DESIGNING AND PLANNING OF CLOSE-RANGE PHOTOGRAMMETRIC NETWORKS: IS AN EXPERT SYSTEM APPROACH FEASIBLE ?

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ABSTRACT

Designing and planning of close-range photogrammetric (CRP) networks require the solution of a number of inter-related problems. Decisions have to be made concerning imaging geometry, recording cameras, targeting, data-processing algorithms, image-coordinate measuring instruments and data acquisition schemes. Some aspects of the decision-making are cognitive in nature and are not suitable for a conventional algorithmic solution. These are therefore not incorporated into existing network design packages. Expert system technology offers a solution to problems involving cognitive decisions. This paper investigates the application of expert system technology to CRP network design, and describes an experimental system which has been applied to close range problems. Some examples are presented which demonstrate how the system facilitates the decision-making process.

KEY WORDS: Close-range, photogrammetry, network design, expert system.

1. INTRODUCTION

It is usual to perform network design as a prelude to undertaking a close-range photogrammetric (CRP) survey. Based upon an initial choice of parameters, photogrammetrists may simulate the results of the initial configuration before proceeding to carry out the later stages of photography, measurement of image-coordinates, and adjustment or data processing. Increased automation has brought about a continuing shift of emphasis to network design.

Network design involves the solution of a number of inter-related problems. Decisions have to be made concerning the choice of imaging geometry, recording cameras, targeting, data-processing algorithms, image-coordinate measuring instruments and data acquisition schemes. Some aspects of the decision-making are cognitive in nature, that is they can be made only on the basis of knowledge gained from a combination of practical experience with CRP measurements, intuition and 'rules-of-thumb'. Cognitive decision-making is not suitable for a conventional algorithmic solution, and is therefore not incorporated into existing network design packages. Many workers, eg Chen (1985) and Shortis and Hall (1989), have emphasised the need to develop an interactive computer package for handling network design.

A great deal of interest has arisen lately in the application of expert system technology to problems in which computer solutions were previously inapplicable. This technology has been employed in a variety of science and engineering environments to solve problems involving cognitive decision-making. An expert system is yet to be developed for designing CRP networks (Shortis & Fraser, 1991).

The aim of this paper is to demonstrate the potential of expert system technology to the planning and designing of CRP networks.

2. EXPERT SYSTEM TECHNOLOGY

2.1 Definition and structure of an expert system

Expert systems are species of computer software which use specialists' knowledge and reasoning techniques to provide advice and counselling, and to solve problems that would normally require the expertise, abilities and experience of human specialists. They assist decision making and allow interactive consultation. Expert systems differ in a number of respects from conventional computer programs such as database management systems (DBMS) or spread sheets. For instance, in expert systems,:

(a) the bulk of a 'program' is made up of statements of facts (or rules) rather than control structures eg **IF...THEN** is a relationship and not a control structure,
(b) the physical order of rules are irrelevant, since manipulation is not done sequentially according to fixed algorithms,
(c) answers can be provided not only to the first order question (ie 'what?'), but also to the second and third order questions (ie 'how ?' and 'why ?')

Expert systems can be divided into two general categories according to the task they perform (Kretsch, 1988): those that **design** something in order to solve a problem within some set of constraints or guidelines, and those that perform **diagnosis** (analysis). In either case the basic structure is the same.

A typical expert system has four main components: 'knowledge-base', 'inference engine', 'working memory', and 'user interface' (Fig.1). The knowledge-base contains structured and codified information about a specific problem area. In most expert systems the knowledge-base is represented in the form of rules. The 'inference engine' is a set of computer programmes which constitute the central problem-solving mechanism that controls and coordinates the operation and reasoning of the expert system (eg Ripple and Ulshoefer, 1987). It is like the 'interpreter' or controller in conventional programming (Sarjakoski, 1988). It runs the program; matches rules with data; determines which of the possible set of rules and/or facts in the knowledge-base is to be applied at each step, and when and how to use them for the current consultation session. The 'working memory' contains the description of the current state of the problem-solving (Sarjakoski, 1988), and the intermediate hypotheses; while the 'user interface' controls how the user may communicate with the system. A user can interact with an expert system either by first suggesting a hypothesis, or by first volunteering some data.

2.2 Expert system technology and close-range photogrammetry

Recently, the need for photogrammetrists to be interested in applying expert system technology to photogrammetry has been suggested (eg Xu, 1988; Sarjakoski, 1986 and 1988). Of the four phases involved in photogrammetric tasks, suggestions have been limited to three: data acquisition, data reduction and analysis (eg Sarjakoski, 1988). We feel the same concern for the network design phase. There has yet been little effort in the application of expert system to close-range photogrammetry.

2.3 What kind of problem can be solved with expert systems ?

The verification of the suitability of a task for ES support involves finding answers to the following questions (eg Martin & Oxman, 1988).

a) Is the task one in which we can express the knowledge required to perform the task as a collection of facts based on experience ?.
b) Does the task require an expert to carry it out ? Are the specialists rare, costly and generally unavailable?.
c) Is the focus of the expertise specific, *albeit* narrow ?
d) Are experts available for the development of the system?
e) Is the problem insolvable by traditional computing methods?
f) Will the proposed expert system save time or money or will it enable a task to be performed in a substantially better way ?
g) Does the task occur frequently ?

If the answer to each of these questions is 'yes', then there is a *prima facie* case in support of the feasibility of an expert system approach to the task. We then need to assess whether it is possible to construct a suitable knowledge-base. If this is possible, then the problem is certainly solvable using expert system technology.

The determination of what constitutes 'the knowledge' of the problem is the most fundamental aspect in the task of developing an expert system (Sarjakoski, 1986, 1988).

3. DESIGNING CLOSE-RANGE PHOTOGRAMMETRIC NETWORKS

3.1 The problem

In order to design a CRP network it is necessary to make decisions concerning

a) the camera and initial imaging geometry,
b) the targeting,
c) the data acquisition scheme,
d) the measuring instrument, and
e) the data processing algorithm.

Some of the above can be expressed purely in terms of a 'knowledge' base; for instance, choice of camera is dictated by available camera types and their parameters can be formally described and incorporated within a database. The initial imaging geometry depends upon such factors as camera type and desired survey accuracy and so cannot be described using a 'knowledge' base. Nor is there a suitable accuracy predictor available without resorting to full scale simulation.

During our research, we soon realised that any expert system for network design would have to be able to determine if a suggested configuration would achieve the accuracy specified for a particular task. This led us to develop an accuracy predictor (Bammeke, 1992a) which is briefly described in section 3.2 and is used to help determine initial imaging geometry. All other aspects of network design can be handled by the expert system itself. As an illustration, we show how the problems of targeting and camera choice can be handled by the system. These matters are discussed in more detail by Bammeke (1992b).

3.2 Development of Accuracy Predictor

The determination of the initial approximation of imaging geometry is a first-order design problem; whereas the selection of camera involves an evaluation of the accuracy potential of the camera, which is a second-order design problem (Fraser, 1989). Mathematically we can say that resolving the two issues is equivalent to solving for the configuration (ie design) matrix A and the weight matrix W, in a system of observation equations of the form:

$$(A^TWA)X = A^TWB \tag{1}$$

However, we cannot solve this design problem without first knowing the accuracy that can be achieved with a particular network. Hence there is a need to employ mathematical formulae for predicting accuracies of close range photogrammetric networks.

Formulae for predicting global estimates of accuracies of object-space coordinates in close-range photogrammetric multi-station networks have been developed. The formula are based upon an initial symmetric network geometry consisting of n camera stations and certain assumptions (Fig. 2). By considering object space point intersection and by retaining the scale factor that arises within the collinearity equations (Bammeke 1992a) we can develop the following formulae:

$$\left.\begin{aligned}
\sigma_X &\approx \left(\frac{1}{\sum_{j=1}^{n}\left(\cos^2((2j-1)\frac{\phi}{2})\right)}\right)^{\frac{1}{2}}\left(\frac{D}{f}\right)\sigma_i \\
\sigma_Y &\approx \left(\frac{1}{n}\right)^{\frac{1}{2}}\left(\frac{D}{f}\right)\sigma_i \\
\sigma_Z &\approx \left(\frac{1}{\sum_{j=1}^{n}\left(\sin^2((2j-1)\frac{\phi}{2})\right)}\right)^{\frac{1}{2}}\left(\frac{D}{f}\right)\sigma_i
\end{aligned}\right\} \tag{2}$$

which give a vector expression

$$\sigma_T \approx \left(\frac{1}{\sum_{j=1}^{n}\left(\cos^2((2j-1)\frac{\phi}{2})\right)} + \left(\frac{1}{n}\right) + \frac{1}{\sum_{j=1}^{n}\left(\sin^2((2j-1)\frac{\phi}{2})\right)}\right)^{\frac{1}{2}}\left(\frac{D}{f}\right)\sigma_i \tag{3}$$

where:
n = No of camera stations in a symmetric network
ϕ = angle between consecutive camera axes
D = average camera-to-object distance,

f = focal length of the camera,
σ_i= *a priori* value of the image-coordinate precision,
$(\sigma_X, \sigma_Y, \sigma_Z)$ are the accuracies of object-point coordinates (X,Y,Z), and σ_T is the vector of positional accuracy.

We can write eq (3) as:

$$\sigma_T = (PEF)\frac{D}{f}\sigma_i \qquad (4)$$

where S (=D/f) is the scale number, and
PEF is the positional error factor

The equations are functions of camera parameters (f, σ_i) and the configuration parameters (ϕ, n, D). Therefore they can be used to:

(a) predict the accuracies which can be expected from a given camera and configuration, and also
(b) determine the camera and configuration parameters which will be required to meet a given accuracy specification.

We use the equations within an experimental expert system to select the camera and initial imaging geometry that are suitable for a task.

4. THE EXPERIMENTAL EXPERT SYSTEM

4.1 Introduction

An experimental expert system has been developed. The system uses an Expert System shell (Expertech Xi Plus ver 3.5c2) which runs on standard IBM PC XT and requires only 512KB RAM. The expert system was designed in modules. It has five integrated knowledge-bases (modules) which interact with each other and help advise on target design, camera selection, imaging geometry, and data acquisition schemes.

The system works by using the accuracy predictors to modify design parameters until the accuracy specified by the user is met.

In order to understand how the system works, we shall first show how it handles the problem of selecting camera and initial imaging geometry; and then show an actual example of a consultation session.

4.2 Selection of camera and initial imaging geometry

The selection of camera and the initial approximation of imaging geometry is a knowledge-intensive issue. We constructed a database which contains details of many cameras; and lists such attributes as camera type, focal length, format size, minimum focusing range, as well as image coordinate measurement precision relating to the cameras. A second database is constructed which gives the calculated PEF for a range of n and ϕ. In our system, these databases are stored in files called cameras.dbf and optconfi.dbf (see Fig 3). These are held independently of the expert system. The set of data within each database is arranged in a defined way in order to speed retrieval and enable interrogation within the expert system. The user supplies information concerning the largest dimension of the object to be measured and the accuracy required. The system works by using formula 3, the two database files, and some user-supplied information (Fig. 3). For example, the system uses cameras.dbf and the largest dimension of the object to determine D and hence S. The steps involved are depicted by the flow chart (Fig. 4), which is a simplified version of the general procedure of 'camera selection'.

4.3 Target Design

The design of a target needs to be not only in terms of physical characteristics (ie shape, size) but also in terms of optical characteristics. The determination of the size of a target that would be appropriate for a particular measurement task is simple. The other characteristics are more difficult. They are determined by finding answers to a number of questions, eg is it necessary to provide artificial targets ?. If so should it be contact (ie physical) or non-contact (ie optical)? if contact, should it be a planar or non-planar ? should the planar (or non-planar) be diffuse or retro-reflective ? etc. The decision-making process requires expertise, without which the desired accuracy may not be achieved. An example is a case (Kenefick, 1971) where the use of diffuse targets could have yielded an accuracy that is 250% better than that achieved with reflective targets. It is, therefore, imperative to use the type of target that is suitable for each measurement task. Existing design packages leave this decision entirely to their users.

A classification scheme for target type has been devised (Fig. 5). Most commonly encountered targets can be categorised into one of the types in this classification scheme. This scheme is reasonably well-defined, and its hierarchical structure is compatible with the problem-solving techniques in expert system technology based on traversing trees. Hence target design makes a particularly good domain for processing with expert system technology. The classification scheme has been converted into a decision tree/table, which in turn is converted into **IF...THEN** structured rules. For each of the target types, the series of conditions under which it is the most suitable type is constructed, for example:

IF image of object is required to be invisible on the photo
THEN target type required is an active light-reflecting(eg retro- -reflective)

5. APPLICATION OF THE EXPERT SYSTEM: AN EXAMPLE

A typical consultation session relating to the selection of camera and initial imaging geometry is shown in Fig. 6. In this session a sample problem and the system-to-user interactions are shown. We note that the characteristics of a camera will determine its suitability or otherwise for a given task. These characteristics are contained in the database file (cameras.dbf) to which the system has an automatic access.

When the system asks a question, the user may want to know why such a question is being asked. This, the user does by selecting a special function key (<F3> in our case). The system then responds by reporting the line of reasoning that led to that particular question being asked. To enable the system to evaluate a camera that is not contained in cameras.dbf, the system provides the user with a form (Fig.7) to fill. The information provided by the user is used not only for the purpose of the current consultation session, but also to update the cameras.dbf for possible future use. In this way, the system updates its knowledge just as a human expert does.

Apart from the body of rules contained in the knowledge base, the primary tool used by the expert system is the accuracy predictor. The accuracy predictor is used with cameras.dbf to modify design parameters until the design accuracy is met. The accuracy achievable for different geometry are shown in Table 1 for Wild P31 (f=100mm σ_i = 3 µm and 2 µm); Zenzanon etr (f=150mm, σ_i = 2.4 µm) (Chen, 1985) and Zeiss UMK (f=100mm, σ_i = 2 µm). The system assumes a safety factor of 1.2, so that the design accuracy in this case is ±0.092 (±0.11/1.2). It also assumes that more than 12 camera stations will be undesirable.

6. DISCUSSION

The result of a consultation with the expert system is a detailed recommendation which describes the equipment and also the initial network geometry for the data acquisition phase. Note that the choice of camera is user-specified; the system responds by establishing if that particular camera is suitable for the specified task. In the case reported, we see that for the same σ_i = 2 µm, the P31 requires 5 stations, while the UMK requires only three. The Zenzanon cannot satisfy the specification. All these clearly show the importance of format size.

Associated with each recommendation, we can develop a **cost**. Clearly, the cost of a three station solution is superior to that of a five station solution in terms of time and amount of measurements to be performed. The interesting problem arises when two different systems yield the same number of camera stations for a specified objective. By formalising the cost calculation, we can resolve this dilemma.

It is interesting to compare equation 4 with the coarse object point accuracy indicator of Fraser (1989)

$$\sigma_{\bar{c}} = qS\sigma \qquad (5)$$

as S = D/f. We find that our PEF is a formulation of the factor q. Fraser reports the value of q varies from 0.5-1.0 for the case of strong geometry (four or more camera stations). We obtain values of PEF in the range 0.6-1.2 for four or more stations (Bammeke, 1992b). We suggest that equation 4 may be taken as a formulation for equation 5.

7. CONCLUSIONS

The criteria for verifying the suitability of using an expert system approach to solve a task are outlined in section 2.3. For the cognitive aspects of network design, it can be shown that the answer to each of the questions (a) to (g) in section 2.3 is 'yes'. Further, we have shown that a suitable knowledge-base can be constructed using databases, appropriate rules and the accuracy predictor.

We have constructed a prototype expert system which can:

(a) recommend an initial configuration for a task.

(b) ensure the recommended configuration satisfies the required accuracy level

Further work should be aimed at developing a full cost model; integrating the expert system with a simulator; and increasing the reliability of the knowledge base through enriching the knowledge content. Finally, the use of the expert system for real projects should confirm the validity of our conclusions or otherwise!

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Table 1: Result of consultation session for three cameras (σ_T in mm)

Geometry n	ϕ	Zenzanon [55x55] f = 150 mm σ_i = 2.4 µm	P31 [100x130] f = 100 mm σ_i = 3 µm	P31 * [100x130] f = 100 mm σ_i = 2 µm	UMK [130x180] f = 100 mm σ_i = 2 µm
2	45	0.310	0.213	0.142	0.109
3	30	0.254	0.174	0.116	**0.089**
4	22	0.220	0.151	0.101	
5	18	0.196	0.135	**0.090**	
6	15	0.179	0.123		
7	13	0.166	0.114		
8	11	0.155	0.107		
9	10	0.146	0.101		
10	9	0.139	0.095		
11	8	0.132	**0.091**		
12	8	0.127			

* The database entry uses σ_i = 3 µm. We include σ_i = 2 µm for comparison.

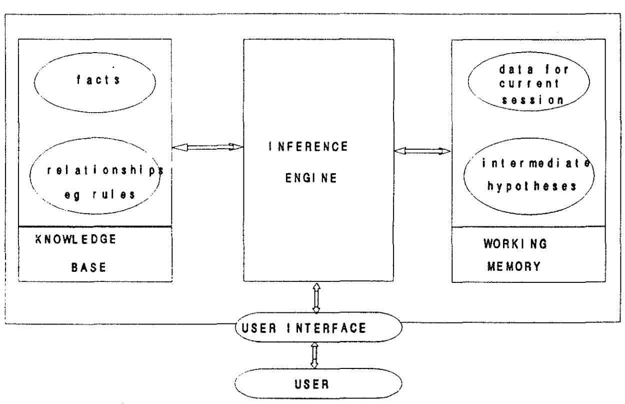

Fig. 1: Structure of an expert system

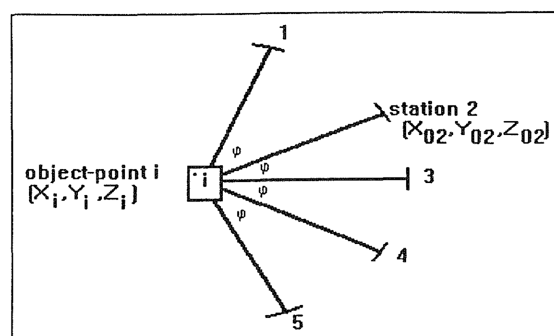

Fig. 2: Symmetric network geometry

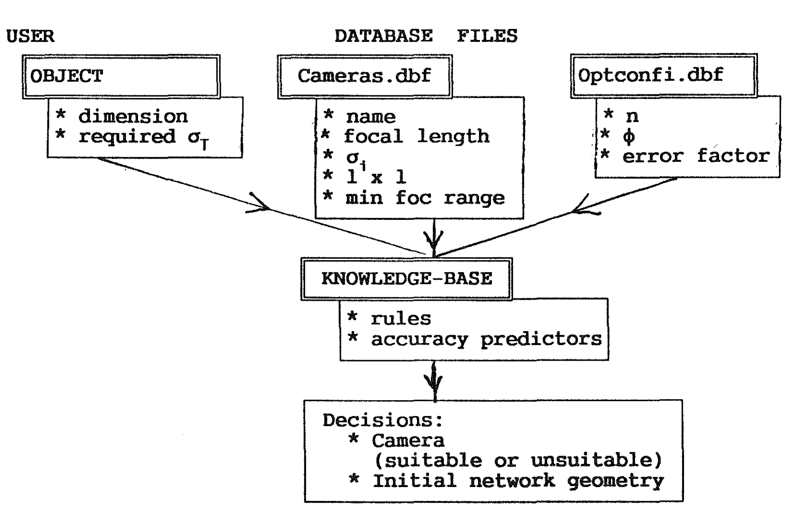

Fig. 3: Main components of 'camera selection' module

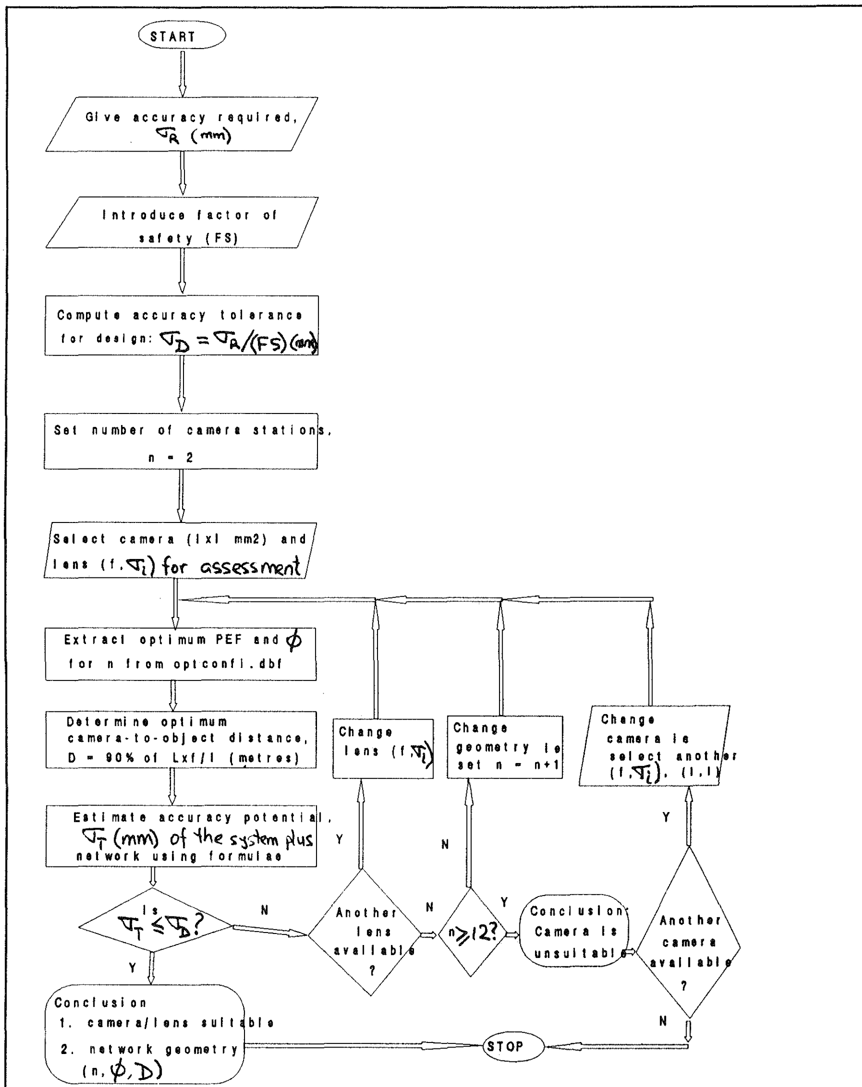

Fig. 4: Flow diagram for determining camera and network geometry required to meet an accuracy

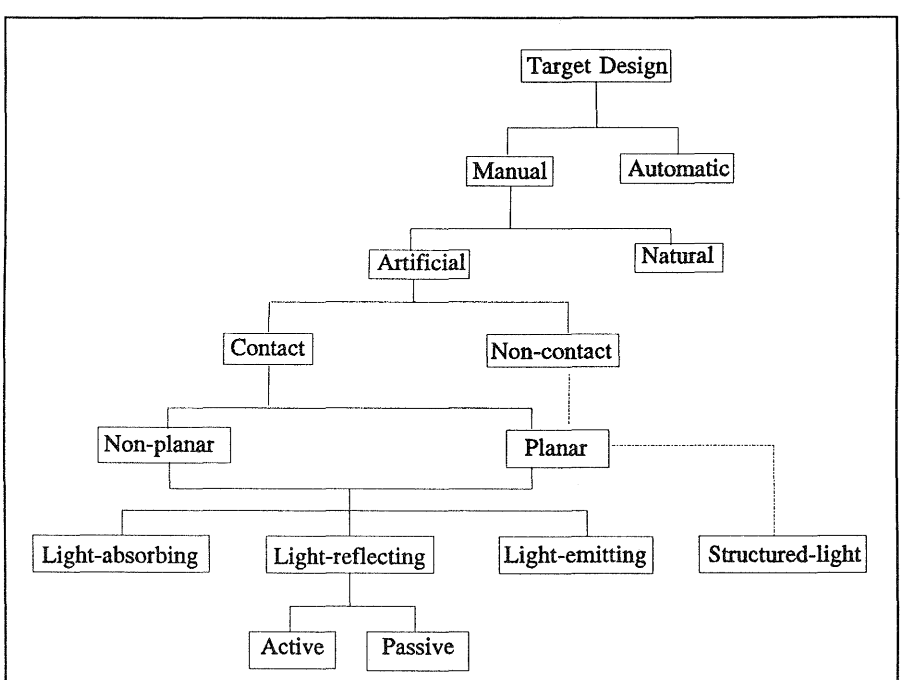

Fig. 5 Classification scheme for target types

PROBLEM: The object-space coordinates of an object (2m x 5m x 3m) are required to be accurate to within ±0.11mm. A P31 (Wide angle) camera with f = 100mm lens, a UMK camera (f = 100mm), and a Zenzanon etr camera with a 150mm lens are available. Determine the suitability of each of these cameras for the task.

SYSTEM	**USER**
What is the object's name ?	water tank
Object-space coordinate of the water tank is to be correct to within ±...mm	0.11
Largest dimension of the water tank:...metres	5
Application is real time ? [yes,no]	<F3>
Helps to determine whether digital or analogue camera is required	
Application is real time ? [yes,no]	no
Analogue camera available is [UMK, CRC-1, P31(Wide angle), other(s)]	P31(Wide angle)
Unit cost per camera station ?	3
P31(Wide angle) is suitable for the task. Want to evaluate another camera ? [yes,no]	yes
Analogue camera available is [UMK, CRC-1, P31(Wide angle), other(s)]	UMK
UMK is suitable for the task. Want to evaluate another camera ? [yes,no]	yes
Analogue camera available is [UMK, CRC-1, P31(Wide angle), other(s)]	other(s)
NOTE: system presents user with a form for updating the camera database, cameras.dbf (see Fig. 7)	
Zenzanon etr is unsuitable for the task. The optimum accuracy that can be achieved with it is ±0.127mm. Press <RETURN> to nominate another camera for evaluation.	

RECOMMENDATION: P31(Wide angle) and UMK cameras are suitable for the task. While Zenzanon etr is not.

Fig. 6: A typical consultation session

UPDATING CAMERA DATABASE

Enter characteristics of camera to fields provided.
Press <CTRL> with <ENTER> to complete the selected function and update the database.
Press <ESC> to quit the selection and return to main menu.

record #:

Manufacturer	:	
Model	:	
Focal length	:	mm.
Length of photo format	:	mm.
Width of photo format	:	mm.
Minimum focusing range	:	metres
a priori precision of image-cood	:	μm.

Fig. 7: form for 'updating database' of cameras