# A BASIC THEORY OF INTELLIGENT PHOTOGRAMMETRON

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**ABSTRACT:**

This paper presents a basic theory of intelligent photogrammetry and corresponding physically independent agent systems named Photogrammetron. Intelligent photogrammetry is a fusion of ideas, techniques and applications from digital photogrammetry, active vision and intelligent agents, aiming at developing highly automatic and intelligent photogrametric systems. The tenet of intelligent photogrammetry is that photogrammetry is a nonlinear process for which a full automation, if indeed required, is only possible if and only if the system is an autonomous and intelligent agent system. In its basic form, photogrammetron refers to a stereo photogrammetric system which is designed to possess an architecture of intelligent agent, a physical structure of qualitative and active vision, and a complete functionality of quantitative photogrammetry. In a broader sense, photogrammetron may have three physically different forms: I – coherent stereo photogrammetron, II – separated stereo photogramemtron and III – multi-camera network photogrammetron. Principal applications of photogrammetron include: photogrammetry-enabled robots, intelligent close-range photogrammetry, intelligent video surveillance, real-time digital videogrammetry. The agent architecture of photogrammetry consists mainly of five components: imaging perception, scene beliefs and models, missions and desires, intentions and planning, action and control. The photogrammetric visual information processing comprises seven major parts: motion camera calibration and relative orientation, optical flow computation and object tracking, stereo focus of attention and vergence control, stereo motion image sequence matching and correspondence maintenance, object structure from motion, multi-object tracking and recognition. While a complete realization of photogrammetron design will take time to appear, this paper only intends to outline a basic theory and address fundamental theoretical feasibility and challenging problems. A real prototype of Photogrammetron-I is under development.

## 1. INTRODUCTION

Analytical photogrammetry and digital photogrammetry are the first and second large development respectively after the advent of digital computer. However, regarding the main theoretical foundations [Gruen, 1994; Fraser 1998; Dold 1998], digital photogrammetry has serious limitations. Some obvious limitations are identified as follows: (1) The imaging process and later stages of information processing are separatedly considered, consequently the complexity of the information processing is unlimitedly high; (2) Due to arbitration, passiveness and non-automation of the imaging process, the whole digital photogrammetric system can hardly be automated completely and realtimely; (3) The whole information processing of digital photogrammetry is designed as a linear procedure, so many complex nonlinear problems become non-solvable or not essentially solvable, such as the disparity discontinuity and occlusion in image matching, object recognition, 3D reconstruction of man-made objects, multi-target tracking, etc.

In our view, photogrammetry as an engineering technology with image information processing as the primary technical contents, its development must synchronize with mainstream technologies of information processing, optics and mechatronics. At the same time, as an engineering technology, photogrammetry must follow time-tested cross-disciplinary principles of engineering sciences. To photogrammetry, if the full automation of the whole process is indeed required, at least two principles of engineering sciences should be considered:

1) to put the whole process of photogrammetry into an engineering system, including at least the imaging process and image information processing;
2) to reduce the complexity of information processing through the engineering design of the system.

From the development of computer vision being a sister discipline largely overlapping with photogrammetry, it has been realized more and more clearly that those physics-based, geometry-based, or even knowledge-based approaches in computer vision all have their insurmountable barriers. It is our view that active vision [Aloimonos et al, 1987] is a major breakthrough and a way of future for computer vision research, which is profound in nature and has much to come. Besides, in artificial intelligence, various analytical modules of intelligence such as perception, learning, reasoning, planning and control are going to integrate and fuse, resulting in the development of intelligent agent theories and architectures [Rao and Georgeff, 1998]. Active vision may be conveniently considered an embodiment of intelligent agents with visual information processing capabilities in an integrated software and hardware system.

As a result of our long years of consideration on the limitations and barriers of digital photogrammetry, and with our vision to the potential of active vision and intelligent agents, we propose a basic theory of intelligent photogrammetry and corresponding agent systems coined photogrammetron. In this basic theory, we shall discuss basic ideas and concepts of intelligent photogrammetry, clarify theoretical and technical issues and problems, and their possible solutions. However, it must be pointed out that this paper is only one of the very early steps in intelligent photogrammetry, we do not aim at a complete theory yet; much of the work has yet to be carried out.

## 2. THE CONCEPTION OF INTELLIGENT PHOTOGRAMMETRY

In our view, driven by the mainstream of digital, intelligent, and networking information technology, photogrammetry has been entering the era of intelligent photogrammetry. With a qualitative uplifting from analogue, analytical and digital photogrammetry, intelligent photogrammetry has the following conception: (1) Photogrammetry is a nonlinear process; (2) This nonlinear process of photogrammetry can only be fully automated through a nonlinear system; (3) According to the states of the art knowledge, such a nonlinear system realizing the whole process of photogrammetry must be an a system which possesses an intelligent agent architecture and mechanism and whose primary goal is the realization of photogrammetric information processing. We call such a system an intelligent Photogrammetron, or simply Photogrammetron; (4) Through inherent system engineering design, Photogrammetron will greatly reduce or constrain the complexity of photogramemtric information processing, so every problem becomes solvable with an engineering solution fulfilling the requirements and goals of the system.

As a new phase of photogrammetry, intelligent photogrammetry has to address the following problems and issues: (1) the analysis and modeling of the photogrammetric nonlinear processes; (2) the design objectives of Photogrammetron; (3) the taxonomy of Photogrammetron systems according to different applications; (4) the structure and architecture of Photogrammetron, including identification of components and their mutual relationships; (5) the design objectives, principle, algorithm, and implementation of every identified component.

The primary difference of intelligent photogrammetry in contrast with traditional photogrammetry is that Photogrammetron is designed to be an automatic, autonomous and real-time intelligent agent system whose main input source data are stereo or multiple motion image sequences, instead of still images. The data and information volume to be processed is at least one order higher than traditional photogrammetry; consequently, the information contents are much richer, which enables the system to reach the highest objectiveness and robustness for 3D reconstruction of objects and to extend the system functionality to new dimensions.

## 3. A BASIC TAXONOMY OF PHOTOGRAMMETRON

Photogrammetrons are intelligent photogrammetric systems with independent self-contained physical hardware. In comparison with digital photogrammetric systems, Photogrammetron has the following characteristics: (1) It is an intelligent agent possessing an autonomous system architecture in which the pose and parameters of the cameras are controlled by the system, not directly by the user; (2) The internal photogrammetric information processing is not limited to linear algorithms, but in general is an infinite nonlinear loop with adaptiveness, autonomy and automation; (3) The primary information sources for photogrammetry are stereo or multiple motion image sequences, but not separated still images; (4) Due to the high-level automation and autonomy, many procedures of photogrammetric information processing have different principles and algorithms than digital photogrammetry.

According to possible physical forms, the following types of Photogrammetron may be identified:

(1) Coherent stereo Photogrammetron, also called Photogrammetron-I. This is the very basic form of Photogrammetron. A Photogrammetron-I has a physical structure inspired by the animal head-eye system. There is a support base, similar to the shoulder, and we shall call it so. On top of the shoulder is the head, which is basically a pan-tilt unit with two degrees of angular freedom: pan and tilt. On top of the head unit a plate is fixed, we shall call it the stereo camera plate, or stereo plate simply. On top of the stereo plate two smaller pan-tilt units are mounted, each supporting one camera. These units are called left and right camera unit respectively. The two cameras units can translate symmetrically from the center of the stereo plate. Although each camera unit also has two angular freedoms: pan and tilt, in general the total four angular freedoms of the two camera units are constrained so the principal axes of the two cameras should be maintained coplanar and should form a forward vergence angle. The baseline length, i.e. the distance between two camera centers, may change in response to different requirement on photogrammetric precisions or other aspects.

(2) Separated stereo photogrammetron, also called Photogrammetron-II. In this second type, two cameras units may be separated, each may be supported by its own base. In other words, the two cameras may be put anywhere as long as the two cameras can form and maintain stereo views. Each camera is mounted on a pan-tilt unit, and each unit is supported by its own base. Therefore, each camera has two orthogonal angular freemdoms: pan and tilt. But the two cameras should be able to communicate with the system core. We distinguish between two levels of stereo mode: the weak stereo in which the principal axes of the two cameras are coplanar and they maintain a forward vergence angle, and the strong stereo in which the two cameras are not only in the weak stereo mode, but also the two principal image points corresponds approximately to the same object surface point in the object space. For Photogrammetron-I, these two stereo modes also exist.

(3) Multi-camera network Photogrammetron, called Photogrammetron-III. In this third type, the number of cameras is greater than 2, and is determined by the actual application requirement. Each camera is mounted on a pan-tilt unit which in turn is supported by a physical base. All the pan-tilt units and cameras are controlled by the system core. In general, we may not require all the cameras look at the same area of the object space, but we require these cameras to form and maintain a photogrammetric view network which covers the scene area of interest completely. This third type may be

considered as an intelligent form of closed-range photogrammetric networks, in which each camera becomes an intelligent agent, and the whole network of intelligent cameras become a multi-agent system or a society of intelligent agents.

## 4. A FEW SCENARIOS OF POSSIBLE APPLICATIONS

The conception of Photogrammetron proposed here has lifted photogrammetry up to the level of high-level automatic and autonomous intelligent agents and active vision system from the offline passive aerial photogrammetry or close-range photogrammetry, such that Photogrammetron as intelligent photogrammetric systems should be able to realize unprecedented new functionalities of intelligent photogrammetry and video surveillance. Main application categories of Photogrammetron include: 1) photogrammetric robots (or say, photogrammetry-enabled robots), 2) intelligent close-range photogrammetry, 3) intelligent video surveillance, 4) real-time videogrammetry (including real-time aerial photogrammetry, mobile photogrammetry, etc). In the following paragraphs, we shall outline a few scenarios of possible applications and clarify their scientific and practical importance:

1) Photogrammetry of static complex surfaces. Due to the exponential decrease of information sensitivity of the central perspective projection from the image center towards the image fringe, reconstructed surfaces from only two stereo snapshots do not have uniform information sensitivity, accuracy and reliability across the surface domain. Therefore, the focus of attention for the stereo cameras should move actively and adaptively over the areas of interest. Complex surfaces, even being static, often cause occlusions and disparity discontinuity in the stereo images, which brings difficult or even nonsolvable problems for image matching. These difficulties may only be overcome through active translation and rotation of the cameras.
2) Close-range photogrammetry in complex environment. Occlusions and view depth variations appear in complex environments. In such cases, any stereo snapthots can hardly reach effective stereo image matching. Therefore, ideal or effective photogrammetry may only be realized through a nonlinear process involving translation, rotation, focusing, vergence, surface reconstruction, etc. This nonlinear process corresponds to an infinite loop of planning-action-feedback.
3) Motion target tracking and photogrammetry. It is our view that target tracking by cameras should be a functionality of intelligent photogrammetry, thought not a part of traditional photogrammetry. Photogrammetron should be able to track motion objects and sometimes also to recognize them. The quantitative aspects of tracking include real-time estimation of object motion and object shape. In general there may be multiple targets moving in the scene domain, tracking and quantitative estimation of multiple targets by cameras pose new and hard problems to intelligent photogrammetry research, which definitely require much higher-level intelligence and processing capability.
4) Real-time continuous photogrammetry. For aerial, spatial or terrestrial photogrammetry, digital video cameras can be used to take continuous image sequences in real time. The extremely richness and high redundancy of the source information can be exploited to reconstruct the geometric shape of complex scenes, minimizing the occlusions and avoiding the unreliability of static image matching. This is particularly useful for constructing digital cities. Traditional aerial photographs of buildings in a city contain innumerous occlusions. Model-based approaches rely on geometric models of buildings for building reconstruction from aerial photographs. However, there are innumerous discrepancies between generic geometric models and real buildings, which often pose impassable barriers. Real-time continuous photogrammetry relies on the extremely high correlation and redundancy of source information, which has the potential to reach the highest objectiveness of photogrammetry.
5) Automatic optimization of close-range photogrammetric network. Close-range photogrammetry, for industrial measurement in particular, uses a multi-camera network covering industrial objects to be measured. However, for different objects with different size and shape, the camera network often has to be reconfigured such that the photogrammetric views are optimized. This optimization can be automated through a multi-scale nonlinear process. Photogrammetron-III provides a prototype or testbed for developing intelligent close-range photogrammetric networks.
6) Photogrammetry-enabled robots. General robots in industrial applications and explorations usually do not have high-precision photogrammetric functionalities. Photogrammetron-I can be adapted to robots endowed with precision photogrammetric capabilities.
7) Remote or Internet photogrammetry. Various forms of Photogrammetron can be placed in remote sites for tourism, surveillance, or remote control in hazardous environments. The communication between the system and the human operator may be via Internet. For these applications, human operators may not always be available for real-time monitoring, or they may be communication delays due to Internet limitations, the system has to have the capabilities of activeness, reactiveness, autonomy and automation.
8) Defense applications. In defense, intelligent weaponry and large area surveillance networks are instances of Photogrammetron in various forms. However, radar plays a dominant role in defense. Intelligent cameras provide another sensor modality.

The following discussions will primarily address the system principle and architecture of Photogrammetron-I for video surveillance applications.

## 5. A PHYSICAL STRUCTURE OF PHOTOGRAMMETRON

The structure of Photogrammetron has three dimensions: the physical structure, the intelligent agent architecture and photogrammetric information processing mechanism. A basic design of the physical structure, shown in Fig.1.

In this design, the basic structure of Photogrammetron-I consists of 5 hardware parts: (1) The support base, also called the shoulder. For this part, an Euclidean reference system $O-XYZ$ is assumed, where the $Z$ axis corresponds to the vertical line pointing from the bottom to the top through the centre of the shoulder. (2) A pan-tilt unit, called the head, is mounted on top of the shoulder. Relative to the shoulder, the head can rotate an angular freedom $\omega$ around the $O-Z$ axis. (3) The stereo camera plate, is basically a plate fixed on the top of the head, and on top of the plate the left and right camera pan-tilt units are symmetrically mounted. The stereo camera plate can tilt with an angle $\phi$. A reference system $S-UVW$ is assumed for the stereo camera plate. (4) The left camera and its pan-tilt unit. The perspective center of the left camera is denoted by $C$. A reference system $C-xyz$ is assumed for the left camera. The $C-z$ axis is the principal axis of the camera pointing through the perspective center $C$ towards the scene. The image plane is on back side of $C$. The focal length is $f$, and the principal point is located at $(x_c, y_c, -f)$. (5) The right camera and its pan-tilt unit. Any element on the right camera or pan-tilt unit is denoted by x' corresponding to its counter part x on the left camera or pan-tilt unit. Therefore for the right camera we have the perspective center $C'$, the reference system $C'-x'y'z'$, the focal length $f'$, and the principal point $(x'_c, y'_c, -f')$.

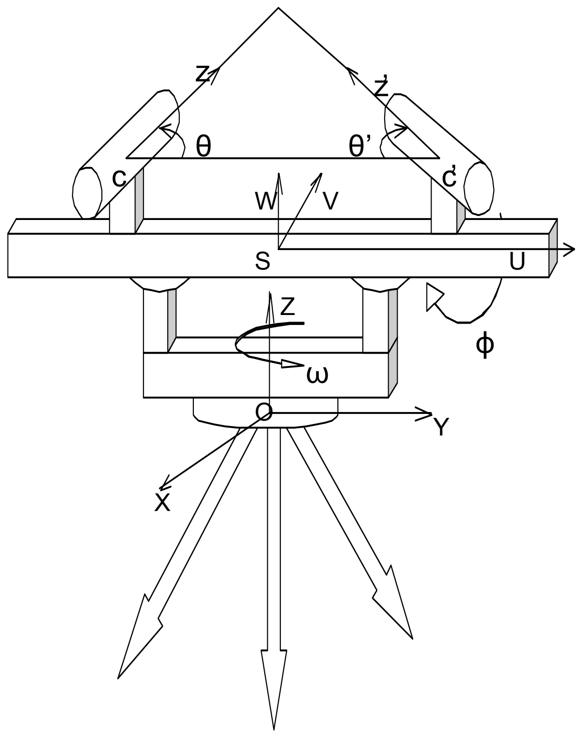


Fig.1 A basic physical structure of Photogrammetron-I

The left and right pan-tilt units can translate but only symmetrically left-right around the center $S$ along the $S-U$ axis in accordance with the requirement on the stereo baseline length change due to different photogrammetric precision requirement. Although each of the left and right camera pan-tilt units has two angular freedoms, we distinguish between two general system modes: stereo mode versus arbitrary mode. On the stereo mode, two principal axes $C-z$ and $C'-z'$ must be maintained coplanar and that plane is called the principle epipolar plane. The two principal axes $C-z$ and $C'-z'$ form two angles $\theta$ and $\theta'$ respectively with the baseline $CC'$. In the strict stereo mode, for the simplicity of the geometry, we freeze the tilt freedom of the left and right camera units, so the two principal axes are parallel with the $S-UV$ plane.

For an ideal Photogrammetron, we assume all the mechanical freedoms can be read out from the automatic control mechanism, including four angles $\omega, \phi, \theta, \theta'$, the baseline length $B$ and two focal lengths $f, f'$. Other constant distances can be precalibrated. The image coordinates $(x, y), (x', y')$ can be measured. Therefore, the position of any object point $P\ (X, Y, Z)$ relative to the shoulder reference system can be calculated at any time. In real systems, considering possible mechanical deformations or imprecisions and system noises, we would need appropriate calibrations with or without control information. A follow-up paper [Pan and Zhang, 2002] provides more details on the geometric structure of Photogrammetron-I and the system calibration.

## 6. AN AGENT ARCHITECTURE OF PHOTOGRAMMETRON

Given an object space under surveillance, it is general enough to assume that this space is bounded by a cubic defined by a ground area of rectangle shape with a maximum height of all possible moving targets. The surveillance area can be presurveyed and thus is assumed to be known to the system before the system starts operating. Possible targets can be humans, animals, or vehicles. Targets may move into, inside, or out of the surveillance area. The primary tasks of Photogrammetron for a surveillance application include: (1) to report when one or more targets move into or out of the area; (2) to track one or more targets moving in the area; (3) to recognize targets; (4) to reconstruct the shape of targets; (5) to recognize the behaviours of targets; (6) to assess the intention of targets; (7) to assess the situation and (8) to remind the supervisor in case certain threats appear and certain actions should be taken.

Inherently the kernel software architecture of Photogramemtron is BDI where B denotes the belief about the surveillance area and space and the system's own status, D denotes the system's desires including the assigned or predefined surveillance tasks or duties and the system's internal motives for maintaining the system's own survival and comfort, I denotes intentions which are prioritized selected desires for which the system has committed resources for realization. The video imagery taken through the cameras motivates the system to react and to act according to the intentions or hard-wired low-level reflections. Fig.2 shows a basic vision-driven reactive BDI agent architecture for Photogrammetron. Photogrammetron has a general architecture of intelligent agents with emphases on visual perception, knowledge and beliefs about the scene; and it has particular photogrammetric missions to accomplish.

Furthermore, it has a physical structure to control, involving the left and right camera and pan-tilt unit, the stereo camera plate, and the head. Photogrammetron takes the BDI architecture as the main framework for modeling logical behaviors, and the Belief and Decision Networks (BDN) as complementary for modeling probabilistic behaviors.

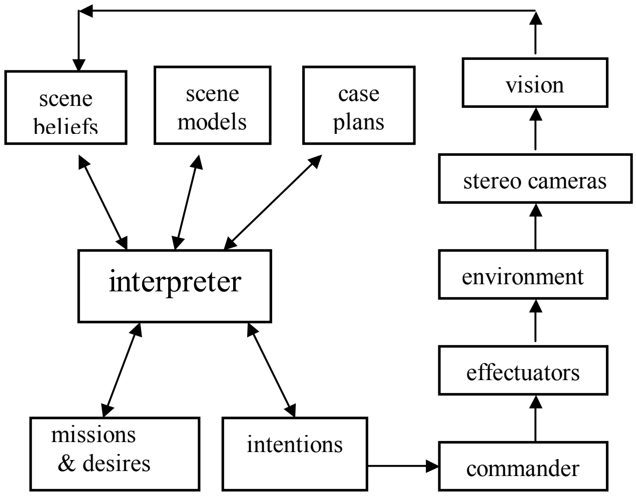


Fig. 2 A reactive BDI agent architecture of Photogrammetron

The main components of this architecture are defined as follows:

(1) Vision or visual processing: the real-time image sequences obtained through the left and right cameras are going through basic image processing and visual information processing, such as feature point extraction and tracking, relative orientation, image matching; the geometrical and matching relations are then established, which provides a geometrical basis for later 3D reconstruction, object tracking and recognition tasks.
(2) Scene beliefs: the visual information extracted from the visual processing component updates the current beliefs of the agent about the scene. The beliefs may take the form of updated maps or new descriptions of the scenes.
(3) Scene models: the knowledge about the scene or scene types are long-term and often generic information, which mainly takes the form of geometric models and descriptive associations.
(4) Case plans: To various possible cases or scenarios of the scene or environment, the system should have corresponding plans. These plans may involve the control of cameras and mechanical parts of the system, such as transition of the focus of interest, change of the system modes such as stereo versus non-stereo mode, etc.
(5) Missions and desires: Photogrammetron is not arbitrary robot or agent, but it must accomplish the photogrammetric tasks assigned by its supervisor. However, missions are not the only content of desires, other desires may be generated by the system maintenance.
(6) Intentions: missions and other desires are going through priority ordering or selection through a mechanism of commitment involving many constraints, which generates or updates lists of executable actions.
(7) Control mechanism: action lists will then drive the effectuators of the systems through command generation, such as the pan of the head, the tilt of the stereo cameras, the left-right pan of the left or right camera, stereo vergence and focusing, etc.

The system should not exhibit arbitrary behaviours, but instead it behaves in different modes and transits from a mode to another driven by events occurred in the surveillance area. In terms of the relative geometry between two cameras, we distinguish between stereo mode and non-stereo mode. In a weak stereo mode, two cameras are aligned so their principal axes are coplanar and converge forwardly. In a strong stereo mode, two principal image points converge on the same spot on the surface of a target or the background. In a non-stereo mode, two cameras can move independently. In terms of surveillance tasks, we distinguish between the default normal mode, image tracking mode and camera tracking mode. In the default normal mode, the system faces right to the surveillance area and two cameras are in a weak stereo mode such that the surveillance area is maximally covered in the images, no stereo coverage is strictly required at this mode. When one and only one target moves into the area, the system including two cameras will move physically so the target can be continuously tracked, and this corresponds to the camera tracking mode. In case multiple targets are moving into the area and they move in different directions, the system may not know which target to track physically, so the system will try to either stay still or to maintain a maximal coverage and each target may be tracked separately in the image spaces; this corresponds to the image tracking mode or a mixture of camera tracking and image tracking.

For each target class, either humans, animals, or vehicles, or other objects, geometrical surface models or parts models and behaviour models may need to be developed depending on the requirement of the surveillance tasks. At least for behaviour modeling, each class should be modeled as an agent. This opens new research areas to the future.

## 7. PHOTOGRAMMETRIC INFORMATION PROCESSING

The photogrammetric information processing in Photogrammetron comprises the following major components:

(1) Optical flow computing and object tracking: A basic functionality of Photogrammetron is to let each camera track objects of interest in motion. The image processing in the image space of a single camera for detecting and tracking motion vector fields of pixels before the stereo matching is so called optical flow computing, which is a basic approach for detecting objects in motion. Through optical flow computing, the system can realize simple loops of pure image processing and system control in order to perform motion object tracking.

(2) Stereo focus of attention, gaze and vergence control: The very first issue of Photogrammetron as an active vision system is how to establish and maintain the stereo focus of attention so that the stereo cameras can look at the same spot on the object surfaces, and translate with the gaze and vergence maintained together. A basic approach to achieve this is the dynamic matching of relatively small neighborhoods of the two principal points while feeding back the corrections for gaze and vergence control.

(3) Stereo camera calibration and general relative orientation: Photogrammetron as an engineering design, we assume the internal parameters such as the rotation angles, focal lengths, and other freedoms can be read out from the

system control mechanisms. These read values are treated as approximation to the true values of the parameters. If control points are available in the environment and can be tracked in the image domains, the exact values of parameters can always be estimated in real-time using the geometrical principles of photogrammetry. However, if no control information is available, only general relative orientation of maximally 7 parameters can be determined. In particular [Pan, 1999] discovered a direct closed-form solution to the problem of general relative orientation which is defined as an extension of the traditional photogrammetric relative orientation of 5 parameters with two additional focal lengths from pure image measurement.

(4) Stereo image matching and maintenance: To the problem of stereo motion image matching, matching the first stereo image pair consumes significantly more computing resources relative to the later image pairs whose matching can be much simplified through the exploitation of the time continuity and information redundancy of stereo image sequences. The stereo hardware setup of Photogrammetron provides instant relative geometry of the stereo images, so the matching of stereo image pairs can be simplified substantially.

(5) Structure and motion from stereo image sequences: A research path in computer vision in the last decades has shown that in orthogonal or paraperspective projections, the motion of the camera and the structure of objects can be solved out through a near perfect factorization from matched image points through an image sequence. However for strict perspective projections, such a factorization is not yet discovered or may not exist at all. A viable approach could be through a bundle adjustment, which however has to be adapted to the sequential nature of motion stereo image sequences.

(6) Multi-object tracking and recognition: Tracking, real-time measurement and recognition of multiple objects or targets is a relatively new problem in photogrammetry and computer vision. This involves not only theoretical challenges but also engineering and implementational difficulties. Previously multi-target tracking has been studied mainly in radar signal and information processing. However, in radar imagery, targets often appear as simple patches with no complicated visible structures, so the tracking algorithms can be simple. But in visual imagery taken by optical cameras, objects appear with clear and complete visible shapes and structures, such that recognition and tracking algorithms can hardly be simple and must require much more computing power.

## 8. CONCLUSIONS

This paper has taken the very first step in developing a theory of intelligent photogrammetry and Photogrammetron. The tenet of such a basic theory is that as a nonlinear process, the automation of photogrammetry can only be realized through an automatic and autonomous agent system; this system integrated the imaging process and later photogrammetric information processing into an infinite nonlinear loop, so the complexity of photogrammetric information processing can be greatly reduced to a manageable level. The minimal set of freedoms of Photogrammetron-I includes totally 7 parameters: the pan angle of the head relative to the shoulder, the tilt angle of the stereo camera plate relative to the head, the variable baseline length, the left and right camera vergence angles and focal lengths. Photogrammetron has a BDI agent architecture complemented by BDN's. Much of the computational theories and algorithms will benefit from the development in active vision, motion vision and multi-target tracking. The basic theory of intelligent photogrammetry and Photogrammetron provides new possibilities and directions for photogrammetry research, and will extend the application of photogrammetry to controlled video surveillance, intelligent close-range photogrammetry as well as realtime aerial and terrestrial photogrammetry.


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## REFERENCES


Aloimonos J.Y., Weiss I. and Bandopadhay A., 1987. Active vision. *International Journal of Computer Vision*, 333-356.

Bratman M.E., Israel D.J., and Pollack M.E., 1988: Plans and resource-bounded practical reasoning. *Computational Intelligence*, 4:349-355.

Dold J., 1998. The role of a digital intelligent camera in automating industrial photogrammetry. *Photogrammetric Record*, 16(92):199-212.

Fraser C.S., 1998. Some thoughts on the emergence of digital close-range photogrammetry. *Photogrammetric Record*, 16(91):37-50.

Gruen A., 1994. Digital close-range photogrammetry: progress through automation. *International Archives of Photogrammetry and Remote Sensing*, 30(5):122-135.

Pan H.P., 2002. Concepts and initial design of intelligent Photogrammetron. *Journal of Surveying and Mapping* (in Chinese), Beijing (accepted).

Pan H.P. and Zhang C.S., 2002. System calibration of intelligent Photogrammetron. *International Archives of Photogrammetry and Remote Sensing*, Vol. IIIIV, Commission 2, August.

Pan H.P., 1999. A direct-closed form solution to general relative orientation of two stereo views. *Digital Signal Processing*, 9(12).

Rao A.S. and Georgeff M., 1998. Decision procedures of BDI logics. *Journal of Logic and Computation*, 8(3):293-344.