Automation in Construction 91 (2018) 216–225

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

An anomalous event detection and tracking method for a tunnel look-ahead ground prediction system

Lijun Wei*, Derek R. Magee, Anthony G. Cohn

School of Computing, University of Leeds, United Kingdom

ARTICLE INFO

Keywords:
GPR data
Event detection
Tunnel construction
Ground prediction system

ABSTRACT

The complicated geological conditions and unexpected geological hazards beyond the face of a tunnel are challenging problems for tunnel construction, which can cause great loss of life and property. While the geological surveys conducted before tunnel construction can provide rough information of construction site, they are not sufficiently accurate for predicting the sudden geological condition changes in local areas. Within the EU NETTUN project, an on-board ground prediction system consisting of multiple ground penetrating radars (GPR) and seismic sensors were developed to "see through" the ground and provide the local ground information behind the excavation front surface of a TBM (Tunnel Boring Machine). In order to facilitate the interpretation of the imaging data captured by this system, an automatic event detection and tracking method is presented in this paper. Anomalous 2D features are detected on each radar profile and reconstructed into a 3D accumulator; then, probable 3D events are detected from the accumulator and tracked at subsequent locations based on the information from multiple sets of radar data. The detection results can be used to generate alarms or be sent to human operators for interactive interpretation. The proposed method was evaluated using two sets of GPR data captured in a designed test field. Experimental results show that the buried targets can be correctly detected by the proposed event detection and tracking method. The proposed method is sufficiently flexible to cope with variations on the spatial configuration of on-board sensors.

1. Introduction

The complicated geological conditions and geological hazards are challenging problems for tunnel construction, which can cause great loss of life and property. For example, large obstacles like boulders, building foundations, archaeological remains and other tunnels can obstruct the digging; geological defective features like cavities, sudden ground changes (e.g. from gravel to fractured rock), groundwater in adverse geological bodies (e.g. faults, karst caves and coal mine collapse column) [1]) can also make the construction dangerous. While geological surveys conducted before the tunnel construction can provide rough information of the construction site, they are not sufficiently accurate for predicting the sudden geological condition changes in local areas. In order to improve the safety and efficiency in tunnelling, geophysical sensors and computer algorithms have been proposed or applied to predict the ground conditions ahead the excavation front surface such that appropriate ground treatment and effective support installation can be conducted. Probabilistic models like neural network [2], Markov random process [3] were proposed to dynamically predict the ground conditions based on the excavated ground data. These methods are useful for determining the short range geology ahead the tunnel face. In addition to these, tunnel look-ahead ground prediction systems (Fig. 1), equipped with different types of on-board ground probing/imaging geophysical techniques, have also been proposed for predicting the ground conditions [4,5], such as tunnel seismic prediction (TSP) method [6], electrical resistivity method [7], transient electromagnetic method (TEM) [4] and ground penetrating radar (GPR) method [8,9]. These systems can help assess the local geology conditions a few metres ahead of the excavation front surface. An overview of the existing tunnel look-ahead geological prospecting systems in tunnelling construction was given by Li et al. in [10].

Currently, most existing ground prediction systems require stopping tunnel construction activities for several hours so experts can install sensors on tunnel front surface/side walls or to drill a borehole through the tunnel front to insert measurement devices. These works usually lead to delay of tunnel construction. For tunnels constructed using a TBM (Tunnel Boring Machine), an on-board ground prediction system with the functionality of automated data acquisition/storage, 3D visualisation, human-machine interactive interpretation and a direct communication with the TBM operator can potentially make the

* Corresponding author.
E-mail addresses: L.J.Wei@leeds.ac.uk (L. Wei), D.R.Magee@leeds.ac.uk (D.R. Magee), A.G.Cohn@leeds.ac.uk (A.G. Cohn).

https://doi.org/10.1016/j.autcon.2018.03.002
Received 18 August 2017; Received in revised form 28 December 2017; Accepted 1 March 2018

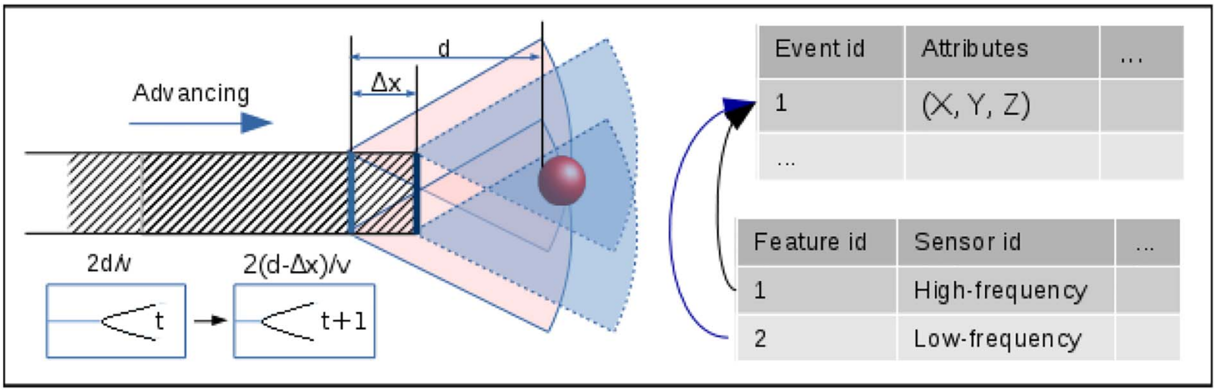

Fig. 1. A detailed illustration of continuous survey for tunnelling construction prospecting. The sensing devices are pushed forward and are getting closer and closer to the targets. Anomalous features are detected from sensor data captured at consecutive locations and associated to the corresponding event.

drilling operation safer and even increase the excavation speed. A prototype of such a system, named Tunnel Look-ahead Imaging Prediction System (TULIPS) [11,12] has been developed within the EU NETTUN project[1].

The TULIPS system consists of multiple sets of GPR antennae of different frequencies as well as a seismic imaging system. There are three sets of complementary GPR antennae on TULIPS: a low frequency GPR to provide a large inspection operating range and two high frequency GPR sensors to detect small-sized targets like rock fractures which might be a few centimetres in length. The imaging system is placed on three different radii sequentially (along an arm), and on each radius the system is rotated in an anti-clockwise direction with a constant rate to collect data, so each GPR sensor can provide one data set per radius and three sensors can generate nine images in total which can guarantee the best coverage of the space in front of the ground prediction system [11]. Examples of the generated three images by the low-frequency GPR sensor are shown in Fig. 2 (left). The ground prediction system is designed to be installed in front of a TBM cutter head, so the imaging process is repeated each time a tunnel segment ring is being erected along the tunnel axis. An anomalous target detection method has been proposed for this system by Wang et al. in [12], in which GPR data is preprocessed to remove noise, then back-projected into 3D for analysis. However, in practice, the surrounding ground could be heterogeneous so the received signal strength (GPR image intensity) could vary in different parts of a GPR image. Directly projecting the image pixel intensities into 3D may not help reveal the targets in areas which are relatively challenging for GPR sensors.

Therefore, in this paper, an automatic event detection and tracking method is proposed for detecting and tracking anomalous 3D events from the GPR data acquired by this system. Potential features are first analysed in local image regions by examining the dissimilarity of a pixel to its surroundings. Then the obtained feature maps are back-projected into a 3D accumulator for analysis. As the detections from a single image profile may not guarantee the existence nor indicate the type/size of a target, the data fusion step correlates all information sets from different GPR sensors at different radii and subsequent tunnel locations in 3D. When the sensor platform moves forward, a 3D target tracking scheme is applied for consistently tracking the targets from frame to frame. Then these corresponding 3D targets are re-projected to individual GPR images as the final anomalous 2D features. Information of the detected 3D events and the associated 2D image features are stored in a database and can be visualised to TBM-operator to facilitate the interpretation by geo-experts. The processing pipeline of the proposed event detection and tracking method is shown in Fig. 3.

The remaining sections of this paper are organized as follows: detection of potential features in individual images is introduced in Section 2, then the data fusion and events identification/tracking method is presented in Section 3, followed by experimental results in Section 4 and conclusions in Section 5.

2. Detection of potential features in ground penetrating radar data

The objective of this step is to identify potential anomalous features in individual GPR images. Features are local changes in the sensor data which could indicate the presence of an "event" in the physical world, such as geology events (e.g. fault, karst) and anthropic structures (e.g. building foundation, pipes). As areas in GPR images with large intensity (except those from ground echo and noise) are generally relating to the reflections from underground objects with high dielectric contrast to the surrounding medium, a GPR image is usually separated into background and foreground (interesting) regions using intensity based thresholding methods [13], i.e. background is related to the areas without obvious/strong signal reflections, and regions of interest are areas with stronger signal reflections. A comparison of three types of thresholding methods for interesting region extraction is given in experimental Section 5.

In this work, instead of considering each GPR image pixel separately, features are considered as local pixels/regions with different intensities with respect to their local neighbouring areas according to image local statistics [14,15,16]. After applying the common preprocessing steps on a raw GPR image (i.e., signal de-wow correction, programmed gain control, horizontal filter, bandpass filter and time/depth correction) using an IDS standard processing software[2], a 3 × 3 median filter is applied to the GPR image to remove background noise, followed by subtracting the average of each horizontal trace from all traces to remove ground echo. Then, the potential feature map is calculated based on the image Laplacian pyramid by comparing the subsampled images in different scales.

Algorithm 1. Extraction of potential features in a radar image I.

for $s \in [S_1, S_2, S_3 \cdots, S_m]$ **do**
  $I_s :=$ sub-sample image I with scale s
  for $\sigma = [2, 8]$ **do**
    $I_s^\sigma :=$ convolve I_s with Gaussian filter $g(\sigma)$
  end for
  $I_s^d := norm(\sum_\sigma \| I_s - I_s^\sigma \|)$
  $I_s^d :=$ resize I_d^s to the size of input image I
  $I_{min}^s :=$ find the average of local maxima in I_s^d
  $p^s :=$ calculate the weight using $(1 - I_{min}^s)^2$
end for
$I_{out} = \sum_s p^s * I_d^s$

[1] http://nettun.org/.

[2] OneVision, IDS, Pisa, Italy.