Accessibility Analysis in Camera Placement Network Design for Vision Metrology

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SUMMARY

Automatic optimum network design for measuring complex industrial objects by vision metrology systems is a real challenge. In the absence of 3D simulated CAD models of the complex objects along with the absence of workspace information, several uncertain parameters are introduced into the camera placement decision-making process. These uncertain factors include the vision constraints such as visibility, accessibility and camera-object distance. The mutual effects of these uncertain factors make the decision making for the camera placement still more complicated. These parameters influence directly not only the mensuration quality but also visibility restrictions. If a priori 3D CAD model of the object and workspace information are available, the aforementioned ambiguities can be tackled. However, the 3D model and the workspace information may not be available in many circumstances. This makes the camera placement problem a nondeterministic process and hence demands a non-rigorous treatment. This paper is concentrated on the solution of the camera accessibility problem. For the complex objects, the accessibility is vastly influenced by the workspace vacancy and tools for putting camera into proper positions. In this paper we propose a novel method for computation of the so called accessibility uncertainty prediction (AUP) for the camera placement using a fuzzy logic approach. The test results indicate the high potential of the proposed method for automatic sensor placement in vision metrology without having access to any 3D CAD model and workspace information.

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1. INTRODUCTION: NETWORK DESIGN CONCEPT

The importance of network design in all close range photogrammetric applications especially in high precision measurement applications with complex object shape and workspace obstructions can not be understated (e.g. Fraser, 1989; Atkinson, 1996). In spite of camera calibration subject, the network geometry is the most significant factor to reach a high precision measurement capability. Complexity behind the multi-image convergent configuration of close range photogrammetric networks leads to pre-analysis network in a simulated environment (Hall, 1989). Many researchers, notably Mason and Gruen (1995) and Olague (1998), have accomplished the network design on a simulation model of object and its workspace. All of these researchers have supposed that firstly simulation model exists and secondly the entire network should be designed.

Indeed from the practical point of view, the network design concept has changed from global optimization to local satisfaction issue. In the other word, the use of digital cameras, development in automatic image measurements (Trinder, 1989), utilizing of self calibration technique (Fraser, 1997), coded targets, EO-device, and image corresponding algorithms have converted the photogrammetric process from a tedious manual process to "all on the one button" automatic technique (Ganci, 1989).

In spite of the past, todays, the number of images is not so critical and user can fly camera around the object and takes lots of images from different positions and situations based on the simple rules of "generic networks" (Mason, 1997). For example four symmetric oblique convergent camera stations should be implemented to the center of each object plan (for more details refer to GSI instruction (2000)). These simple instructions can give us a relatively strong primary network that usually fulfills the measurement accuracy requirements.

However, if an object shape is so complex and placed in a high obstructive environment, some shortcomings will appear in the network. To satisfy these weaknesses, some extra images have to be taken from weak points. The position and situation of extra camera stations are related to local network configuration around each weak point. To recognize the solution, user has to check the number and distributions of received rays to each weak point, the visibility of weak points, and accessibility of camera stations simultaneously. As mentioned above, it is a very difficult problem for inexpert users in complex states.

If an assistant can survey the network and suggests the position and situation of extra camera stations to satisfy the weak points, it will be a step toward the realistic automation of network design. The assistant should be able to model the visibility of object points and accessibility of suggesting camera stations only based on existing information of network. Since there is very much uncertainty in visibility and accessibility models extracted just from extant network information, a fuzzy based modeling should be performed.

After taking images from proposed camera stations, the bundle adjustment is repeated and network is updated. Due to uncertainty in constructed models, some weak points may be not fulfilled which leads to iterate above process. The iteration in this case is definitely less than cases in which an inexpert user designs the network personally.

Changing the concept of network design in VMS causes to avoid all mentioned problems which practically abort the previous simulated based methods. In the other hand, using the concepts propounded in this method can revolve intelligent cameras and improves the automation of close range photogrammetry process significantly in future (Shortis, 1998).

The aim of paper is a camera accessibility analysis can be named as accessibility uncertainty prediction (AUP) method in order to determine whether camera position is accessible or not. In continue, after describing vision constraints with more attention to accessibility issue, our AUP model is presented. Some experiments are done and their result is discussed and concluded.

2. VISION CONSTRAINTS

Network design or what so called sensor placement in computer vision (Cowan, 1991) involves with satisfaction of some vision constraints as well as optimization of accuracy and cost criteria simultaneously. To understand the fuzzy modeling of vision constraint in proposed method, firstly, the three classes of vision constraints are discussed. Some constraints appear in several classes because of their complex nature. Figure 1 is a symbolic presentation of these constraints derived from Mason (1997).

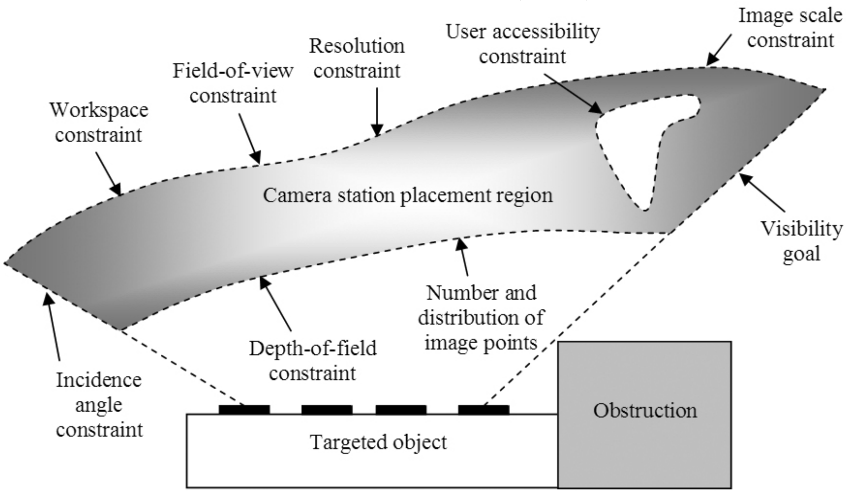

Figure 1: Vision constraints in photogrammetric network design derived from Mason (1997)

2.1 Range Related Constraints

Range or distance related constraints include those applying to imaging scale, resolution, camera FOV, depth of field (DOF), nu1mber and distribution of points and workspace. An outcome of any analysis of these constraints will, in the first instance, be a maximum and minimum camera-to-object or camera 'set back' distance. Other factors impacting upon the camera set-back distance are required angular measurement resolution (Fraser 1989) and the area of the image format occupied by the targets which are visible from the particular camera station. Visibility conditions for a given camera position can be modelled by taking into account all applicable range related constraints.

2.2 Visibility Related Constraints

The visibility of a cluster of object points from a camera station can be a complicated matter which depends upon the constraints of target incidence angle, occluded areas, and camera FOV, as illustrated in Figure 2. The cone shown in the figure has its axis normal to the target surface and an opening angle from about 120^0 for retroreflective targets to 150^0 for high-contrast non-retroreflective targets. Of course, a spherical target has no incident angle constraints and a back-to-back target will have two 'visibility cones', one being a mirror image of that shown in Figure 2, behind the target plane. Once the target type and orientation are known, a visibility analysis that takes into account the constraints indicated can be carried out.

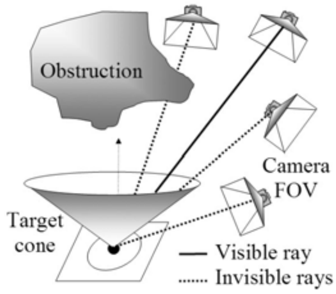

Figure 2: Visibility as a function of incidence angle, camera FOV, and occluded area constraints

2.3 Accessibility Related Constraints

This class of constraints is the aim of the paper though it is least likely to be explicitly modelled in the network design process due to the need for a model of the workspace. The accessibility for camera station positions is typically dependent upon physical constraints of space, obstructions and often the infeasibility of occupying certain geometrically favourable locations. A preliminary site inspection will typically dictate alterations to a planned network design due to accessibility related constraints.

Accessibility related constraints often have been not explicitly considered by user. Accessibility of camera position depends on accessibility constraint, workspace constraint, and object and obstructions inside. First subject, as arisen from its name, entails capability of work with camera at concerned location. Herein, if the camera is installed on a robot arm, then the accessibility of robot arm to its circumstance will be interpreted as accessibility constraint. However in manual photography, it depends on accessibility of user's hands to feasible locations in workspace. For instance, user can not usually take image from the top view of a tall object. This class of constraints is so uncertain and complex that can not be modeled perfectly. One popular solution is that user walks in the workspace and checks the accessibility of concerned camera station. In continuing, we propose our novel but simple method based on the fuzzy concept to solve the mentioned problem.

3. THE FUZZY MODELLING OF ACCESSIBILITY

Without the benefit of a model of the object (other than a point cloud) and workspace, the task of estimating whether a planned new camera station will be in an 'accessible' location is very difficult. After all, the desired location has been determined through network geometry consideration alone and not through consideration of characteristics of the site. Thus, in a network improvement process, there is really only one practical option for automatically ascertaining the accessibility of a new camera station and that in through consideration of existing camera station locations. In the context of fuzzy criteria, a new camera station location will have a higher probability of accessibility the closer it is to an existing camera station. We can therefore use proximity as a basis for uncertainty modelling, with an appropriate uncertainty function being the Butterworth function which is used more commonly as a low pass filter in signal processing. This function gives the accessibility uncertainty prediction score W (again between 0 and 1) as follows:

$$W = \frac{1}{1 + \left(\frac{D_{\min}}{D_0} \right)^{2n}} \qquad (1)$$

D_0 is accessible vicinity radius around existing camera stations. Where n is a uncertainty behaviour factor that controls the width of fuzzy boundary between accessible and inaccessible transit areas (Gonzales, 1993). Usually n is less than 4 especially when camera stations are far from each other. D_0 is set by user depending on the object and workspace conditions and is usually about half of average density of camera positions (Figure 3).

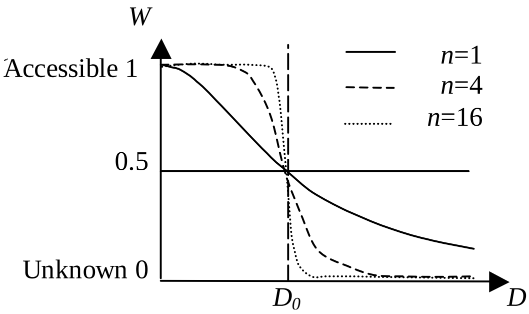

Figure 3: Definition of fuzzy membership function of accessibility

As a general rule, in the open workspaces with low obstructions, a high value for D_0 and a low value for n are proper. Notably, a bad setting of these parameters leads to have a very unreal large or small accessible area definition. Figure 4 shows an example of accessible area with fuzzy membership value more than 0.4 when D_0=1.5m and n=1 in our practical sample data shown in Figure 9.

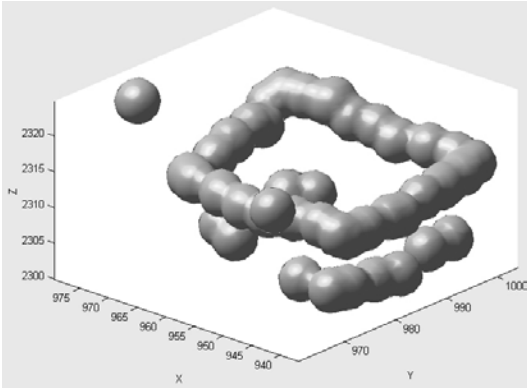

Figure 4: A sample modeling of fuzzy accessible area for camera positions

4. EXPERIMENTS

To test the proposed method of accessibility analysis, a lab and a practical data set have been experimented. To check the validity of predicted accessibility of camera stations, for each data set, some extra images as control data so called here 'control image' have been used.

4.1 Lab Data Set

To test the capability of fuzzy modeling of camera accessibility in the network, a car door object which is put behind a box as obstruction (for visibility tests that are out of the aim of this paper) is used and photography has been done through 30 camera stations illustrated in Figure 5. In Figure 6, the reference network including 30 camera stations, test 1, 2, and 3 consist of 22, 17, and 8 camera stations and 8, 13, and 22 control images are illustrated correspondingly.

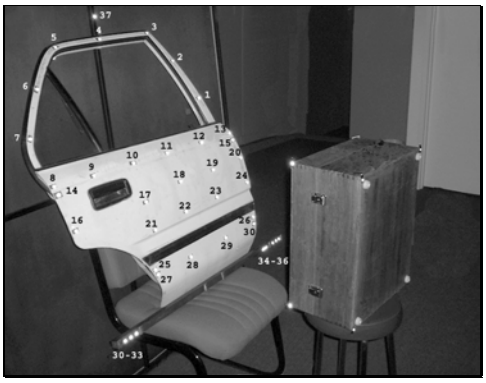

Figure 5: The car door behind a box for visibility test

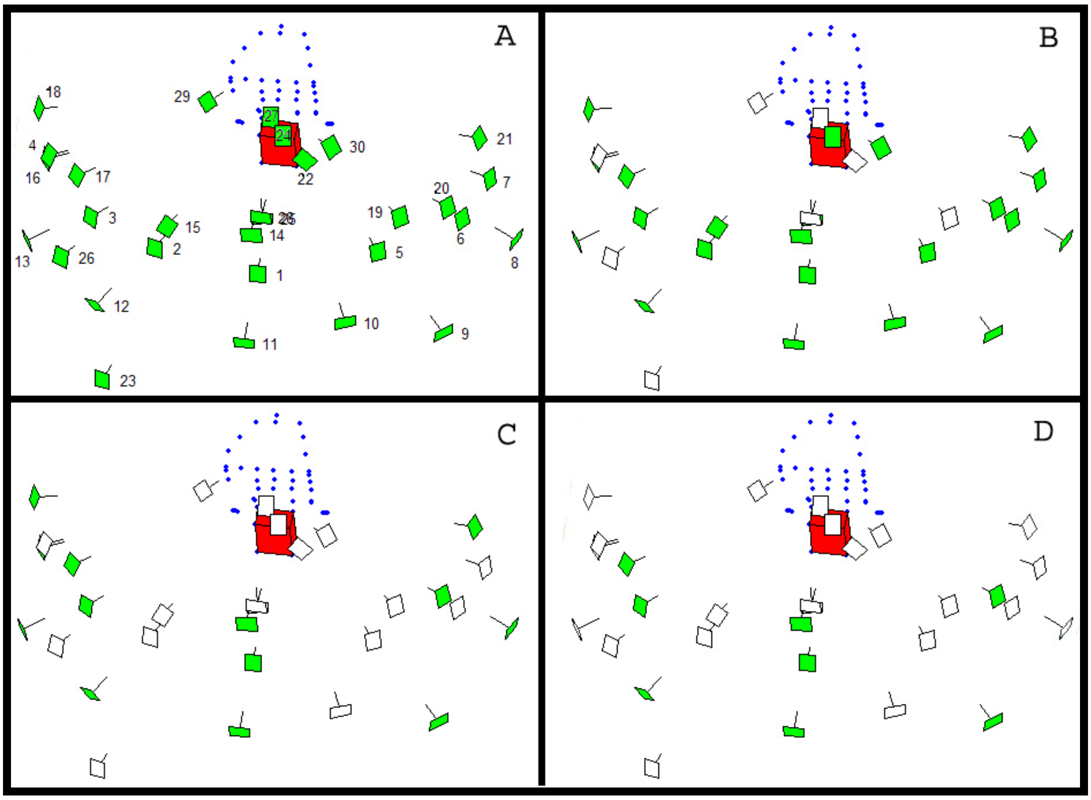

Figure 6: A is the reference network and B, C, and D are tests 1, 2, and 3 correspondingly. Dots are object points, 3D box is the obstruction, dark rectangles are camera stations and white ones are control images

To study our fuzzy accessibility model which is based on closeness to extant camera stations, the accessibility average of control image positions are estimated under different neighborhood radiuses D_0 (0.5, 1, 2, 4, and 8 meters) and different fuzzy behavior factors n (0.5, 1, 2, 4, 8) defined in Equation 3. Figure 16 shows the results of three tests in which test 1 relatively has better result than other tests because it includes more camera stations close to control images. Therefore, to better model accessibility, more images should be taken in primary network. In addition, new camera stations should not be placed far from extant ones. Figure 7 illustrates that although test 2 includes less camera stations than test 3, their accessibility estimations are approximately the same. It is because, many control images are far from eliminated camera stations of test 3 (Figure 7). In the other word, the distribution of camera stations of test 3 is still proper enough in comparison with test 2. Therefore, more distributed camera stations in the 3D space can better model the accessibility.

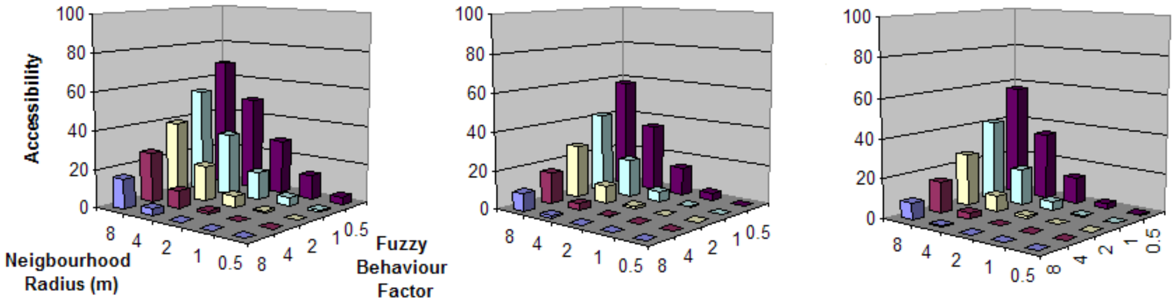

Figure 7: Accessibility behaviors for three tests 1, 2, and 3 in lab data set from left to right

4.2 Practical Data Set

To demonstrate the capability of proposed accessibility model in network design, a practical sample data related to a complex network including 57 images and 220 points installed on an ancient church building again has been selected and tested (Figure 8 and 9). The number of 10 images was used as control and visibility and accessibility models were built by 47 remained images.

Figure 8: A view of ancient church which measured by close range photogrammetry

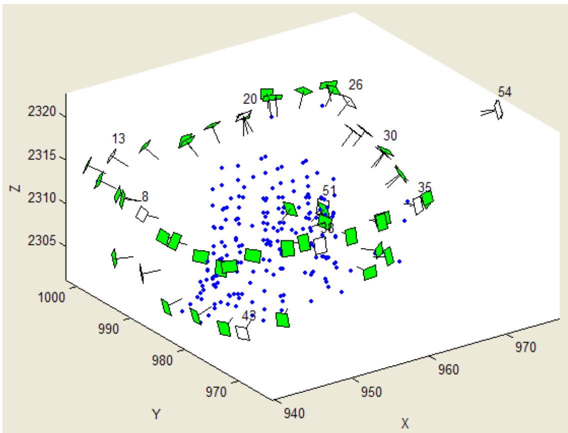

Figure 9: The network implemented on the church including dots, dark and white rectangles as objectpoints, camera stations and control images (with their numbers) correspondingly

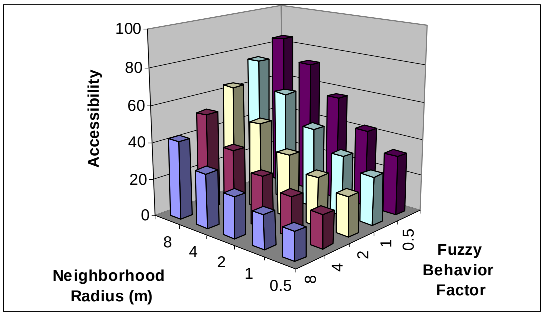

Figure 10: Accessibility of control images in practical data set

To investigate the accessibility modeling of this complex network, average of fuzzy accessibility of all 10 control image are calculated under different D_0 and *n*. Higher D_0 and lower *n* have better results that is not always true. Since the ancient church is in a pit, all area between floor of earth and pit are not accessible. If D_0 is very high, all points in this area estimated as accessible. So a good value for D_0 is the half average distance between extant camera stations. The average accessibility for D_0=1.5m and *n*=1 is 0.4. Figure 4 shows the area with accessibility more than 0.4 under above parameters.

5. CONCLUSION

Perhaps the most challenge in vision metrology system which still is not solved perfectly is network design phase in complex cases. Many efforts have been accomplished to automate this phase. Since these methods require a 3D simulated model of object and workspace to design the network, most of them have not been practically accepted by users. The paper proposes this assumption that if the network design is accomplished without the expensive 3D simulated model, it is possible to be successfully automated in practice.

Our proposed accessibility model can be successfully substituted by external 3D simulated models. The comparison of camera accessibilities in each control image between real 3D model and proposed accessibility model proved the validity of accessibility analysis in two tests. The reliability of proposed model is usually about 75% means 3/4 predictions are true. It is a good result since the 3D model of object and workspace are not required.

To better model the accessibility by proposed method, the primary network should have enough number and good distribution of camera stations. Generally in proposed model, a closer new camera stations to extant camera stations has more reliable accessibility.

The proposed model changes the network design to a fuzzy multi-objective optimization problem. The optimal new camera station can be found in a multi-objective optimization process in which visibility of image points, accessibility of camera station and its effect on precision improvement of weak points are maximized simultaneously. This process can be implemented in an intelligent camera in order to advice user to satisfy the weak point or does the network design in the field during taking images. Our future investigations will concentrate to solve this optimization problem.

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