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Time-Of-Flight technology applied in pedestrian movement detection

Minjie Chen [a,*], Günter Bärwolff [a], Hartmut Schwandt [a]

[a] *Institut für Mathematik, Technische Universität Berlin, Straße des 17. Juni 136, 10623 Berlin, Germany*

Abstract

We propose a new method based on the Time-Of-Flight (TOF) measuring technology for the automatic pedestrian trajectory extraction. We start with a new data structure called TOF-tree for the segmentation of the frames in a sequence of recordings. The tree structure enables an efficient calculation of the segmented objects (TOF-objects). While a real object (pedestrian etc.) in the scene is always associated with a set of connecting TOF-objects, combined TOF-objects can be matched with each other from frames in the sequence to reconstruct the trajectories of the moving objects in the original scene. The trajectory information of the pedestrians can be adapted for industrial usage, for example, automatic passenger counting in public transportation.

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Keywords: distance measurement; Time-Of-Flight; object detection; pedestrian movement; trajectory extraction

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1. Introduction

For the validation of pedestrian simulation tools real-world data are indispensable. In particular, trajectory information of pedestrians involved in the test environment is often sought after. In the current work we propose a new method based on the Time-Of-Flight (TOF) measuring technology (Schwarte et al. (1995); Spirig et al. (1995); Lange (2000)) for the automatic object detection and trajectory extraction. In this context, distance measurement is the very first step to undertake. Traditional laser-based methods of distance measurement requires precise measurement of light travel duration. In a short distance range, this is hard to achieve even by means of contemporary technology. In TOF, the phase shift $\Delta\phi$ of an amplitude-modulated light wave with frequency f plays a key role. Within a certain distance range $d < d_{\max}$, the following relationship between the phase shift $\Delta\phi$ and the light travel duration can be established

$$\Delta\phi = \frac{4\pi f}{c} \cdot d \tag{1}$$

in measuring the distance d. Thus, direct measurement of light travel duration is no longer necessary. The maximum valid range of (1) is $d_{\max} = \frac{c}{2f}$, with c denoting the light speed as in (1). A typical modulation frequency $f = 20\text{MHz}$

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[*] Corresponding author. Tel.: +49-30-314-28565.
E-mail address: minjie.chen@math.tu-berlin.de

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would guarantee a maximum distance of $d_{\max} = 7.5$m for the ranging system. A good explanation of the calculation of $\Delta\phi$ via sampled intensity values of the light signal can be found in Creath (1988). For a detailed error analysis of the measurement we refer to Frank et al. (2009).

2. System construction

Our system contains a TOF sensor installed perpendicular to the ground floor Ω (also called observation area) which provides us with a cloud of points at the time of recording. The positions of these points can be easily converted into (x, y, z)-coordinates in the coordinate system defined by the floor plane and the optical axis of the sensor, see Fig. 1. x and y can be rescaled into integers to denote the discrete positions in the floor plane. After resampling, we acquire the height information of the two-dimensional intervals associated with the (x, y)-pairs. The recording of the scene through the sensor provides us with ranging data stored in a sequence of n frames $F_0, \dots, F_{n-1}$, and in each of these frames, a set of sample points of (x, y).

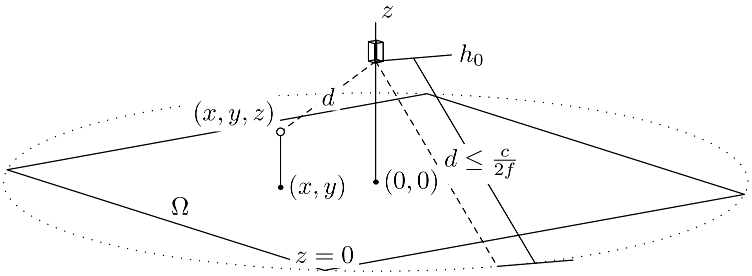

Fig. 1. Installation of the TOF sensor at a height of h_0 in the local coordinate system. The radial distance d to the object will be converted into the z-component of the coordinates.

Our previous work (Chen et al. (2010)) proposed a quadtree-like data structure called “TOF-node”. Each TOF-node stores the z-value associated with the position (x, y) and holds pointers to up to four child TOF-nodes (written as W, N, E and S). Naturally, the child pointers are allowed to be void and thus de-reference no further TOF-nodes. A simplified representation of this structure is given in Fig. 2. The child nodes, written as W (west, stands for $(\Delta x, \Delta y) = (-1, 0)$), N (north, $(\Delta x, \Delta y) = (0, 1)$), E (east, $(\Delta x, \Delta y) = (1, 0)$) and S (south, $(\Delta x, \Delta y) = (0, -1)$), refer to the immediate neighbouring positions with $(\pm 1, 0)$ and $(0, \pm 1)$ where the z-values are lower. A TOF-node, which is itself not child of any TOF-nodes, will be referred to as a “TOF-tree” (cf. Fig. 2). Since the monotonicity respecting the z-values is imposed, the root node of a TOF-tree is always associated with a local maximum in z. Furthermore, convex objects can be represented in TOF-trees. We notice that in this data structure the original geometric information is completely preserved.

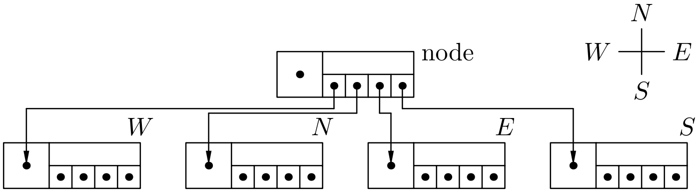

Fig. 2. Simplified representation of the TOF-node. The TOF-node “node” stands for a TOF-tree at the same time.

3. Algorithm

3.1. Construction of TOF-trees