3D Discrepancy Check via Augmented Reality

Svenja Kahn* — Fraunhofer Institute for Computer Graphics Research

Harald Wuest† — Fraunhofer Institute for Computer Graphics Research

Didier Stricker‡ — German Research Center for Artificial Intelligence (DFKI) & University of Kaiserslautern

Dieter W. Fellner§ — Fraunhofer Institute for Computer Graphics Research & TU Darmstadt

Abstract

For many tasks like markerless model-based camera tracking it is essential that the 3D model of a scene accurately represents the real geometry of the scene. It is therefore very important to detect deviations between a 3D model and a scene. We present an innovative approach which is based on the insight that camera tracking can not only be used for Augmented Reality visualization but also to solve the correspondence problem between 3D measurements of a real scene and their corresponding positions in the 3D model. We combine a time-of-flight camera (which acquires depth images in real time) with a custom 2D camera (used for the camera tracking) and developed an analysis-by-synthesis approach to detect deviations between a scene and a 3D model of the scene.

Index Terms: I.2.10 [Artificial Intelligence]: Vision and Scene Understanding—3D/stereo scene analysis, Video analysis; I.3.m [Computer graphics]: Miscellaneous—Augmented Reality, Difference Visualization; I.4.8 [Image processing and computer vision]: Scene analysis—Range Data, Sensor fusion, Shape, Tracking;

1 Discrepancy Check with a Time-of-Flight Camera

Discrepancy checks between a 3D model and a scene are used to ensure that the 3D model accurately matches the real geometry. For many tasks like markerless model-based camera tracking, prototyping or construction planning it is important that the 3D model of a scene accurately represents the real geometry of the scene. It is therefore important to detect deviations between a 3D model and a scene. Up to now, there exists no approach which allows to move a camera freely in a scene and to automatically detect and visualize 3D differences in real-time with a dense 3D discrepancy check. Previous approaches for discrepancy check were mainly based on 2D camera images and thus 3D discrepancy checks were either not possible [3] or limited to single 3D points [6]. Bosché et al. [2] transformed the 3D data of a CAD model and 3D data measured with a time-of-flight camera into a common voxel occupancy grid but used a static camera position and thus did not need to solve the registration problem.

Time-of-flight cameras [4] acquire dense 3D measurements in real-time. The 3D discrepancy correspondence problem (that means, the information about which 3D measurement of a real scene corresponds to which position in the 3D model) was up to now unsolved for moving 3D data acquisition devices. We present a solution for this task which is based on estimating the position and orientation of a time-of-flight camera with camera tracking algorithms. By tracking the pose of a time-of-flight camera, a synthetic 3D image of the given 3D model can be created from the current point of view of the time-of-flight camera with an analysis-by-synthesis approach. By rendering a synthetic image of the 3D model from the current camera pose and calculating a synthetic 3D image from the depth buffer of the graphics card, the 3D measurements of the time-of-flight camera and the corresponding 3D positions in the 3D model can be compared efficiently and in real-time to detect 3D discrepancies. The detected 3D discrepancies are visualized by an Augmented Reality visualization which visually overlays the detected differences onto the current camera image in real time. The user can move the camera freely and is more flexible in difference detection tasks than in photo based approaches which are based on still 2D images.

*e-mail:svenja.kahn@igd.fraunhofer.de

†e-mail:harald.wuest@igd.fraunhofer.de

‡didier.stricker@dfki.de

§e-mail:d.fellner@gris.informatik.tu-darmstadt.de

2 Camera Pose Estimation

The intensity image of the time-of-flight camera has a low resolution (176x144) and thus the camera pose can only be estimated approximately with the time-of-flight camera itself. This limitation is overcome by the use of an additional higher resolution 2D camera for the tracking task with which the pose of both the 2D camera and the time-of-flight camera can be calculated robustly. The time-of-flight camera and the higher resolution 2D camera are rigidly coupled with a camera rig. The relative transformation $(\Delta R, \Delta t)$ between the two cameras was calculated with the calibration algorithm described in [5]. With the following equations the camera pose of the time-of-flight camera (R_{ToF}, t_{ToF}) is calculated from the pose (R_{Cam2D}, t_{Cam2D}) of the higher resolution 2D camera:

$$\begin{aligned} R_{ToF} &= R_{Cam2D} * \Delta R \\ t_{ToF} &= R_{Cam2D} * t_{Cam2D} + \Delta t \end{aligned} \quad (1)$$

The camera pose is initialized with a marker whose coordinates are specified in the coordinate system of the given 3D model. In order to allow camera movements beyond the parts of the environment in which a marker is visible, the 3D coordinates of tracked features are reconstructed online via Structure from Motion [1].

3 Difference Detection via Analysis-by-Synthesis

To compare the 3D data acquired by the time-of-flight camera and the 3D model the discrepancy between the 3D measurement and the corresponding 3D position in the 3D model is calculated for each pixel via analysis-by-synthesis: The 3D model is rendered from the current camera pose with the intrinsic and extrinsic parameters of the time-of-flight camera and a synthetic 3D image is calculated from the depth buffer of the graphics card.

A depth buffer stores the depth values in the range [0;1] which depend on the near and far clippling planes z_{near} and z_{far} used for the rendering. After mapping a depth buffer value $z_{DepthBuffer}$ to the range [-1;1] (z') it is converted to a depth value in the camera coordinate system (equation 2).

$$d_{cam} = \frac{-2 * z_{far} * z_{near}}{z'(z_{far} - z_{near}) - (z_{far} + z_{near})} \quad (2)$$

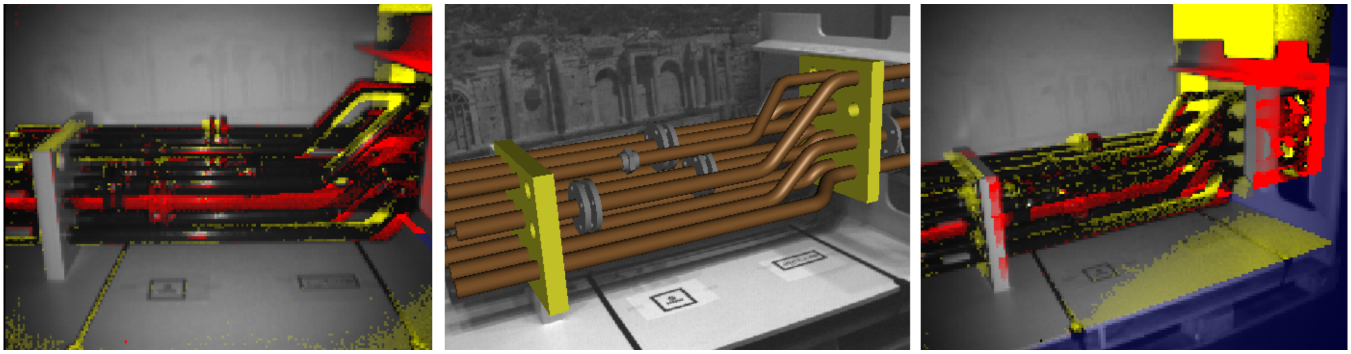

Figure 1: Center: One of the pipes is missing in the 3D model. Left and right: Color encoded visualization of the differences between the 3D model and the real scene.

Equation 3 transforms the depth value d_{cam} of a pixel (p_x, p_y) in the 2D image coordinate system to a 3D point $p_{CCS}(x,y,z)$ in the camera coordinate system.

$$p_{CCS}\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} (p_x - c_x) * \frac{1}{f_x} * d_{cam} \\ (p_y - c_y) * \frac{1}{f_y} * d_{cam} \\ d_{cam} \end{pmatrix} \quad (3)$$

For each pixel the euclidean distance is used to calculate the difference between the 3D value of the synthetic 3D image and the 3D measurement of the time-of-flight camera at the same pixel.

4 Visualization and Application

To visualize the discrepancies, the camera image is augmented with a semi-transparent RGBA image whose colors represent the 3D differences (see table 1). At red pixels the real scene is closer than its counterpart in the 3D model, at yellow pixels the real scene is farther away and blue pixels show parts of the scene which do not exist in the 3D model.

Table 1: Colors of the semi-transparent discrepancy image

	r	g	b	a
$z_r \neq 0$ *and* $z_s \neq 0$ *and* $z_s \geq z_r$	255	0	0	$alpha_{dist}$
$z_r \neq 0$ *and* $z_s \neq 0$ *and* $z_s < z_r$	255	255	0	$alpha_{dist}$
$z_r = 0$ *or* $z_s = 0$	0	0	255	$alpha_{noRef}$

To visualize the degree of the discrepancies between a 3D point (x_s, y_s, z_s) in the synthetic 3D image and the 3D point (x_r, y_r, z_r) at the corresponding pixel in the 3D image measured by the time of flight camera, the transparency of each pixel in the difference visualization image is set such that pixels visualizing close distances have a higher transparency than pixels at positions where there is a large discrepancy between the 3D model and the real measurements (see equation 4). The user can set the opacity factor o to change the transparency of the whole discrepancy visualization image.

$$alpha_{dist} = \sqrt{(x_r - x_s)^2 + (y_r - y_s)^2 + (z_r - z_s)^2} * o \quad (4)$$

We used the proposed approach in an industrial scenario to detect differences between a 3D model of several pipes and a built prototype of these pipes. One of the modelled pipes was removed from the 3D pipe model. Figure 1 shows that the missing pipe is easily detected and visualized with the proposed discrepancy calculation and visualization approach. When the camera is moved to the right, also other discrepancies become visible: The wooden part of the scene at the right through which the pipes pass is modelled differently than its real counterpart and the doorway in the back of the real scene is incorrectly modelled as a continuous plane.

5 Conclusion

The discrepancy check and AR visualization techniques presented in this paper extend the current state-of-the-art by the possibility to calculate and visualize 3D discrepancies between a 3D model and a scene for a moving camera. This lays the foundation for two new fields of research: On the one hand, how can the given 3D model be adapted automatically such that it corresponds to the real measurements? Secondly, future work (from a human factors point of view) will consist in developing and evaluating further 3D discrepancy visualization techniques.

Acknowledgements

This work has been performed within the research project AVILUS-plus (grant number 01IM08002) funded by the German Ministry of Education and Research (BMBF). The authors wish to thank Howaldtswerke-Deutsche Werft (HDW) for providing the pipes and the 3D model of the pipes.

References

[1] G. Bleser, H. Wuest, and D. Stricker. Online Camera Pose Estimation in Partially Known and Dynamic Scenes. In *ISMAR 2006: Proceedings of the Fifth IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 56–65, 2006.

[2] F. Bosché, J. Teizer, C. T. Haas, and C. H. Caldas. Integrating Data from 3D CAD and 3D Cameras for Real-Time Modeling. In *Proceedings of Joint International Conference on Computing and Decision Making in Civil and Building Engineering*, pages 37–46, 2006.

[3] P. Georgel, P. Schroeder, S. Benhimane, S. Hinterstoisser, M. Appel, and N. Navab. An Industrial Augmented Reality Solution for Discrepancy Check. In *ISMAR 2007: Proceedings of the 6th IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 1–4, 2007.

[4] T. Oggier, F. Lustenberger, and N. Blanc. Miniature 3D ToF Camera for Real-Time Imaging. In *Perception and Interactive Technologies*, pages 212–216, 2006.

[5] I. Schiller, C. Beder, and R. Koch. Calibration of a PMD-Camera Using a Planar Calibration Pattern Together with a Multi-Camera Setup. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, volume XXI. ISPRS Congress, pages 297–302, 2008.

[6] S. Webel, M. Becker, D. Stricker, and H. Wuest. Identifying Differences between CAD and Physical Mock-Ups Using AR. In *ISMAR 2007: Proceedings of the Sixth IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 281–282, 2007.