Plausibility-based approach to eliminate line-pattern indexing ambiguities

Svenja Ettl*,**, Florian Willomitzer**, Gerd Häusler**

*Max Planck Institute for the Science of Light, Erlangen

**Institute of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nuremberg

mailto:svenja.ettl@fau.de

Multi-line triangulation sensors suffer from line indexing ambiguities, when parts of the projected pattern are missing or show discontinuities. We present a solution which exploits context information. First results show a tenfold increase of data density with almost no remaining outliers.

1 Introduction

Single-shot multi-line triangulation, a common 3D measurement principle (see Fig. 1), suffers from line-indexing ambiguities. Ambiguity occurs when parts of the projected pattern are missing or show discontinuities. With a proper sensor geometry it is possible to avoid ambiguities by employing “regions of uniqueness” (RoUs), but only inside a restricted measurement volume [1]. More information has to be acquired to eliminate ambiguities reliably. One option is to add one or more cameras [2]. Another option is to exploit spatial and/or temporal context information.

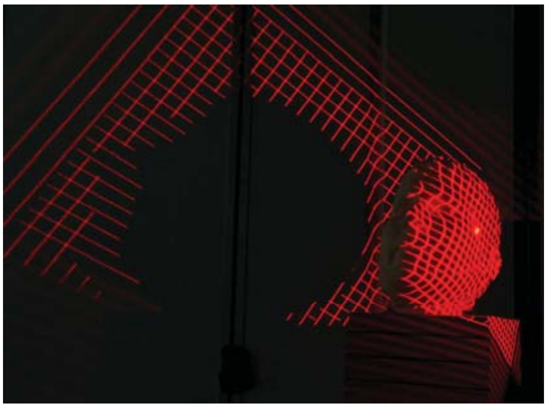

Fig. 1 *Projected pattern of a multi-line triangulation sensor (image: courtesy by MPL D. Ausserhofer).*

We present a novel indexing method which exploits plausibility information. The basic idea is to use a line pattern for which each n^{th} line (n>>1) is encoded and has a unique line index. These few lines are used to generate a sparse 3D model of the object. Based on this model, the remaining lines are successively indexed by performing an a posteriori plausibility check.

As an important consequence, the depth of the measurement volume can be extended and the number of projected lines can be increased. This is a further step towards a single-shot 3D camera. Experimental results demonstrate the potential of this novel method.

2 Problem motivation

Our long-term aim is a 3D movie camera. It should be easy to handle, motion-robust, with high lateral and longitudinal resolution, and of high 3D data density. Are we there yet? Although Flying Triangulation (FlyTri) sensors possess most of these properties, a high data density in each acquired single shot is still needed. Unfortunately, higher data density commonly is linked with outliers caused by incorrect line indexing (see Fig. 2).

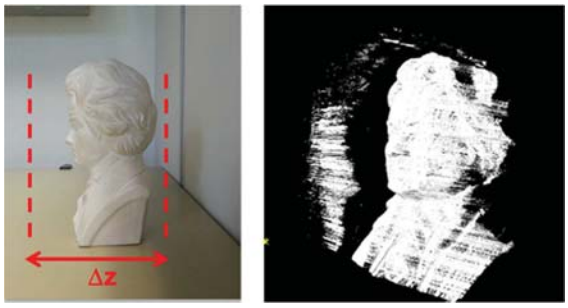

Fig. 2 *Incorrect indexing leads to outliers (wall data) if scene parts are measured outside the depth range* Δz*.*

If an object is measured entirely inside the measurement depth range Δz, incorrect indexing can be avoided by employing RoUs (see Fig. 3). In practice, however, it is inevitable to measure object parts outside this depth range.

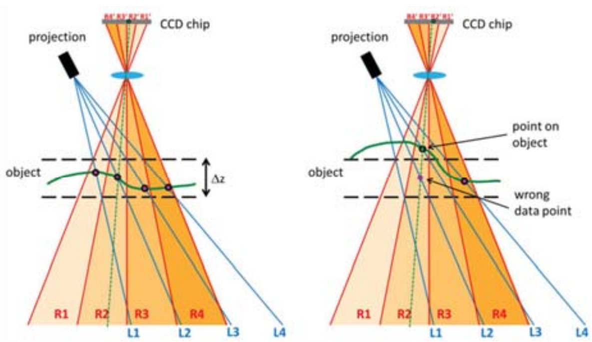

Fig. 3 *Incorrect indexing despite RoUs. An object measured inside the depth range* Δz *yields correct data (left) while object parts acquired outside* Δz *are observed in adjacent line regions which result in outliers (right).*

Although some outliers can be eliminated by post processing [3], this does not prove feasible for outliers close to or even mixing with correct 3D data. New methods are required.

Some applications only permit minimal hardware usage, because of space limitations, such as intraoral teeth measurements, or because of environmental conditions, such as MEG measurements. We will now present a novel solution for these circumstances which is based on algorithms.

3 Plausibility-based solution

The key idea is to use distinguishable principal (p-) and subsidiary (s-) lines, for example by spatial encoding of the p-lines only. Between two p-lines are several s-lines. The large distance between two p-lines yields a large depth range *p*-Δz, in which the lines are uniquely indexed. The s-lines are much narrower; hence their unique depth range *s*-Δz is much smaller and ambiguous indexing has to be resolved.

From a short sequence of exposures, a sparse 3D model is generated from p-lines. For each ray of vision, the intersection points with the s-lines are calculated, yielding “potential s-points” (see Fig. 4). From this point set, the 3D point with the highest density of sparse 3D p-model points close to it is selected yielding a complete, dense 3D model.

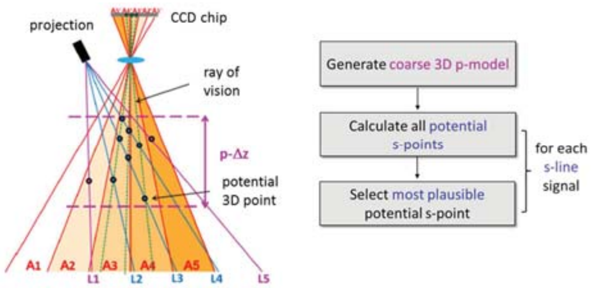

Fig. 4 *New indexing method. Left: Inside the depth range p-Δz, for each ray of vision all intersection points with projected s-lines are calculated. From this point set, correct 3D points are selected via plausibility considerations. Right: Work flow for novel method.*

4 Results

We simulated in Matlab the realistic acquisition with a multi-line triangulation sensor. The projected horizontal (vertical) pattern consists of 101 (111), i.e. 11 (12) principal and 90 (99) subsidiary, lines. At 11 sensor positions, 3D data are acquired with alternating pattern projections, resulting in about one million 3D points. The novel method is applied for index correction. The object and the results before and after correction are depicted in Fig. 5.

The simulation now allows an analysis of the corrected 3D model. Comparing the final 3D model with the perfect, original 3D data, we find that less than 0.35% are incorrectly indexed 3D points and less than 1.87% are points deleted based on the chosen threshold for the plausibility check.

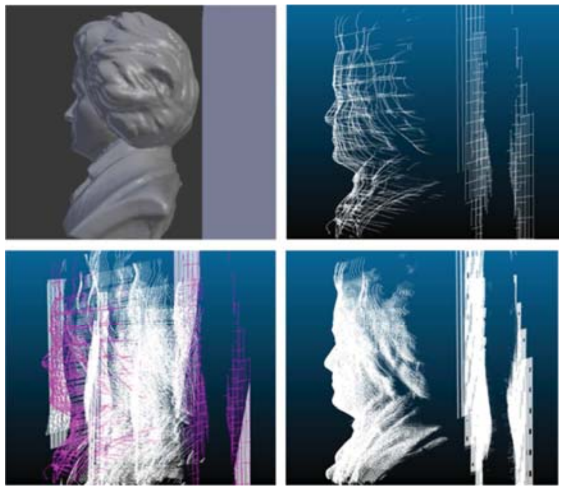

Fig. 5 *Result for simulated measurement. Top left: Object under test is a bust in front of a wall. Top right: Outlier-free sparse 3D model generated from principal lines. Bottom left: Complete measurement result, including correct data from principal lines (purple) and subsidiary line data with outliers (white). Bottom right: Final, dense 3D model after index correction.*

5 Summary and outlook

We presented a novel algorithmic solution to resolve indexing ambiguities. An advantage of the method is that it enables the acquisition of 3D data of high density in each single shot, while widely reducing outliers. Further, it allows for fast measurements of high resolution (along more than 90% of total lines). The method requires additional context information and generates the complete, dense 3D model only a posteriori, from a short sequence of FlyTri exposures.

Our next investigation will be to generate dense 3D data from two successive 3D views. We will correct the s-lines closest to p-lines, add the resulting 3D points to the p-lines, and continue with s-lines closest to this reference, until all lines are indexed.

References

[1] S. Ettl, O. Arold, Z. Yang and G. Häusler, "Flying Triangulation - an optical 3D sensor for the motion-robust acquisition of complex objects," Appl. Opt., vol. 51, pp. 281-289 (2012)

[2] F. Willomitzer, S. Ettl, G. Häusler, “Light-sectioning with many lines - how to settle the information deficit,” Proc. DGaO 2014, A22 (2014)

[3] S. Ettl, O. Arold, G. Häusler, I. Gurov, M. Volkov, “Optimized data processing for an optical 3D sensor based on Flying Triangulation,” AIP Conference Proceedings, 1537, pp. 60-67, 2013

[4] S. Ettl, “Introductory review on "Flying Triangulation"- a motion-robust optical 3D measurement principle”, accepted by Contemporary Physics, June 2014