A STEREO LINE SENSOR SYSTEM TO HIGH SPEED CAPTURING OF SURFACES IN COLOR AND 3D SHAPE

Trendafil Ilchev[1], Erik Lilienblum[3], Bernd Joedicke[2], Bernd Michaelis[3] and Markus Schnitzlein[1]
[1] Chromasens GmbH, Max-Stromeyer-Straße 116, 78467 Konstanz, Germany
[2] Hochschule Konstanz, University of Applied Sciences, Brauneggerstr. 55, 78462 Konstanz, Germany
[3] Otto von Guericke University Magdeburg, Institute for Elektronics, Signalprocessing and Communications (IESK,) Chair Technical Computer Science, PO Box 4120, 39016 Magdeburg, Germany

Keywords: Stereo Vision, Line Scan Camera, 3D Measuring Technology, Color.

Abstract: Line scan cameras offer very high spatial resolution, allowing even multispectral color acquisition and are therefore often used for quality control at the conveyor belt. A logical extension is to complement the broad spectrum of the missing channel depth data. For industrial use, the technology combines the advantages of customized cameras with proven 3D evaluation methods which are known from 3D-matrix camera systems. The present system allows the rapid and simultaneous detection of color and 3D depth with small random errors, preferably relatively flat (not fissured) surfaces. Standard deviation of 10 microns could already be realized in practice. Color and 3D data are from the same measurement system and are in exactly the same coordinate system. This can be a significant advantage in quality assurance, such as testing manufactured goods to a good match of form and texture. The use of massively parallel hardware (GPUs) currently allow performance of approximately 100 million disparity values per second.

1 INTRODUCTION

Procedures for non-contact optical surface measurement of three-dimensional objects are becoming increasingly important. There exists a wide range of applications to detect the surface shape and detection of surface defects, which is covered by a variety of different methods (Nalpantidis, Sirakoulis and Gasteratos, 2007). Important system parameters, especially for applications in industrial manufacturing process are the speed and resolution of the 3D survey in relation to the size of the surface to be detected. In this regard, the established measurement methods based on matrix cameras often cannot meet the relevant system requirements.

By using line sensors we propose a new method to increase significantly the speed and resolution of the optical and 3D measurement for special applications. The hardware for image acquisition essentially consists of two coplanar oriented tree linear line scan cameras, which generate a continuous stream of stereo RGB color lines. The system is based on a stereoscopic recording of the original surface. Based on texture, the two images are correlated and the corresponding altitude information is captured (Figure 1). The altitude measurement precision is in the region of 1/5-1/10 of the object pixel. The software calculates a colored 3D surface reconstruction with high spatial resolution. The algorithm for computing the colored 3D point cloud is implemented in CUDA and runs in real time on multiple GPUs simultaneous with the image acquisition (Calow and Ilchev, 2010).

2 DEMO SETUP

The new approach was first successfully tested by simulations. On this basis a real stereo line-scan camera is designed and realized as a demonstrator of the technology. The camera on the top of the demo setup (Figure 2) works like a scanner. The objects to measure are placed on a height adjustable stage underneath the camera. The linear unit moves the stage forward and the camera acquires the images during the movement.

Based on the acquired images the calculation of the 3D object surface is carried out. The result of the

Ilchev T., Lilienblum E., Joedicke B., Michaelis B. and Schnitzlein M..
A STEREO LINE SENSOR SYSTEM TO HIGH SPEED CAPTURING OF SURFACES IN COLOR AND 3D SHAPE.
DOI: 10.5220/0003941508090812
In *Proceedings of the International Conference on Computer Graphics Theory and Applications* (IVAPP-2012), pages 809-812
ISBN: 978-989-8565-02-0

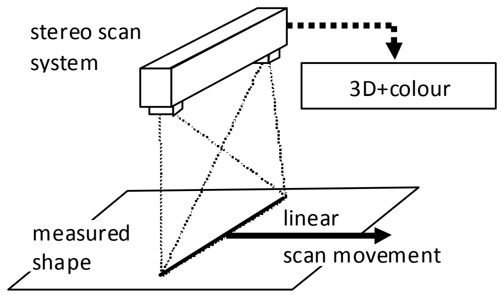

Figure 1: Schematic diagram of the overall scan system.

3D calculation is shown as a texture images, depth map in false color and as a 3D view (Figure 4). The 3D data and the color images can be saved for further processing. This demo setup may be used as well for real application. Table 1 summarizes the data with a potential application of this camera.

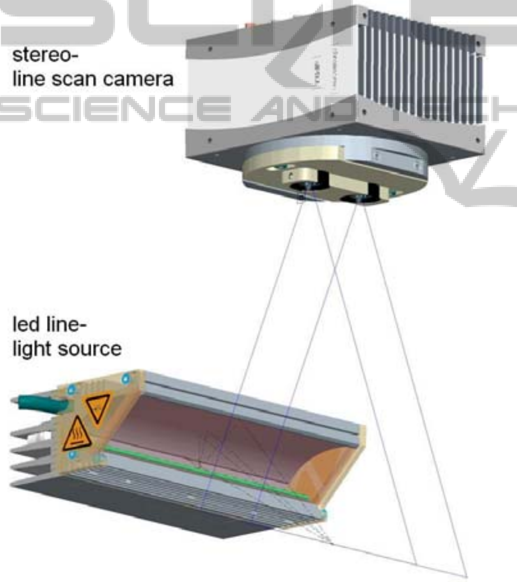

Figure 2: CAD model of the image acquisition stereo system.

Table 1: Example of an application.

Features	Example of an application
Scan width	150 mm
Scan range	continuous
Scan speed	up to 1,38 m/s (22000 lines/s)
Height range	10 mm
Resolution lateral	0.063mm
Resolution axial	0.020 mm
Color	24 bit (RGB)
Duration of image acquisition and 3D calculation	continuous
Performance of the 3D computation	approximately 100 million disparity/s

3 DESCRIPTION OF THE WORK

The establishment, adjustment and calibration of the measuring system is done offline. Targets can then be measured online, keeping pace with the movement. The image data of the trilinear color line scan cameras are first rectified, correcting the color channels red, green and blue, so that they lie exactly above one another in both camera images. Corresponding points between the camera images are provided in a picture line (epipolar constraint). The resulting image is buffered for later texturing of the 3D surface. Subsequently, the pixel by pixel mean values of red, green and blue channels are calculated to obtain a rectified gray-scale image with a lower temporal noise for each camera.

The rectified greyscale images serve as the basis for the ensuing correlation method for searching corresponding points. The displacement of the corresponding points will be delivered in the form of a disparity map. It is approximately inversely proportional to the distance of the object point to the camera system. The disparity maps contain either the measured disparity or an appropriate error status, if no disparity was found for a given pixel position. The previously buffered color image and the disparity maps are positioned accurately over one another. For many applications, such a disparity or depth map is already sufficient. From the disparity maps a textured 3D point cloud can be calculated and presented in an OpenGL window from different views. The whole procedure is implemented using ring buffers, allowing streaming mode, e.g. a continuous processing. The search for corresponding image points (disparity calculation) and the 3-point calculation of the depth maps is done in blocks and parallel on currently available graphics cards (GTX285 or GTX485). The code was created in the CUDA development environment. CUDA SDK allows to program in C-like programming style. However, certain conditions must be considered so that the code can be efficiently executed on the GPU (Calow and Ilchev, 2010).

4 CAMERA MODEL AND CALIBRATION

For the recording the color information a trilinear line sensors are used. A standard matrix camera model was used for the modelling of each line scan camera. Only the three middle lines from the matrix camera model (corresponding to the three color channels red, green and blue) were used for the calculations. The relative position of both cameras to each other is assumed to be constant during the measurement. The movement of the whole camera head is represented by a 4x4 homogeneous transformation matrix for each line. A linear model to calculate the motion of the 4x4 transformation matrix of each image line is used for the application of the camera head combined with a linear unit.

This approach allows great flexibility, both in describing the optical properties of the cameras as well as in modelling the trajectories of the camera head. On the other hand it gives rise to two new problems. The calculation of the projection of a point in space in the line scan camera system (function "World2Pix") is complicated. Secondly, the number of camera parameters is comparatively high and the determination in the part of a calibration is possible only under the assumption of additional boundary conditions. A precise calculation of each individual camera parameter is not required in practice, if consistency of all parameters of the whole system can be achieved. One possible strategy, for example, is not to introduce all parameters simultaneously into the equation system, but gradually, respectively alternately.

The calibration is done by recording an optimized calibration body from several directions. Twenty-eight-coded circuit marks are printed on the calibration chart. Three of them are positioned on a raised stamp. The hierarchical search for the circle marks starts in a lower resolution. After finding the brand position of the marks, the precise re-measurement is performing with original resolution. (0.02 pixels accuracy possible). The search is performed separately in each color channel, because in a trilinear line camera, the color channels do not overlap. Thus a much larger number of observations can be generated. From those measurements we determine the parameters of interior and exterior orientation of the cameras and some parameters of the movement of the camera head by linearization (numerical differentials) and compensation calculation iteratively. Good initial values are necessary for determining the system parameters, which can be extracted from the CAD data (Calow and Ilchev, 2010).

5 CORRELATION METHOD

The three lines of trilinear color line scan cameras record an object point in time one after the other, resulting in a misalignment between the three color channels of the raw images. This offset is visible as colored edges on light-dark transitions. The size of the offset depends on the ratio of speed to the line frequency. Given a known trajectory, the scan offset is calculable from the calibration data, and can be directly corrected by re-sampling of the three color channels. Thus re-sampling ensures that corresponding points between the left and right camera are almost in a row (rectification), so that the search for corresponding points in only one line (one dimension) must be done. In order to perform rectification efficiently, the necessary sample points are calculated using the offline calibration data, and are then pre-stored in tables. For noise reduction and a simultaneous reduction of the search effort for the correlation, only gray-scale images from the average of all three color channels are used. Due to very good experience in terms of accuracy, contrast and illumination invariance, the normalized cross-correlation coefficient (5.1) was used as similarity criterion (Calow and Ilchev, 2010).

$$k = \frac{\sum_{i=1}^{N}\left[(a_i - \bar{a})\cdot(b_i - \bar{b})\right]}{\sqrt{\sum_{i=1}^{N}(a_i - \bar{a})^2 \cdot \sum_{i=1}^{N}(b_i - \bar{b})^2}} \qquad (5.1)$$

N – Number of pixels of the image block to be compared

a_i, b_i- Gray values of one and the other camera image

$\bar{a}$, $\bar{b}$ – Mean values of one and the other camera image

For each pixel position of the maximum cross-correlation quotient the observed disparity on this position will be saved. The data is stored in a ring buffer, so that it can be accessed not only on the maximum correlation, but also on the correlation values of the previous and successor disparity. Correlation maximum from his predecessors and successors can help to achieve sub-pixel accuracy by fitting a parabola, if the surface gradients (relative to the receiving direction) are small (Mecke, 1999).

6 EXAMPLES

Some objects scanned with the measurement setup are shown below. The examples have enough texture so that the correlation of the stereo image provides a unique result. Initial investigations of the reproducibility, in a series of 20 measurements of a plane object, showed a standard deviation of less than 10 microns at a resolution of the optical system of 65 microns per pixel.

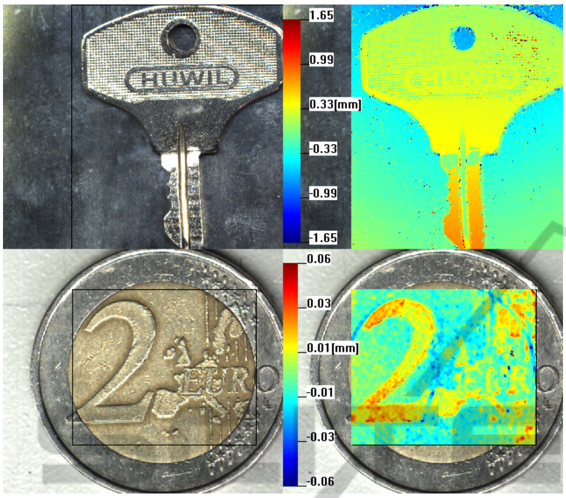

Figure 3: Examples of height differences, which can be resolved by the system.

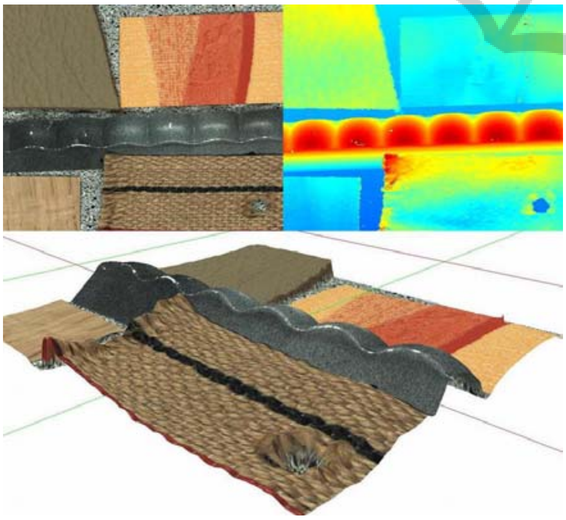

Figure 4: These examples show some materials (leather, synthetic material, wood, textiles, etc.) that can be measured with the method. In the last image is shown the merged result of texture and height data.

REFERENCES

Nalpantidis, L., Sirakoulis, G. C., Gasteratos, A., 2007. Review of Stereo Algorithms for 3D Vision. *International Symposium on Measurement and Control in Robotics. ISMCR.*

Calow, R., Ilchev, T., 2010. Schnelles Zeilensensorsystem zur gleichzeitigen Erfassung von Farbe und 3D-Form. In *Forum Bildverarbeitung, Hrsg. Karlsruhe: KIT Scientific Publishing*. P. 181–192.

Mecke, R., 1999. Grauwertbasierte Bewegungsschatzung in monokularen Bildsequenzen unter besonderer Beruecksichtigung bildspezischer Stoerungen. Dissertation, *Shaker Verlag GmbH*.