On the Detection of Moving Objects in Laser Scan Data: the Highest Point of Interest (HPOI) Method

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Abstract. There are many sensors and measuring methods for detecting moving objects, each with its advantages and disadvantages. In active tracking methods (based on e.g. GNSS technology), the user is informed and actively participates, for instance by installing a smartphone app. These methods typically have the problem that only a limited part of the moving objects is tracked. In passive tracking methods (e.g. video recognition), the moving person is not informed of being subject to the data acquisition. These methods are typically privacy-invasive. Many techniques also require complex calculations to transform the raw data into accurate and meaningful trajectories of moving objects. However, such trajectories usually require only one point of the moving object at any given time. If the moving object is a person walking or cycling, then such a point of interest is the highest point of the person's head (i.e. “highest point of interest” or HPOI). Detecting this point typically demands computationally intensive mining of the trajectory data, for example using deep learning approaches in video recognition. We present the use of static LiDAR technology, a well-established, precise and anonymous 3D data acquisition method, for this use case. By continuously (i.e. at a high temporal rate) laser scanning an environment in which pedestrians or cyclists move, multiple epochs of point clouds are obtained. A robust vertical threshold filtering allows reducing aforementioned high-dimensional, bulky point cloud data to easily visualisable and interpretable trajectories of HPOIs.

Keywords. LiDAR, object tracking, trajectory data mining, point cloud processing, spatiotemporal data, visual analytics

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1. Introduction

3D laser scanning is often used for data acquisition in complex situations, ranging from acquiring surface or terrain characteristics in environmental sciences to detection of obstacles surrounding autonomous cars in the field of robotics to (Chen, Fragonara, and Tsourdos 2021; Fan et al. 2021). This work presents the use of LiDAR technology for a simple, but overlooked situation: scanning moving objects from a single stationary point of view. Although not new, the concept of people tracking with 3D LiDAR data has typically relied on computationally intensive deep learning techniques (Yoon, Bae, and Kuc 2020; Brščić et al. 2020; Ma et al. 2019). We propose a passive but non-privacy-intrusive approach entitled the "highest point of interest" (HPOI) method. HPOI has great potential for real-time anonymous trajectory acquisition of moving objects. It exploits a very important intrinsic strength of 3D scanning: fast and precise acquisition of dense point clouds with known (x, y, z, t)-coordinates. Using simple methods from trajectory data mining (Wang, Miwa, and Morikawa 2020) and some principles from time geography, the highest points of objects moving throughout the scene can be quickly and easily filtered, forming the basis for the trajectories. This robust technique has great potential to provide data input for numerous applications within trajectory data analysis, both in outdoor and indoor environments.

This work-in-progress paper is organised as follows: first, in the methodology section, an experimental data acquisition set-up is discussed. Second, the pre-processing of the point cloud data is outlined. The third part of the methods section encompasses the idea behind HPOI. Next, in the results section, the potential of HPOI is demonstrated using meaningful visualisations. Finally, potential applications are highlighted.

2. Methodology

2.1. Experimental Set-Up

An Ouster™ OS1-64 mid-range high-resolution LiDAR sensor (Ouster, 2021) was installed on the first floor of a building near an open window, overlooking a roadway and sidewalk on De Sterre Campus of Ghent University (https://goo.gl/maps/HEUZW8bnrhZ7TmAv6). This particular route on the campus was chosen because of the frequent passage of cars, cyclists and pedestrians. During a period of 15 minutes, the roadway, sidewalk and surroundings were scanned with a vertical resolution of 64 channels and a horizontal resolution of 1024 channels at a rotation rate of 10 Hz. To avoid an overload of data acquisition, the vertical field-of-view was set at 45° and the horizontal field-of-view at 90°.

Figure 1. HPOI method laser scan set-up of case study at Ghent university campus (Belgium)

2.2. Pre-Processing

This subsection gives an overview of the pre-processing, step-by-step. The source code used to process the point cloud data can be found on a GitHub repository (https://github.com/samuvack/Highest-Point-of-Interest-HPOI-Method). Due to the static way of setting up the laser scanner, all raw backscattered points were observed in coordinates relative to the origin of the laser sensor. Because we were mainly interested in the absolute Z-coordinates, perpendicular to the topographic surface of the terrain, a local plane was determined by averaging out the Z-value of a subset of points on the road. Then, a coordinate transformation was applied to the point cloud to rotate and translate all points to a local coordinate system with the Z-axis along the normal of the surface of the road.

2.3. Highest Point of Interest (HPOI)

In most cases, 3D laser scanning is used to model objects in great detail. In the case of the HPOI method, the shape of the object during tracking is of minor importance. Moreover, an oriented bounding box, or even a single point (e.g. the highest point of the scanned point cloud in relation to the surrounding terrain) is sufficient to track an object along its path. As a result, this method requires a low computational load, making it possible to easily track moving objects in near real-time. Additionally, the position of an object along its trajectory is measured relatively accurately compared to image recognition of camera images.

3. Results

3.1. Visual Exploration

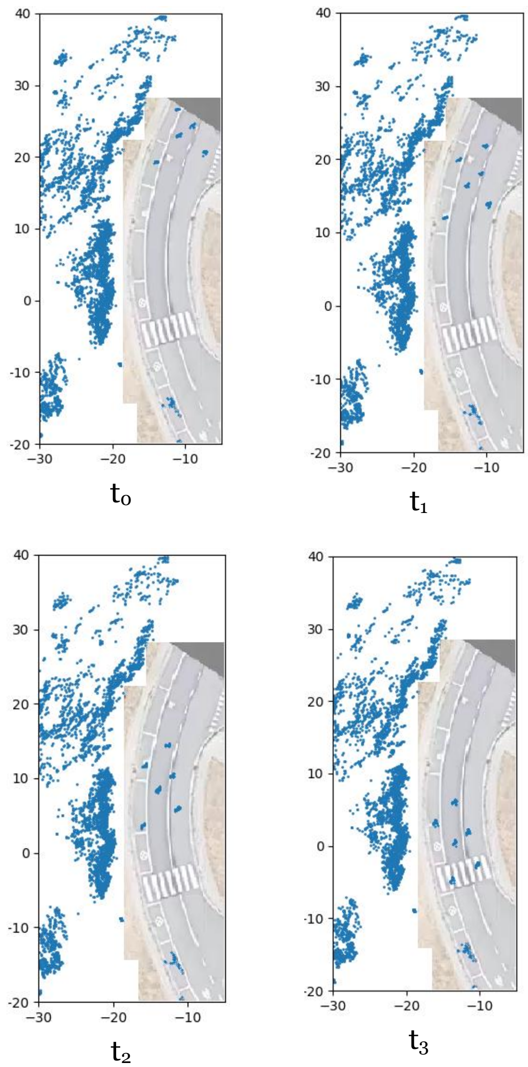

Figure 2. Processed point cloud, in which six cyclists are detected via the HPOI method

First of all, the figure above shows that the HPOI method clearly distinguishes six moving objects on the road segment. Since the position of the HPOI points varies with respect to each other and the six representative trajectories also differ from each other, it can be concluded that these six HPOIs represent six independent moving objects. From the height, speed and context (moving objects along a road segment), one can conclude that six cyclists were tracked in this case study.

Second, when looking at the road segment in the above figure, we can spot a parked car in the parking lane (bottom right of the time frames). Although the shape of the car obviously does not change in reality, the shape of the point cluster (extracted with HPOI) does change. Therefore, in addition to the benefits of HPOI, this case study also shows that further research is needed to avoid dubious interpretations of the result.

It must be noted that at no point in time the privacy of the six tracked cyclists was at risk. It can also be stated with certainty that a parked car was detected in this short recording via the HPOI method, without registering the type of vehicle or its number plate.

4. Discussion

4.1. Accuracy

The position of the highest measured point (relative to the surrounding terrain) of an object will change in the oriented bounding box along its trajectory. This can be caused by several things. First of all, depending on the distance, speed and direction of the object, more or fewer points of the object will be measured. Secondly, depending on the type of object (e.g. reflective, wet, rough) the number of measured points of the moving object can vary. Next, the object can also change shape during the trajectory (e.g. oscillating movement of a cyclist on his bicycle).

4.2. Potential Applications

The highest point of interest method (HPOI) can be used in all kinds of applications where the presence and movement of an object must be detected easily and quickly, and where the nature of the object is of secondary importance or can be inferred easily. The type of movement, the spatiotemporal and environmental context, the oriented bounding box (taking into account shadow effects, reflection and noise) can be used to determine which object was detected. For example, a moving object whose trajectory is mainly along a bicycle path, with a fairly constant speed, can be assumed to be a cyclist. Different types of animals (e.g. sheep and cows) can be determined to a certain extent by means of variation in height in a meadow full of cattle, or by linking the type of livestock at the starting point (e.g. by having the animals enter from different gates) or any other point in time along their trajectory.

The nature of the moving object needs to be determined only once along its trajectory, and, moreover, the level of detailed definition of the nature of the object can be fully determined. Of course, this is only the case if the path of the moving object is not interrupted at any time. In this case, shadow effects from obstacles in the environment must be taken into account when setting up the laser scanner. If it is still not possible to detect all trajectories of the objects uninterruptedly, a combination of several laser scanners may be a solution.

In the near future, an extensive feasibility study will be conducted to test under which conditions (weather, range and incidence angle of the scanner, density and speed of the moving objects, size of the scanning area, ...) this method works optimally and for which applications in mobile data research and activity analysis it can be best used.

5. Conclusion

This work presents the use of LiDAR technology for a simple but overlooked situation: scanning moving objects from a single stationary point of view.

Although not new, the concept of tracking people from 3D LiDAR data has typically relied on computationally intensive deep learning techniques. In contrast, the HPOI method offers great advantages in tracking objects in a simple, fast and non-privacy-invasive manner. As the privacy of every moving object is guaranteed with the HPOI method, contextual information is needed to determine the nature of a tracked object. Further research is needed to test under which conditions (weather, range and incidence angle of the scanner, density and speed of the moving objects, size of the scanning area, ...) this method works optimally and for which applications in mobile data research and activity analysis it can be best used.

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