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## 3D contour detection by means of a multi camera system

### ABSTRACT

In this paper we show a solution dedicated to measure spatial contours by means of multiple cameras. The contours allow to derive position and orientation, if necessary, of objects which have to be measured very precisely. The use of multiple cameras makes the system very flexible and robust. Set up, processing tasks and results of the system are presented.

### SET UP

The system has a solid optical head (cf. fig. 1), to be used as base for cameras and light source. This head can be mounted on a robot arm and then serves as effector which observes objects at predefined positions. This allows fast and flexible measurements of various spatial elements belonging to the object. But in general, the system could also be used in a stationary way, when numerous elements have to be measured under fixed conditions.

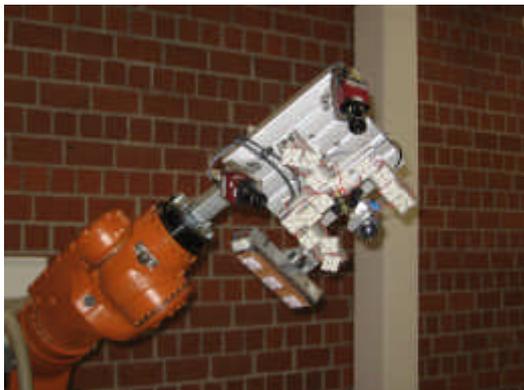


Figure 1 optical head

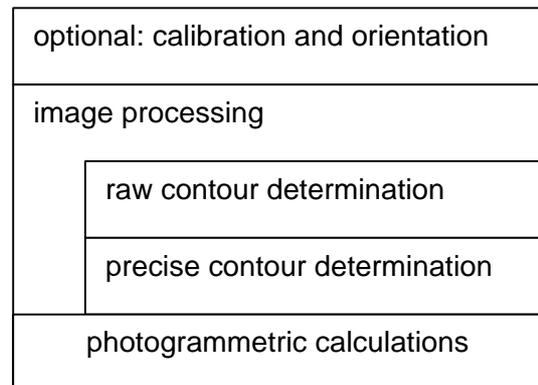


Figure 2 workflow of calculations

On the optical head at least 2 cameras have to be mounted, but this can be simply extended to more sensors, because robustness and accuracy then will profit. In the center of the head a light source is mounted which may project diffuse light but also can use special patterns if necessary to illuminate the object in a characteristic way.

In the first development stage we used 2 cameras in order to have the base for spatial calculations, but 3 cameras are more convenient due to check results more easily against blunder and the impact of viewing directions and provide a higher degree of

accuracy.

## Processing

As can be seen from fig. 2 the whole process consist of three steps. One of those only has to be used if necessary (calibration) and assures the geometrical quality of the system, the other ones have to be applied onto each image provide the final spatial information for each object observed.

### Camera Calibration and Orientation

A geometrical preprocessing of the system is necessary due it's flexibility with respect to the types of cameras used, to their mounting and orientation on the frame, which can be changed if necessary to adopt the configuration to the needs of the application. Furthermore possible forces (movements, thermal environment) may cause changes which have to be checked more or less frequently. The steps to be realized comprise a control of the internal camera geometry (calibration) and a check of the external relations on the frame (orientation).

A camera is calibrated when the focal length ( $c$ ), the principle point ( $H'$ ) and some distortion parameters ( $\Delta r$ ) are known. These parameters describing the camera properties are summarized in literature as the parameters of the interior orientation (IO) [1;2].

The determination of the parameter values for each camera is integrated into the workflow by matter of an automatic calibration procedure. The used calibration method allows a full automatic workflow to determine the IO parameters. Figure 3 shows the procedure of our calibration method.

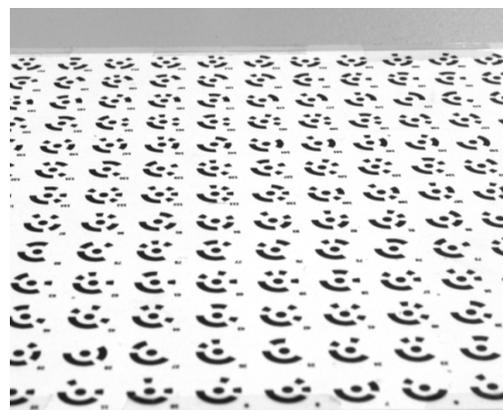
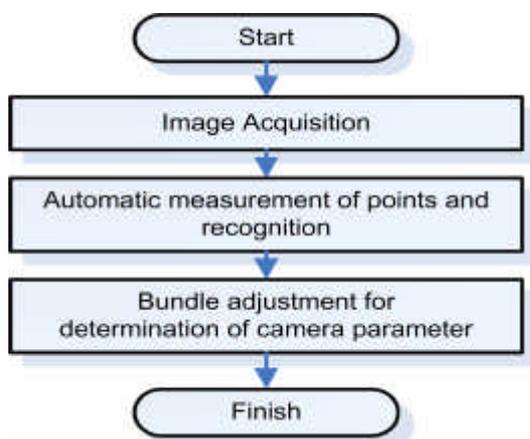


Figure 3 Procedure of the used calibration method

Figure 4 view onto point field used for calibration

About 32 images are acquired of the calibration panel (cf. Fig. 4) from different directions, inclinations and rotations of the camera around the optical axis. Within each image the center of all points are automatically measured, using the center of gravity (COG) method together with an analysis of the code ring [3] providing the point ID.

The measured image coordinates, the approximated object coordinates and the estimated exterior orientation [4] are brought together to calculate the parameters of the interior orientation with an adjustment library (AxOri [5]). The adjustment is free supported by the picture coordinates, the EO and the IO, whereas the object coordinates set the date (scale, rotation and translation) of the system.

In order to give an estimate of the geometrical quality of a calibration step Table 1 summarizes the root mean square values (RMS) of the object coordinates, the standard deviations of the EO and of course the standard deviations of the IO, for three AVT Marlin F-046B (b/w) cameras (pixel size 8.3 x 8.3 μm, 16mm objective). As can be seen, the results are sufficient to achieve precise results during the later measuring process.

	Camera (μm)			Image points (μm)		Object points (μm)		
	c	xH'	yH'	X	y	X	Y	Z
Cam. A – C	1.8 – 2.1	4.6 – 5.2	3.3 – 3.8	0.1 – 0.2	0.1 – 0.4	1.0	1.0	1.1

Table 1 Root mean squares of significant parameter of the IO bundle ([μm])

A calibration only should be necessary when cameras have been exchanged or modified, or other reasons for a change of their internal set up exist.

More often the external configuration might be changed, what then needs to check the geometrical configuration between the cameras or, if existing, in relation to an external coordinate system. This task uses the same strategy as with calibration, but allows a reduced number of images to be taken. Results of an orientation are show below:

	Image points (μm)		Object points (μm)		
	X	y	X	Y	Z
Cam. A-C	0.1 – 0.2	0.1 – 0.2	1.0	2.5	3.6

Table 2 Root mean squares of significant parameter of the EO bundle ([μm])

**Contour Detection**

The calculation of the spatial contour is based on all images taken by a simultaneous shot of all cameras. These images are then individually processed in order to detect the 2D-contours of the object and are then combined in a photogrammetric calculation, which results in a spatial description of the object. Redundancy due to multiple images

allows to check the results and to eliminate blunder or regions where the contour is damaged.

For the 2D-contours it is assumed, that there exists a mathematical model, which can be used for a fitting process. This allows to process all contour elements with respect to this model giving a higher degree of accuracy. Actually elliptical contours are realized, but this can easily be substituted in case of other geometrical objects. The process of fitting is splitted in two parts. A raw determination of the 2D-contour (cf. Fig. 4) and a following exact determination by analyzing the gray scale value-profiles along the normal vectors of the contour (cf. Fig. 5).

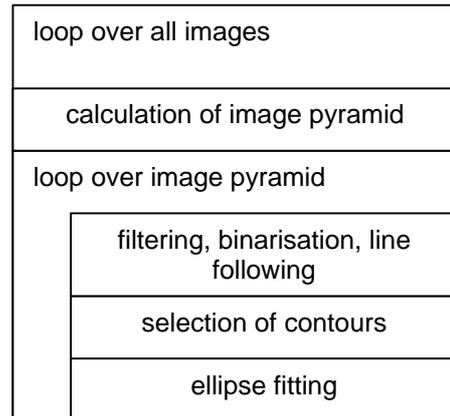


Figure 4 image processing (part1)

The **raw determination** consists of an edge detection by filtering, binarisation and line following process. The contours found during edge detection are evaluated and selected by means of geometric properties. All segments retained are used for an ellipse fitting. This process loops over an image pyramid allowing to reduce the impact of parasitic image elements appearing in the edge detection and increases the robustness.

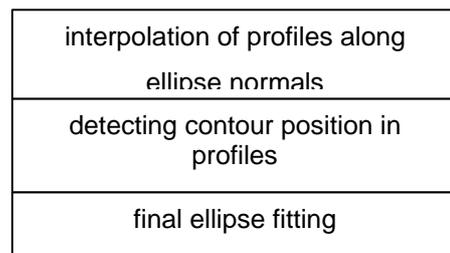


Figure 5 image processing (part2)

The **precise contour determination** happens only on the level of highest resolution. First, discrete gray scale values along local profiles normal to the contour are generated, in order to give a detailed local description of the transition from regions inside the contour to outside. In each profile the position of the maximal gradient close to the preliminary contour is determined, checked for plausibility and compared to the results of the neighborhood. The peaks found in all profiles are then used for a repeated ellipse fitting. The adjustment includes a blunder detection and finally provides the parameters of the elliptic contour in the image coordinate system.

As result of this process a parametric description of all contours is available and can be used for the final photogrammetric treatment of the data.

This is founded on the knowledge about the geometrical relationships between the images coming from the preceding calibration and

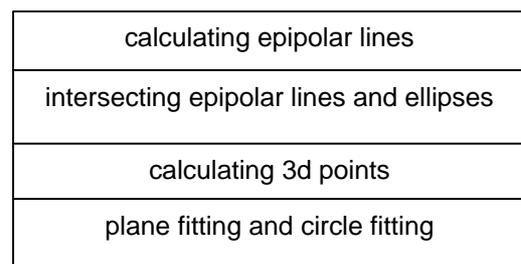


Figure 6 photogrammetric calculation

orientations steps. As the contours don't provide individual points to be used as input for spatial calculations these points are generated artificially using epipolar constraints. Starting with a first image pair, each contour is intersected with a number of epipolar lines for the respective image. In case of multiple images the points generated in one image are used to extend this process to all other contours. Each artificial point then has a number of counterparts – at least one – which then can be used to intersect the corresponding rays yielding a 3D point.

As matter of control all 3D-contour points are fitted into a plane, in order to check for deviations in the 2D-contours. If they are displaced, this results in changes of the distance to the spatial contour, what can be identified in the residuals of the plane. These residuals can be used to analyze erroneous contour parts and to reject points if necessary. As long as the plane gives acceptable results the spatial contour points can be fitted into the appropriate mathematical model, providing the final result.

## RESULTS

At the moment the processing chain is completely realized for the use of 2 images. Some minor steps concerning data control and blunder detection in case of more than two images have still to be implemented. We therefore present results of a two image situation.



Figure 7 test object shown in image A

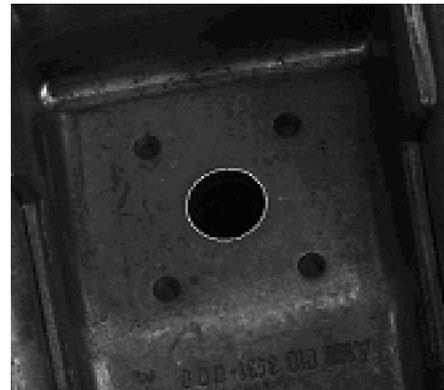


Figure 8 detected contour plotted in image B

Figure 7 shows the object measured, Figure 8 displays the contour detected and Table 3 gives an idea of the quality. The example belongs to a car body and shows a hole used to fix a seat of a carriage.

From table 3 it can be deduced, that the quality achieved is satisfying. In relation to the size of an individual pixel the center of the contour object has been determined with a 40th of an image element, what is a satisfactory value.

2D	$\sigma$ ellipse of image A		$\sigma$ ellipse of image B		Cell size
	0.003		0.003		
3D	$\sigma$ plane	$\sigma$ circle	$\sigma$ center x	$\sigma$ center y	Pixel in space
	0.032	0.021	0.003	0.004	

Table 3 standard deviations of one camera combination (images A and B); all values in mm

After integration of the remaining analysis steps concerning more than two cameras the system may serve as base for a flexible and reliable tool for the determination of spatial contours and their position and orientation in space.

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