even for a photogrammetrist it is difficult to have an overview over all components and possibilities. As mentioned above, there is no formalized method to compare different solutions efficiently. This problem has been recognized and in Germany a team consisting of members of institutions and industry will work on this subject. Some basic considerations will be made below.

6.1 Ready-to-use systems

Ready-to-use systems have a standard set of hardware and software and are adaptable for different objects. The quality and accuracy can be proved at already installed equipments or in test configurations, if the layout for the desired task does not differ too much.

6.2 Individual configurations

In the case of individual configurations where new hardware components have to be used and a very specialized software package has to be developed, usually no testing and comparing possibilities for the complete layout are given.

6.3 System parameters

The performance of a measurement system is defined by a lot of hard- and software parameters, e.g. point measurement accuracy, camera resolution, synchronisation stability, etc. Very important is to include configurational aspects like image scale, ray intersection angles, redundancy, etc..
A catalog of comparable system parameters may have the following structure:

- a grouping of parameters in a hierarchy of importance
- a diagram of dependencies between parameters
- standardized testing procedures
- standardized configurations
- guidelines for configuration layout

Independency from existing equipment is not completely possible because of certain limits defined by hardware. Therefore the connections between parameters have to be updated periodically.

6.4 Evaluation methods

The following methods can be used to evaluate system parameters or a whole configuration:

- single parameter determination
- individual test of component groups
- standardized testing object
- testing at real object
- simulation

The results from the first two possibilities are more or less difficult to transfer to a whole configuration. Nevertheless this is in most cases the only available possibility for comparing systems.
Standardized test objects may be defined, but real objects vary in a very wide range and the probability of having a similar situation is low.
Performing a test measurement under real conditions is the optimal way to find out whether a measurement system is suitable for the desired task or not. For individual configurations this is impossible because of missing hard- and software. For ready-to-use systems it may be realized, but even here the effort to be done for adapting and installing is high.
Configuration simulations are known from bundle block adjustment. They are used to optimize the geometrical stability of a block. They can be used with video systems to evaluate the geometrical layout and will show the dependencies between certain hardware parameters. Any hardware quality aspects cannot be verified.

7. CONCLUSIONS

The complexity of online video measurement system configurations leads to difficult optimization and evaluation processes. Alternative techniques can be helpful for detail solutions and have to be investigated for efficiency and side effects. More emphasize has to be put on the standardization of system evaluation parameters in order to simplify planning tasks.

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