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OPTIMUM SELECTION OF IMAGES IN INDUSTRIAL PHOTOGRAMMETRY USING FUZZY COMPUTATION

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ABSTRACT:

Achieving coordinates of object coordinate points with optimum accuracy is one of the most important issues in close range photogrammetry. In this context, network design plays a vital role in determination of angles and distances between imaging stations. This is, however, not a trivial task due to various constraints affecting the geometry of the network. As a result, most camera station networks are defined on a try and error basis based on the user's experience. In this paper, a new fuzzy approach is adopted, in which the constraints affecting the network design are all modeled. As a result, the position of all camera locations are defined based on fuzzy rules. The tests carried out show that by applying fuzzy rules inappropriate images can be defined and eliminated from the process leading to some 20% accuracy in the determination of object coordinates.

1. INTRODUCTION

Today, acheivng high quality and low cost in production and dimensional quality control processes is an important aspect of industrial measurements. As a non-contact, flexible, and accurate technique, photogrammetry can be used to facilitate the measurements in various applications (Amini, 2006). A very most important issue which affects the accuracy of measurments is the design of an appropriate network. In practice, due to existing environment constraints, network design is not fully observed and imaging is performed experimentally. As a result, photogrammetrists prefer taking a large number of images from the objects, many of which may not be necessary. As a consequence, taking inappropriate images may lead to decreasing the accuracy of the object points.

In this paper, a new fuzzy computation system is proposed that is able to determine unsuitable camera stations based on network design constraints that may have unfavorable effect on the result of the bundle adjustment. In this system, all the constraint related to distance are modeled based on fuzzy rules to decide whether or not a given image be taken into account to compute object coordinates. .

In the following, various models developed in this paper are discussed followed by experiments carried out to evaluate the accuracy of the results. The conclusions of the system are finally mentioned.

2. FUZZY MODELLING THE NETWORK DESIGN CONSTRAINTS

Network design or camera placement involves the satisfaction of some vision constraints as well as optimization of accuracy. On the other hand, the most important issue which affects the quality of industrial photogrammetry is image acquisition based on network design constraints (Atkinson, 1998). Image acquisition according these constraints leads to the best accuracy on the position of targets on the object. Network design constraints (Atkinson, 1998) are shown in figure (1).

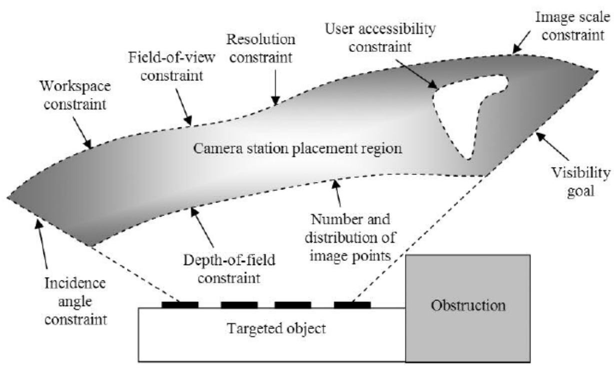

Figure 1. Vision constraints in photogrammetric network design

One important part of these constraints is range or distance related constraints. Range constraints are divided in to two parts (Saadatseresht, 2004):

- Constraints related to minimum distance from camera to the object
- Constraints related to maximum distance from camera to the object

2.1 Applied Membership Functions

To fuzzy modeling of minimum distance constraints, "smf" function is used (Menhaj, 2008). In this function, a value between 0 and 1 for distances around the minimum distance, value 1 for distances larger than this boundary and value 0 for distances less than this boundary is defined. An example of "smf" function is shown in figure (2).

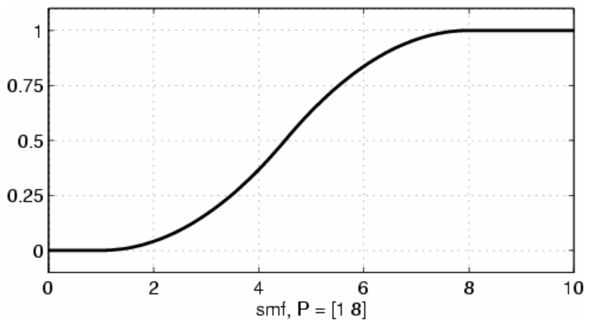

Figure 2. An instance of "smf" functions from the toolbox of Matlab

To fuzzy modeling of maximum distance constraints, "zmf" function is used (Menhaj, 2008). In this function, a value between 0 and 1 for distances around the maximum distance, value 1 for distances less than this boundary and value 0 for distances larger than this boundary is defined. An example of "zmf" function is shown in figure (3).

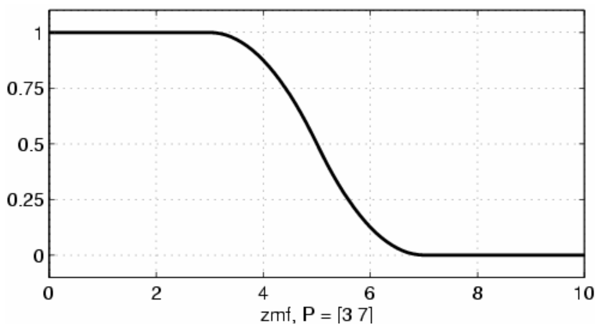

Figure 3. An instance of "zmf" function from the toolbox of Matlab

To combine these two constraint sets, "pimf" function is used (Menhaj, 2008). In this function, value 1 for distances in inner area, a value between 0 and 1 for distances in near boundaries and value 0 for distances in outer area is defined. An example of "pimf" function is shown in figure (4).

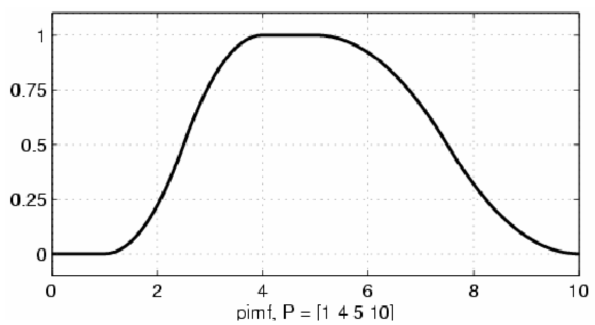

Figure 4. An instance of "pimf" function from the toolbox of Matlab

2.2 Fuzzy Modeling of Range Constraints

As mentioned, range constraints are included as (Saadatseresht, 2004):

- Minimum distance constraints: camera depth of field, and number and distribution of targets
- Maximum distance constraints: image resolution, image scale, and camera field of view

For each constraint, in addition to a value between 0 and 1, an attribute label is dedicated according to table (1).

Fuzzy value	Corresponding label
x = 0	unsuitable
0 < x < = 0.7	weak
0.7 < x < 1	appropriate
x = 1	robust

Table 1. Relation between each fuzzy value and corresponding label for each constraint

Fuzzy modeling of each constraint is discussed in continue.

Camera depth of field constraint: Camera depth of field is an area around the object that for a special distance between camera station and the object, a sharp image will be obtained (Saadatseresht, 2004). This constraint is appeared in Eq. (1):

$$D_{Depth}^{\min} = \frac{d}{1 + \dfrac{d - f}{D_{HF}}} \tag{1}$$

In this equation, $D_{Depth}^{\min}$ is depth of field distance, D_{HF} is the ultrafocal distance, d is the initial distance between object and camera, f is the focal length, F_{stop} is the inner parameter of camera and δ is the diameter of ambiguity circle. Fuzzy modeling of this constraint is defined in table (2).

Depth of field constraint	Fuzzy value	Corresponding label
distance < 0.9 D_{Depth}	x = 0	unsuitable
0.9 D_{Depth} < distance < 1.1 D_{Depth}	x = smf (distance)	if 0 < x <= 0.7 : weak if 0.7 < x < 1 : appropriate
1.1 D_{Depth} < distance	x = 1	robust

Table 2. Fuzzy modeling of depth of field constraint

Number and distribution of targets constraint: At least k targets that have suitable distribution on the image is an appropriate attribute for number of targets constraint and solving unknowns in adjustment (Saadatseresht, 2004). Equation (2) defines the appropriate distance to appear at least k targets in each image:

$$D_{Po\,\mathrm{int}}^{\min} = \frac{af\sqrt{k}}{d} \tag{2}$$

In this equation, a is the mean distance between targets in object space, k is the desired number of targets, f is the focal length and d is the frame size of the camera. Fuzzy modeling of this constraint is defined in table (3).

Distribution of targets constraint	Fuzzy value	Corresponding label
distance < 0.9 D_{point}	x = 0	unsuitable
0.9 D_{point} < distance < 1.1 D_{point}	x = smf (distance)	if 0 < x <= 0.7 : weak if 0.7 < x < 1 : appropriate
1.1 D_{point} < distance	x = 1	robust

Table 3. Fuzzy modeling of number and distribution of targets constraint

Image resolution constraint: Image resolution constraint is mentioned to the ability of identifying the targets in an image (Saadatseresht, 2004). Equation (3) defines maximum distance between object and camera due to the image resolution constraint:

$$D_{Res}^{\max} = \frac{f.D_t.Sin\varphi}{I_{Res}.T} \tag{3}$$

In this equation, φ is the angle between camera optical direction and object surface, D_t is the target dimension in millimeter, f is focal length, T is the minimum number of target pixels and I_{Res} is the dimension of each pixel in millimeter. Fuzzy modeling of this constraint is defined in table (4).

Image resolution constraint	Fuzzy value	Corresponding label
1.1D_{Res} < distance	x = 0	unsuitable
0.9D_{Res} < distance < 1.1D_{Res}	x = zmf (distance)	if 0 < x <= 0.7 : weak if 0.7 < x < 1 : appropriate
distance < 0.9D_{Res}	x = 1	robust

Table 4. Fuzzy modeling of image resolution constraint

Image scale constraint: Image scale constraint determines the maximum distance that the accuracy decreases for more than that distance (Saadatseresht, 2004). Equation (4) defines this constraint:

$$D_{Scale}^{\max} = \frac{D_0 f \sqrt{k}}{q S_p \sigma_i} \tag{4}$$

In this equation, f is focal length, k is the repetition of images in each station, S_p is the relative error value of measuring, D_0 is the maximum diameter of the object, σ_i is error of image coordinate measurement and q is the network stability factor. Fuzzy modeling of this constraint is defined in table (5).

Image scale constraint	Fuzzy value	Corresponding label
1.1D_{Scale} < distance	x = 0	unsuitable
0.9D_{Scale} < distance < 1.1D_{Scale}	x = zmf (distance)	if 0 < x <= 0.7 : weak if 0.7 < x < 1 : appropriate
distance < 0.9D_{Scale}	x = 1	robust

Table 5. Fuzzy modeling of image scale constraint

Camera field of view constraint: This constraint specifies maximum distance between the object and camera that all or a part of the object covers the image space and the object is not appeared in a part of image space (Saadatseresht, 2004). Equation (5) defines this maximum distance:

$$\alpha = \tan^{-1}\left(\frac{0.9d_0}{2f}\right) \qquad D_{Fov}^{\min} = \frac{D_o Sin(\alpha+\varphi)}{2Sin(\alpha)} \tag{5}$$

In this equation, α, φ, D_0, d_0 and f is half angle of vertex of camera pyramid, angle between camera optical direction and object surface, length of maximum diameter of the object, minimum of frame size and focal length in sequence. Fuzzy modeling of this constraint is defined in table (6).

Camera field of view constraint	Fuzzy value	Corresponding label
1.1D_{Fov} < distance	x = 0	unsuitable
0.9D_{Fov} < distance < 1.1D_{Fov}	x = zmf (distance)	if 0 < x <= 0.7 : weak if 0.7 < x < 1 : appropriate
distance < 0.9D_{Fov}	x = 1	robust

Table 6. Fuzzy modeling of camera field of view constraint

Combining all constraints: In order to final decision about the quality of the camera position, it is necessary to combine all mentioned constraints. For this reason, the appropriate image capturing area is obtained according to Eq. (6) (Saadatseresht, 2004):

$$\begin{aligned} D_{min} &= \max(D_{Depth}, D_{Point}) \\ D_{max} &= \min(D_{Res}, D_{Scale}, D_{Fov}) \\ Range &= D_{max} - D_{min} \end{aligned} \tag{6}$$

Final combined fuzzy modeling of all constraints is defined in table (7).

Combining all constraints	Final fuzzy value	Corresponding label
distance < 0.7D_{min} or distance > D_{max}+0.3D_{min}	x = 0	unsuitable
0.7D_{min} < distance < D_{max}+0.3D_{min}	x = pimf (distance)	if 0 < x <= 0.5 : unsuitable if 0.5 < x <= 7 : weak if 0.7 < x <= 0.9 : appropriate if 0.9 < x < =1 : robust

Table 7. Combined fuzzy modeling of all constraints

According to the final fuzzy value, the system is decided whether each image is suitable for using in final bundle adjustment procedure or not. Providing that there is any unsuitable image, that image must be eliminated and not to be used in adjustment procedure.

3. INPUT AND OUTPUT DATA

Input data in this procedure includes a data file of coordinates, camera information, object information, target characteristics and network design information. Output data includes the result of fuzzy modeling and decision about each image.

3.1 Input Data

In complete, data input includes:

A position data file:

- Target positions in an arbitrary coordinate system
- Camera positions in the same coordinate system

Camera characteristics:

- Focal length
- F-stop parameter
- Pixel size
- Dimension of sensor (number of rows and columns)

Object characteristics:

- Maximum length of the object
- Expected accuracy on target positions

Target characteristics:

- Diameter of target
- Number of pixels in each target
- Number of expected targets in each image
- Mean distance between each target

Network design information:

- Network stability factor
- Minimum angle between camera optical direction and object surface.

3.2 Output Data

Output data includes a decision about the quality of each image after fuzzy modeling of each constraint. Output information briefly includes:

- Displaying targets and camera station positions
- Membership functions of constraints
- Fuzzy value of each constraint
- Final decision whether the image is appropriate for using in bundle adjustment procedure or not.

A displaying of output information is shown in figure (5).

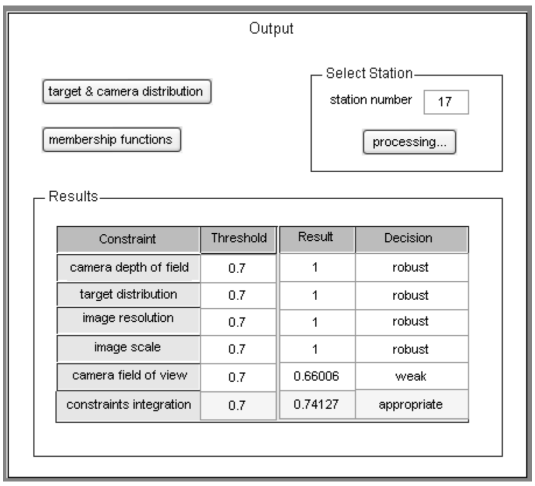

Figure 5. An instance of fuzzy value and decision of each constraint

4. AN EXPERIMENT

In an investigation to quality control of a propeller of a plane, 3D modeling of its surface was implemented by photogrammetry method. The purpose of the investigation was determining the deformation between its two wings (Amini, 2006). The propeller is shown in figure (6).

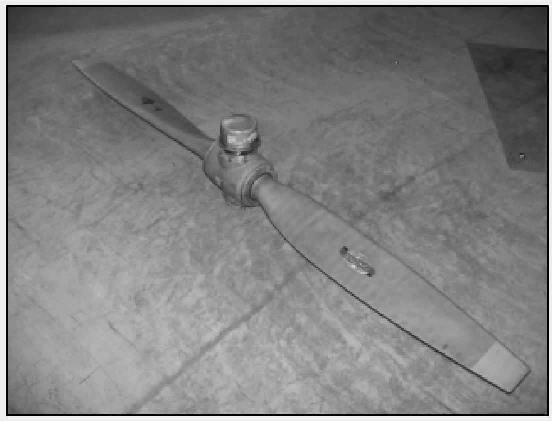

Figure 6. Investigated propeller of the plane

In this investigation, 19 images were captured and after bundle adjustment procedure, the mean accuracy of x, y and z coordinates of the targets of wings A and B were determined. The results are shown in table (8).

Wing	δ_x(mm)	δ_y(mm)	δ_z(mm)	RMSE(mm)
A	0.0241	0.0697	0.1165	0.1379
B	0.0283	0.0829	0.1233	0.1512

Table 8. Mean accuracy of x, y and z coordinates of the targets

To investigate the quality of images, the fuzzy computation system was utilized. According to the results of the system, the quality of 19 images for wing A is shown in table (9).

Image	Fuzzy Value	Decision	Image	Fuzzy value	Decision
1	0.79824	appropriate	11	1	robust
2	0.80313	appropriate	12	1	robust
3	0.58863	weak	13	1	robust
4	1	robust	14	0.92915	robust
5	1	robust	15	1	robust
6	0.95446	robust	16	1	robust
7	0.21082	unsuitable	17	0.74127	appropriate
8	1	robust	18	0.42569	unsuitable
9	0.88364	appropriate	19	0.80187	appropriate
10	1	robust			

Table 9. Fuzzy value and the quality of each image

According to table (9), three images for wing A have fuzzy value less than o.7. Consequently, these three images were omitted and bundle adjustment procedure was done with 16 images for wing A. Also, after omission of two inappropriate images for wing B, bundle adjustment procedure was done with 17 images. The result of bundle adjustment after omission of inappropriate images is shown in table (10).

Wing	δ_x(mm)	δ_y(mm)	δ_z(mm)	RMSE(mm)
A	0.0211	0.0515	0.0903	0.1061
B	0.0244	0.0619	0.1003	0.1204

Table 10. Mean accuracy of x, y and z target coordinates after omission of inappropriate images

With comparison of table (8) and table (10), it is identified that the accuracy of the x, y and z coordinates improves about 20 percentage rates.

5. CONCLUSIONS

Close range photogrammetry is a suitable and efficient method in dimensional quality control, deformation determination and accurate measurement (Luhmann et al., 2008). The most important issue affected the accuracy in a close range photogrammetry procedure in an appropriate network design. But as mentioned, in practice, network design is not fully observed and imaging is performed experimentally and consequently, some images may not suitable for using in bundle adjustment procedure.

In this paper, a decision system is established base on fuzzy computation that can be able to specify unsuitable images based on network design constraints that may have unfavorable effect on the result of bundle adjustment. The program is experimented on the images captured from a propeller of a plane in order to 3D modeling its surface. Bundle adjustment is done according to all images and also after elimination of improper images. The results of the two adjustments are showed that the accuracy on the point's coordinates of the object is increased about 20 percent rate.

Consequently, employing this fuzzy system helps to improve the results of the bundle adjustment in close range photogrammetry and improves the accuracy of coordinates of targets laid on the object surface.

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