STEREOPHOTOGRAMMETRIC MEASURING IN RISK AREAS WITH THE AID OF REMOTELY CONTROLLED EQUIPMENT

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ABSTRACT:

The paper deals with the development and practical testing of a sterophotogrammetric method that is suitable for carrying out the measurements in areas that are dangerous for human beings. The stereophotogrammetric images are taken either from a pair of conventional digital cameras or from a pair of industrial cameras that are carried on a remotely controlled crawler vehicle that was developed and built for this purpose. For calibrating the stereo camera pair and for measuring in the scene, our own software was created.

1. INTRODUCTION

The human activities in various fields face the need to enter risk areas, namely in the case of extraordinary situations, e.g., releases of toxic gases, liquids, and radioactive materials. Entering such areas always means endangering the health or even the lives of human beings. By making use of the contemporary technical means, it is possible to solve the problem by using remotely controlled devices that may carry out the reconnaissance of the dangerous areas. In this contribution, a photogrammetric set for 3-D measurements carried on a remotely controlled crawler vehicle is presented. The results of testing are presented too. The development of this equipment is being funded from the grant GAČR 105/03/0719 that will be finished by 31 December 2005.

The development of the mobile photogrammetric set included the following activities.

- The design and construction of the remotely controlled vehicle that is equipped with the mechanism for carrying and adjusting the photogrammetric base.

- The design and construction of the photogrammetric base. The base was realised in two variants. In the first, two conventional Olympus digital cameras were used. The second used a pair of industrial CCD cameras connected to the computer through a frame grabber.

- The design and development of the software for calibrating the base and for carrying out the photogrammetric measurements.

- The design and development of the software for controlling the vehicle, setting the position and orientation of the fotogrammetric base, and for setting the parameters of the cameras.

In the following sections, the above-mentioned activities will be described in more details.

2. THE DESIGN AND CONSTRUCTION OF THE VEHICLE

As a carrier for the photogrammetric base, a remotely controlled crawler vehicle driven with electrical engines has been constructed (Figures 1, 9). The vehicle bears a platform that can be adjusted into the horizontal position before a measurement is carried out. On the platform, there is a vertical axle on which a 500 mm long photogrammetric base is fixed. The desired orientation of the base may be set by making use of the view from the range-finder camera. For orientation of the operator and for image capture in low-lit conditions, the vehicle is equipped with a headlamp. The vehicle also bears a computer based on the Intel Pentium Mobile processor. The task of the computer is to grab the images for the photogrammetric measurements from the main cameras and to send them to the control station in which the software for carrying out the measurements runs. From the control station, the computer also receives the commands for adjusting the orientation of the photogrammetric base. The vehicle itself is remotely controlled with a radio set.

3. THE DESIGN AND CONSTRUCTION OF THE FOTOGRAMMETRIC BASE

With respect to the fact that the use of calibration points is not possible or desirable in the area being measured, the classical arrangement of two cameras with the parallel (or nearly parallel) optical axes was chosen (the normal case of stereo-photogrammetry). The cameras are fixed on both ends of the bar that forms the base. The base may rotate around its vertical axis and around its longitudinal horizontal axis in the range of

30 degrees down and 90 degrees up. Since the measured area is expected to be approximately up to 10×10 meters in size, the length of the base was chosen to be 500 mm. (Moreover, some practical experiments with the base of length 400 mm were carried out too.) During the experiments, i.e., during testing the achievable precision, the base was fixed on a measuring tripod (Figure. 2).
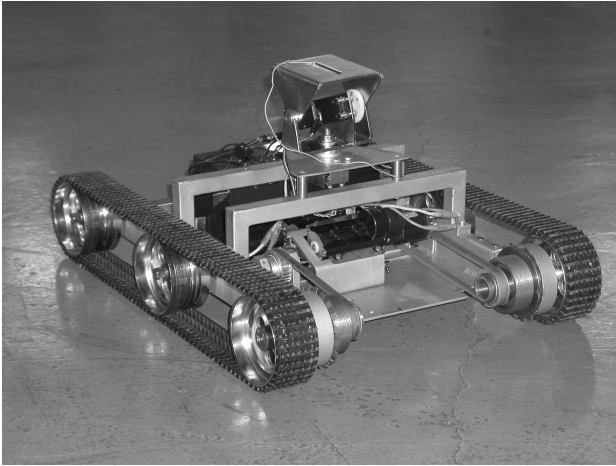

Figure 1. Remotely controlled crawler vehicle

Figure 2. The photogrammetric base equipped with a pair of the Olympus C-4040 cameras placed on a tripod

3.1 The base equipped with the Olympus C-4040 cameras

The essential parameters of the Olympus C-4040 cameras used in the first version of the base are as follows:

Resolution: 2272×1704 pixels
CCD chip size: 1/1,8 inch
Lens: zoom lens f = 7,1 – 21,3 mm
Iris number: 1,8 – 10 (for minimal focal length), 2,6 – 10 (for maximal focal length)
Shutter speed: 1/800 – 4 s
Focusing distance: 0,8 m – infinity
Build in flash
Possibility of manually controlling the focal length, focusing distance, and the iris number

After obtaining practical experience with the various settings, the focal length was always set to 7.1 mm, the iris number was set to 4, and the focus distance was set to 4 m in all the subsequent calibrations and measurements.

Calibrating the base: For the calibration, a series of images of a chessboard calibration pattern (10×10 square fields of size 5 cm) was used (Figure 3). Our own software described in Section 5 was used to perform the calibration of the photogrammetric base. The results of calibration are written into a file in which all the intrinsic calibration parameters (focal distances, coordinates of the principal point, distortion coefficients) and the extrinsic parameters (the vector of translations and rotation angles between both cameras) are stored. During the calibration, the fixed values of focal distance, shutter and iris were always used. During repeated performance of the process of calibration, some instability of the principal point position was revealed. It is probably due to not very rigid construction of the camera lenses. This problem may be solved by calibrating the cameras just before carrying out the measurement, preferably without switching the cameras off. For the use in this photogrammetric method, the cameras with a more robust construction and with a fixed focal length would be naturally more suitable. These, however, were not available to us.

Practically testing the base: For completing the practical tests of the base, a three-dimensional model (Figure 4) was built in the measuring laboratory in the Institute of Geodesy at VŠB-TU Ostrava. The model consists of 24 control points indicated by circular targets whose diameter is 50 mm (Figure 5) that are placed in space. The positions of all the points were measured geodetically in our own local coordinate system; the coordinates were determined with the precision greater than 2 mm. The distances between selected pairs of points were also checked by measuring them with a steel tape measure. Independently, the 3-D model was also measured with the above-mentioned photogrammetric set (our software makes it possible to determine the distance between arbitrary points directly in the images from the cameras). The precision of the photogrammetric method was determined by comparing the distances determined geodetically and photogrammetrically. The difference varied in the range of 3 to 37 mm in all our tests.
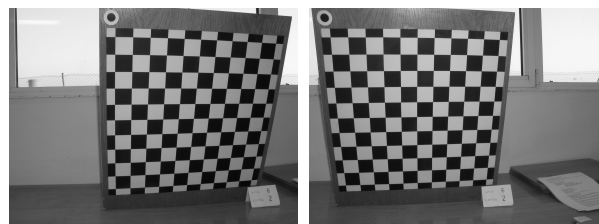

Figure 3. An example of the image pair for calibrating the cameras
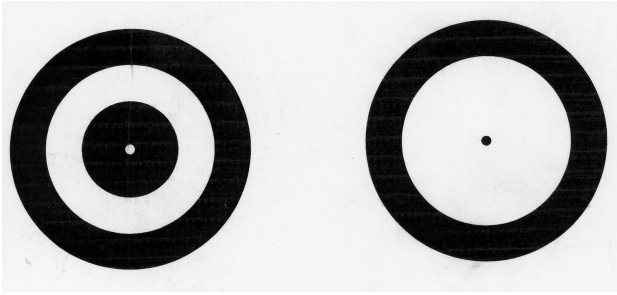

Figure 4. The 3-D model consisting of 24 points

Figure 5. The targets of 50 mm in diameter used in the model

3.2 The base equipped with the Imaging Source DFK 31F03 industrial CCD cameras

The main parameters of the cameras and the camera lenses used in the second variant of the base are as follows:

> Resolution: 1024×768 pixels
> Frame rate: 15 frames/s
> Interface: IEEE 1394 (Fire Wire)
> Dimensions: 60×60×42 mm
> Lens: Pentax H416
> Focal length: $f = 4$ mm
> Iris number: 1,6–16 (controlled manually)

Calibrating the base: Again, the calibration was carried out for the whole photogrammetric set, i.e., for the cameras fixed on an approximately 0.5 m long base. (The length of the base was also checked by making use of the laser comparator and was determined to be 500,3366 mm). With respect to the considerable geometrical distortion of the camera lenses (comparing with the distortion of the Olympus C 4040 cameras), the chessboard pattern used for calibration had only 8×8 square fields with the length of side 6 cm in this case.
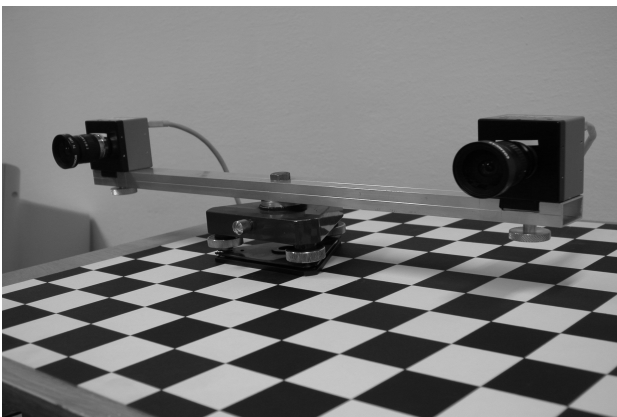

Figure 6. Photogrammetric base equipped with the Imaging Source DFK 31F03 industrial CCD cameras

Practically testing the base: The practical testing of this photogrammetric base was realised by measuring the 3-D model with 24 control points again. The difference between the distances determined geodetically and photogrammetrically (with the mentioned base) varied in the range of 3 to 53 mm in this case.

4. TRANSMISSION OF THE IMAGES AND CONTROL SIGNALS

The communication and control system of the vehicle is based on several wireless technologies. In fact, we are using three separate technologies. For movement control of the vehicle and photogrammetric base, we use the RC interface that provides the operator with maximal sensitivity and freedom of movement even in complicated environments. Visual data from the navigation and range-finder camera is transmitted with the use of an analog radio system. We see the reason for using such a system in its relatively long operational distance. All other communication is based on the 802.11 b/g (Wi-Fi) standard. The robotic platform is equipped with a Wi-Fi access point that provides multi-user access to the resources (computer unit, sensory systems) and to data stored on-board. We are using the standard TCP/IP protocol and the standard services over it. The computing unit runs the secure ftp server (FTPS), SSH server, http server (web) and two types of remote desktop sharing that allow direct control and configuration of the operating system and system environment. Multiple remote users may access the stored images or see the view of "robots eyes" and cooperate in this way. Security of data transfers is managed by the encryption algorithms implemented in the hardware and software layers of wireless networks (WEP) and TCP/IP protocol and the services over it (SSL, SSH).

Primary data processing is done directly on-board as mentioned before. The capture of the image stereo pairs that are suitable for photogrammetric measuring is done either manually by the operator using the remote desktop feature of the system or automatically in scheduled time intervals. Both methods require previous stabilization of photogrammetric base to horizontal position. Near-real-time post processing (measurements) may be done in the on-board computer with our software as well as in any other computer that has access to the data (images) stored in the robot. Post processing may also be done later, with the use of advanced photogrammetry software like ERDAS Imagine. We are planning to use a tablet PC computer (penbook with Wi-Fi) to communicate with the robot and to perform near-real-time measurements in the field. The reason why we want to use the tablet PC is the great mobility it gives to the operator for working outdoors and even for walking during the work. Another but also important reason is the possibility of natural control with the use of the touch screen and voice.

5. SOFTWARE EQUIPMENT

For calibrating the photogrammetric stereobase and for photogrammetric measuring, our own software has been developed. The calibration of the base includes determining the intrinsic parameters of both the cameras (focal length, position of the principal point, coefficients of nonlinear distortion of the lenses) and the extrinsic parameters of the camera pair (the vector of translations and the vector of rotation angles between the cameras). For calibrating the base, a chessboard calibration pattern was used (Figure 3). The software realizes the calibration in the following four steps: (1) creating and managing the set of calibration images (the set contains pairs of images captured from the cameras); (2) processing the images of calibration patterns (finding the chessboard pattern and the calibration points in it); (3) preliminary estimation of the intrinsic and the extrinsic parameters of the base; (4) final iterative solution of all the calibration parameters. For the initial estimation of the parameters, the method proposed by Zhang [Zhang 1999; Zhang 2000] was used. The final solution was

done by the minimisation approach. The sum of squares of the distances between the theoretical and the real projections of the calibration points was minimised by the Levenberg-Marquardt method.

After the base had been calibrated, the photogrammetric measurement can be carried out. The software makes it possible to measure the coordinates of points, the distances and the angles in the scene. The coordinates are determined by the similar minimisation approach as was mentioned in the previous paragraph for calibration. The measurements that are performed by the operator may be completed with explaining annotations. The measurements form a set that may be recorded into a file. The software also offers the means for later editing the set and for exporting the measured data. Figures 7 and 8 show screen shoots taken during the work with the program.
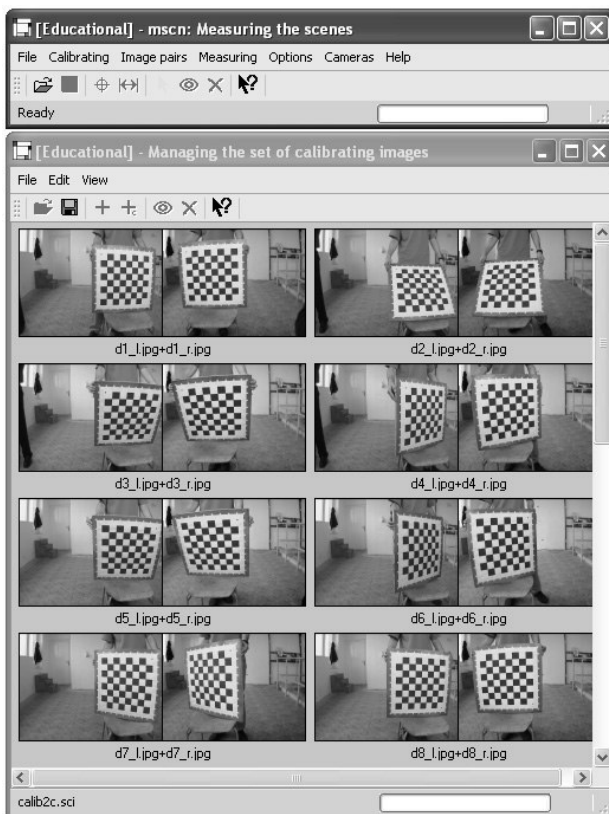

Figure 7. Managing the set of calibration images

Figure 8. Measuring length

Figure 9. The computer model of the complete device

6. CONCLUSION

The aim of this project was to develop a low-cost system for remote gathering 3-D metric data in places that are dangerous or inaccessible to people. The main accent was on real-time processing (perhaps at the expense of the accurracy of measurements). The practical experiments we have carried out have shown that a mobile device and the photogrammetric method are suitable for the intended purpose. After finishing all the above-mentioned planned works and after finishing the whole equipment (the mechanical part has not been fully finished yet), practical experiments in real operational conditions will be done.
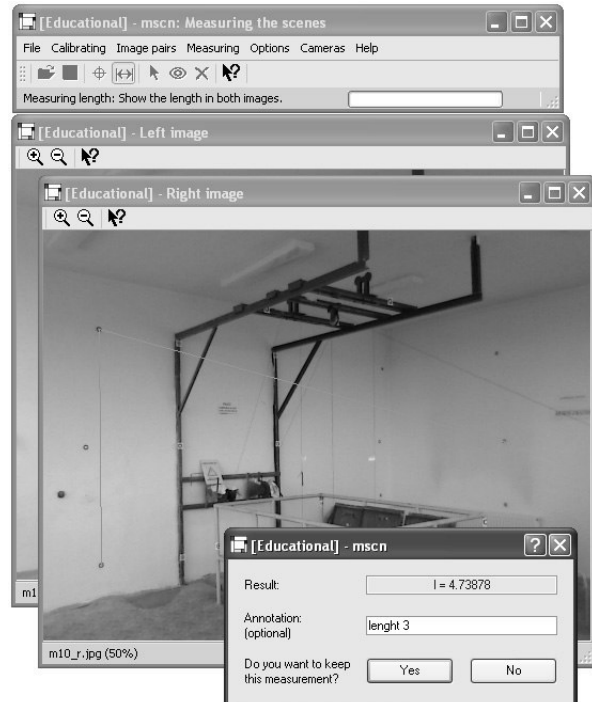
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