Recording Indoor Scenes using a Rotating Camera with Linear CCD-Array

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ABSTRACT

This paper presents a method for intelligent recording the texture of an enclosed space such as a room in a building, a hallway or a courtyard in a city block using a rotating CCD line. The main objective is the design of a sensor platform to record the photorealistic texture automatically. Such a sensor platform with their main components will be shown. The introduced imaging system forms the basis for new methods and techniques to create three-dimensional and textured databasis of enclosed spaces in a semi-automatic manner. Design and implementation are described in detail, and the first results will be shown.

KURZFASSUNG

Diese Veröffentlichung stellt eine neue Methode zur intelligenten Erfassung von Innenräumen, z.B. Raum bzw. Gang in einem Gebäude, Innenhof eines Häuserblocks in einer Stadt, usw., dar. Dazu beschreiten wir einen neuen Weg bei der Bilddatengewinnung. Diese erfolgt anhand einer rotierenden CCD Zeile. Das Hauptaugenmerk liegt dabei im Entwurf und der Realisierung eines Kamerasystems, anhand welchem die Fototextur eines Innenraumes auf (semi-)automatischen Weg erfaßt werden kann. Das Kamerasystem und deren Hauptkomponenten werden hier vorgestellt. Dieses Aufnahmesystem bildet die Basis für neue Methoden und Techniken zur fotorealistischen Modellierung realer architektonischer Objekte. Der Entwurf und die Implementation dieses Aufnahmesystems werden beschrieben und die ersten Ergebnisse werden gezeigt.

1 INTRODUCTION

In the last years powerful computer graphics hardware and software were developed. This enables users in a wide range of applications to gain better insight into processes by visual simulation. For instance landscape and city planners as well as tourism agencies are interested to simulate photo-realistic views of the environment. Architects and city planners for example construct new buildings with CAD systems and are interested to visualize their impact onto the existing enviroment beforehand. To reach real realism, it is necessary to place the buildings, to be reconstructed, inside a 3D reconstruction of the real environment. It is therefore necessary to reconstruct the existing environment as a 3D model of the real scene with as little effort as possible [*Durisch, 1992*].

Further more surveying methods based on imaging sensors are used in many applications in Machine Vision, Robotics, Industrial Metrology and Computer Vision. Although there is great interest in surveying and documenting the cultural heritage [*Waldhäusl, 1992*], modern image acquisition methods and analysis techniques are rarely used, mostly for reasons of cost and complexity. Of interest is the creation of 3D computer models of existing objects, both with their geometry and surface properties [*Leberl et al., 1994*].

Advances are needed to develop automated measurement routines that are specific for the application and related to CAD databases. This includes a concept for intelligent imaging. A first step is the development of a sensor platform to record the photorealistic texture automatically. We focus on a platform for recording the texture of an enclosed space such as a room in a building, a hallway or a courtyard in a city block. Design, implementation and results of this specific electronic imaging system will be described in this paper. Its application to the modelling of closed spaces will be discussed.

2 RELATED WORK

Much work has been done in the surveying and documentation of historic buildings. Very precise geometric measurements of such man made structures are performed in close range photogrammetry. The tool to obtain such precise 3D measurement is usually a bundle block adjustment, where many photographs of the object are taken from different view points and selected image features together with some prior measured 3D object coordinates are evaluated. For this procedure a high degree of manual interaction is still needed [*Streilein et al., 1992*], [*Wester-Ebbinghaus, 1978*].

Creating photorealistic textured models of a city block [*Gruber, Meissl, Böhm, 1995*] and of a historic site [*Gruber, Sammer, 1995*] was performed manually and based on traditional perspective camera photography.

Till now no further works on the topic of indoor room recording and reconstruction were found in the literature study.

3 PRINCIPLES OF ELECTRONIC IMAGING SYSTEMS

Digital photographs can be conventionally acquired with film-based cameras and subsequent digitization. Or electro-optical cameras combined with solid-state sensors (see figure 1).
Close range photogrammetry seems to increasingly employ electro-optical tools [*Wester-Ebbinghaus, 1984*], [*Grün et al., 1993, 1995*]. A variety of solid-state imaging systems, from inexpensive camcorders to specialized systems with high-resolution sensors usually at a maximum 2000x2000 pixels are commercially available [*Luhmann, 1992*]. One technique to increase the resolution of such a commercial sensor is to move it in the image plane. Only static objects can be recorded, since the image is being acquired sequentially from several partial images. Essentially there exist micro-scanning cameras which offer a resolution from 2300x3000 pixels [*Lenz et al., 1990*] to 4500x3000 pixels [*Richter et al., 1992*]. With macro-scanning the sensors are moved in multiples of the sensor size, which results in a larger image format. Merging of the partial images into a seamless image arranges by precise mechanical equipment [*Poitz, 1992*] or with a réseau [*Riechmann, 1990*], [*Leberl et al., 1987*].
An alternative to the use of square array sensors is the use of linear CCD array sensors, that is being transported across the focal plane of an optical system. This is implemented in numerous commercial products.

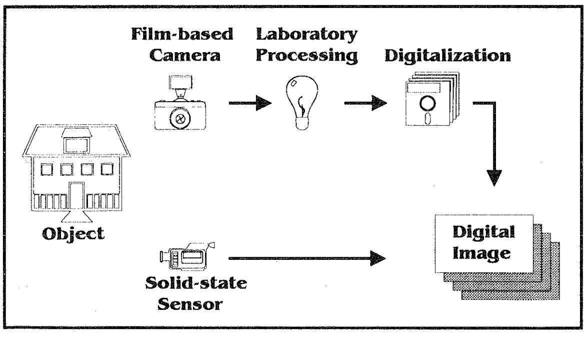

Figure 1: Two different methodes for generating digital images

4 CONCEPT AND IMPLEMENTATION OF A NEW „Indoor Room Imaging System“

Our attempt to reach a progress in the building of 3D models of a scene concentrates on two objectives:

- reducing the manual work in building 3D models
- increasing the level of detail in such 3D models

Therefore we need a new and intelligent recording strategie. A recording platform that acquires electronic images of a scene by scanning across it is necessary. From these image data we want to extract the geometry and the photo-realistic texture of the scene.
Area sensors which offer high geometric resolution, e.g. 1000x1000 pixels, are very expensive. Today tri-linear CCD arrays up to 8000 pixels each line are commercially available at a fair price. In order to design an imaging system, which offers a high geometric resolution without cost explosion, we decided to use a linear array sensor, a specific camera and a camera motion equipment.

4.1 Basic principle

We propose an electronic imaging system, that is based on a rotating camera with a linear array sensor. It is a macro-scanning camera, where merging of partial images into a seamless image is based on a precise camera movement. CCD lines are normally used in a linear motion to automatically acquire electronic images at a high resolution in close range photogrammetry. CCD based line scanning technology is already used in remote sensing [*Ebner et al., 1992*] [*Hofmann, 1986, 1988*] [*Wang et al., 1994*]. We differ from these ideas by using a rotational motion.

4.2 Image data representation

In our case the image data are acquired by sensor rotation. Thus we obtain a cylindrical projection. One advantage of a cylinder is that it can be easily unrolled into a simple planar map. The surface is without boundaries in the azimuth direction. One shortcoming of a projection on a finite cylindrical surface are the boundary conditions introduced at the top and bottom.

4.3 Acquiring cylindrical projections

A significant advantage of a cylindrical projection is the simplicity of acquisition. The only acquisition equipment required is a line camera and a tripod capable of continuous panning. Ideally, the camera's panning motion would be around the exact optical center of the camera lens system. In practice, in a scene where all objects are relatively far from the tripod's rotational center, a slight misalignment offset of 20 millimeter causes an error of about 0.025 pixel. Following from this example we see that it is not necessary to rotate the line camera exact around the optical center.
For convenience we define the sensor's local coordinate system (X',Y',Z') in the center of projection. The rotation of a CCD line around the center of projection can be summerized in the following mathematical model. A line camera with a focal length f rotates around the Z'-axis by the angle α. A point P=(x,y,z) in the object space (figure 2) is then mapped to the position z_{ccd} in the CCD line according to the equations:

$$\alpha = \operatorname{atn}(y'/x') \qquad (1)$$

$$z_{ccd} = z \cdot f / \sqrt{x'^2 + y'^2} \qquad (2)$$

From these two equations we see that one image coordinate is represented by the rotation angle of the line camera and the other by the perspective view along the CCD line.

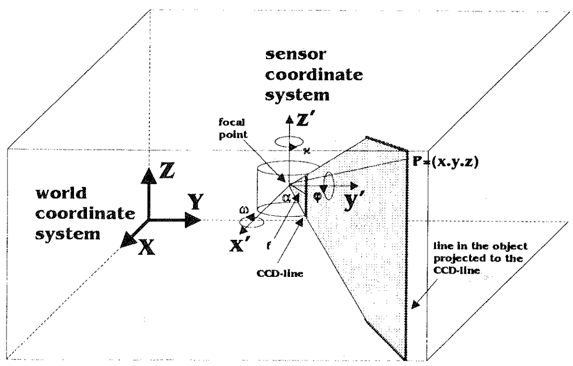

Figure 2: Principal recording configuration using a CCD line

4.4 Data acquisition of enclosed spaces

As seen in figure 2 the panning line camera is placed at a determined point inside a closed space, typically a room. During operation scan-lines are captured sequentially at predefined angular increments. These increments are defined in order to achieve the same horizontal and vertical angular view of each pixel. So the captured images consist of a sequence of quadratic pixels. Each pixel corresponds to an instantaneous 'angle of view'. A 360° image sweep, known as panoramic images in the literature, can be acquired with such a setup.

In order to scan a wide field of view expensive lens systems to avoid optical distorsion are necessary. To keep the costs of such an imaging system low we decided to use a cheep standard lens. The resulting disadvantage is a narrow field of view of the imaging system. We overcome this by arranging a tilt of the scan axis.

To solve the problem of occlusions considerations to a suitable choice of the recording locations are necessary. Further more, for calculating the 3D object coordinates from the image coordinates we need stereoscopic images. Therefore one main objective is to get a stereo image pairs of the whole scene by using a minimum of recording locations. Considerations for finding the optimal recording locations depends on the complexity of the scene to be reconstructed.

4.5 Requirements

The implemented electronic imaging system has to meet the following requirements:

- 5 mm geometric resolution at a distance to the object of 10 m;
- 0,03° accuracy of the mechanical motion equipment;
- 360° total angle-of-view;
- variable time of exposure for experimentation purposes (electronic shutter);
- on-line real-time data storage;
- high radiometric properties;
- high mobility of the recording system;

With the Eastman Kodak KLI-6003 Linear CCD Image Sensor it is possible to satisfy the radiometric and geometric requirements. One line consists of 6000 pixels each 12µmx12µm wide. Thus the active length of the CCD-line is 6000x12µm=72mm. This sensor is the heart of our experimental recording platform. With our experimental equipment experiments on acquiring electronic images with different geometric resolutions can be done. We do this by summing up neigbourhood pixels to one pixel. In our case one object pixel is formed by two CCD pixels. The selected lens has a focal length of f=80mm. With an average object distance of g=10m we can verify that:

The geometric resolution $Y = \frac{g}{f} \cdot y$ is

$$\frac{10000\text{mm}}{80\text{mm}} \cdot 0.012\text{mm} \cdot 2 = 3\text{mm};$$

The width of the recording swath is

$$3000\text{x}3\text{mm} = 9\text{m};$$

The amount of data per image line is

$$3000 \frac{\text{pixel}}{\text{line}} \cdot 3 \frac{\text{colors}}{\text{pixel}} \cdot 8 \frac{\text{bit}}{\text{color}} \cdot \frac{\text{byte}}{8\text{bit}} = 9 \frac{\text{kbyte}}{\text{line}};$$

The angle increment for one object pixel is

$$\arctan \frac{3\text{mm}}{10000\text{mm}} = 0.017°;$$

Thus one 360° image swath consists off

$$\frac{360°}{0.017°} \cdot 9\text{kbyte} = 188.496\text{Mbyte};$$

4.6 Implementation

The implemented hardware, shown as block diagram in figure 3, consists of the four main components.

(a) Scanning unit

A tri-linear RGB-color sensor (Red-Green-Blue) of 6000 pixels each line is the heart of the implemented experimental scanning camera. A low cost lens with a focal length of 80 mm is currently being used. The interface for data acqusition is the KLI-6003EB-2 evaluation board [*Kodak, 1992*] designed to drive the Eastman Kodak KLI-6003 CCD line. This board supplies three analogous signals (red, green, blue) of the occured intensity along the CCD line.

(b) Motion unit

A turn-around table driven by a stepping motor (0.9°/step) over a gear (1:162) is responsible for accurately sweeping the line camera across the scene. With this mechanical motion equipment we reach a minimal angle increment of 0.9°/162=0.0056°.

The instructions to control the motion platform are supplied by the serial board of the computing unit. Image capture and line camera motion are synchronized by the 'Timing-Generator' [*Ebben, 1992*], which is also a part of the computing unit.

(c) Computing unit

The two main tasks of this unit are the control of the overall system and image storage. These are managed by the central processing unit which currently is a Pentium 90 processor.

The 'Timing-Generator', responsible for synchronization and support of the linear CCD-array with the necessary timing signals, is designed as a PC-interface board. The analog data signals, sequentially read out from the CCD-line, are converted to the corresponding digital words by the ADC PC-interface board. Thus, every pixel is represented as a 24-bit digital value (8-bit per color) which is stored in the standard PPM-format on the disk for further processing. During the recording time the image captured is shown on a 17" color monitor.

(d) Supply unit

This unit supports the scanning, motion and computing unit with electrical power.

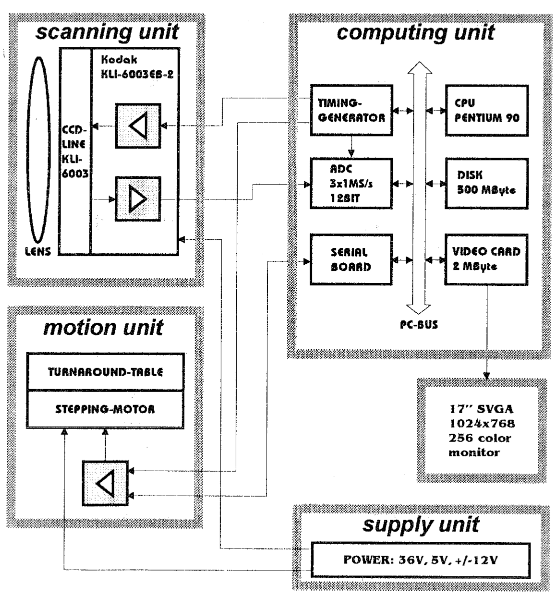

Figure 3: Block diagram of the indoor room imaging system

A picture of our implemented experimental recording platform is shown in figure 4.

5 RESULTS

This paper presents a status report of a project to build an automated indoor imaging and modeling system. We introduced a new electronic imaging system. The innovation of this system is the line sensor of high geometric resolution and the image acquisition by rotating this sensor. The costs of a line sensor are quite low in relation to an area sensor offering the same geometric resolution. Further more, line sensors with up to 8000 pixels are commercially available.

Our experimental electronic imaging system is functional and initial experiments have begun to scan indoor scenes across an angle of 360° with high geometric resolution. Of course, given proper focoussing, we can generate panoramic images of outdoor scenes as well. Figure 5 represents two 180° indoor sweeps from different recording locations. No geometric nor radiometric corrections were applied to these electronic images. One problem is the camera focusing when the object distance varies in a wide range. This can be seen in figure 5.

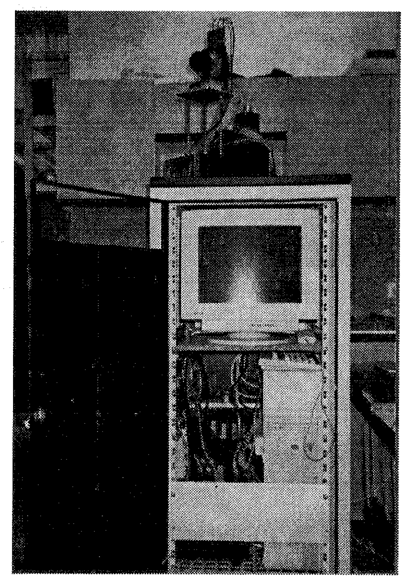

Figure 4: Experimental recording platform for indoor room image acquisition

6 FURTHER PLANS AND OUTLOOK

Intrinsic and extrinsic parameters of the imaging system must be calibrated, resulting in investigations of the accuracy of this imaging system. The next step is then to create algorithms to reconstruct the geometry of indoor scenes. This will be accomplished using knowledge about straight lines, planes, perpendicular angles etc. and using stereo images. Finally the geometry of models will be augmented by photographic textures to support a computerized virtual environment.

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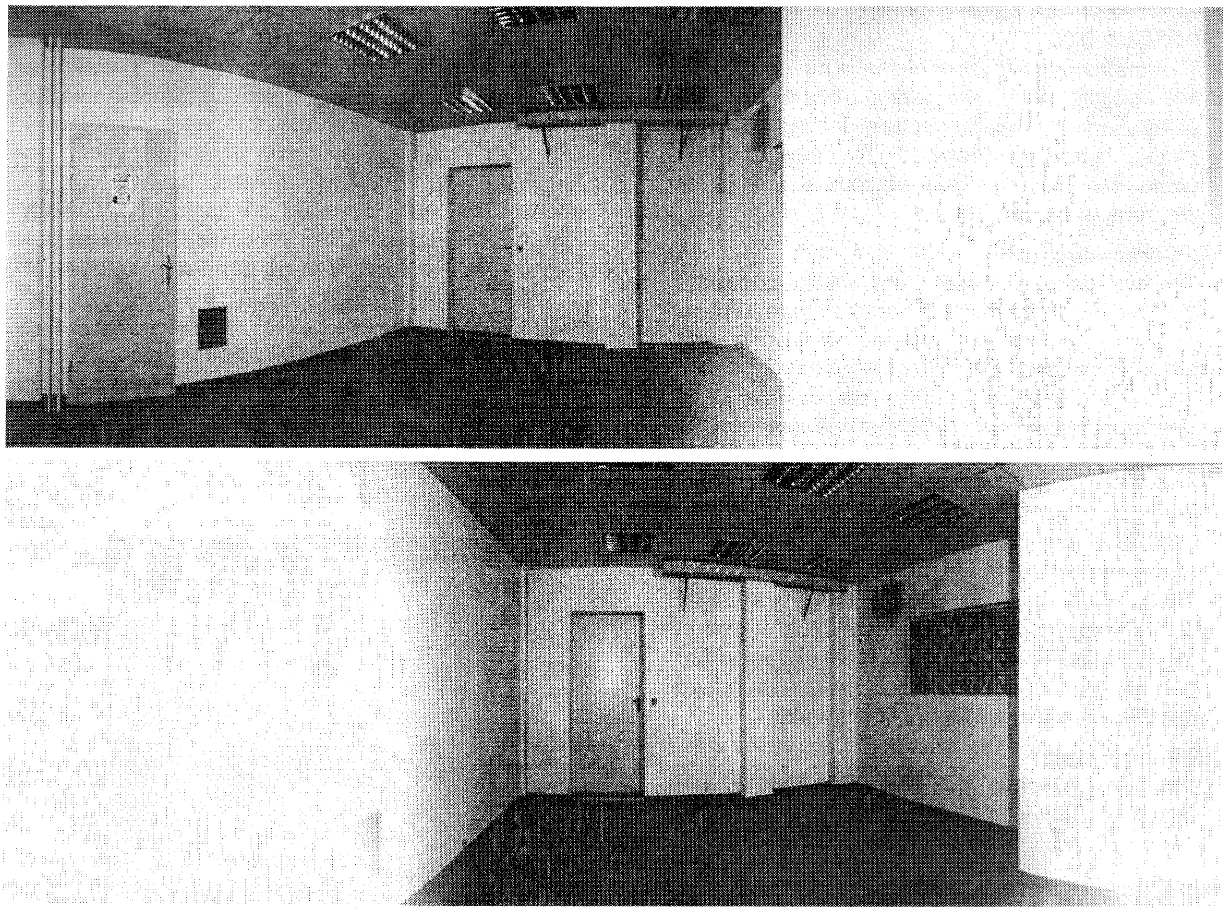

Figure 5: 180° indoor image sweep aquired with a rotating CCD-line, producing 3000 pixels vertically and 8000 pixels horizontally. Each pixel represents an instantaneous angle of view of 0,02°.

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