Research paper

Method for automated reconstruction of a car's path during crash from GPS/INS data using a Kalman filter

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ABSTRACT

This article presents a method for automated reconstruction of a car's path during crash. Unlike conventional methods, which rely on indirect measurements like tire marks, property damage, etc. and on human intervention, the presented method uses only data from direct measurements, made by an EDR device. The method is compatible with devices built with low cost MEMS sensors. The path reconstruction is done fully automated, using a Kalman filter, similar to the ones used in inertial navigation.

The test results show that the method has practical value as a source of information for the final expert report in a car crash investigation. It can also be used to perform a remote crash reconstruction if the data is sent over e.g. mobile network, thus being of benefit even to emergency call center operators.

1. Introduction

The large number of road accidents in the world has forced the creation of specialized investigation bodies. They perform measurements, analyze crash site data and create road accident expert reports. The exact development of the crash must be reconstructed in order to identify the factors that led to the crash – car technical defects and/or design flaws, bad road conditions, untimely or inadequate driver reactions, etc. Part of that reconstruction is the car path reconstruction. From this information, conclusions are made and measures can be taken in order to prevent future accidents. These measures can include changes in car design, administrative regulations, etc.

Conventional crash reconstruction techniques rely on indirect measurements – road tire marks [1], car deformation [2], damage to surrounding objects, etc., as well as data from direct measurements made by event data recorder (EDR) devices installed in the car [3]. Using mathematical models and the gathered data, crash investigators prepare their expert reports, describing the development of the crash. The downsides of this approach are the use of indirect measurement data to reconstruct the car path during the crash, as well as the need of human intervention on different stages of the process [4].

The method, presented in this article, is based entirely on data from direct measurements recorded by an EDR device in the car in the timeframe around the crash. The reconstruction of the car path is done fully automated by a software, with no need of human intervention.

Given that the data from the EDR is sent over a mobile network and using the developed method, it is possible for the reconstruction to be made remotely, shortly after the crash, e.g. on the work station of an emergency call center operator. In this way it will allow the operator to make a rough preliminary assessment of the road accident, even before the arrival of the rescue forces on the crash site. If higher data security is needed it can also be end-to-end encrypted [5].

As participant in the second part of the HeERO project [6], the team from the Technical University of Sofia (TU-Sofia) designed and produced an In-Vehicle System (IVS) device prototype for the purposes of testing the pilot implementation of the eCall system [7] in Bulgaria. The device needed to be retrofit for an aftermarket install in older cars, which led to the necessity of autonomous working capability, without connection to the car's onboard systems. For the autonomous crash detection an inertial (INS) module, consisting of low-cost MEMS sensors, was installed in the device. Accounting the already present GPS and GSM modules, this effectively turned the device into an IVS-EDR capable device [8]. From this the idea for the method, presented in this article, was first conceived.

The car path reconstruction method presented in this article closely resembles the ones used to reconstruct the vehicle path for inertial navigation. The essence of the presented method is in the two step process of pre-processing the GPS/INS data and then feeding it into a Kalman filter. The pre-processing is necessary because of the specifics of the EDR data, recorded during the collision. These specifics are described below.

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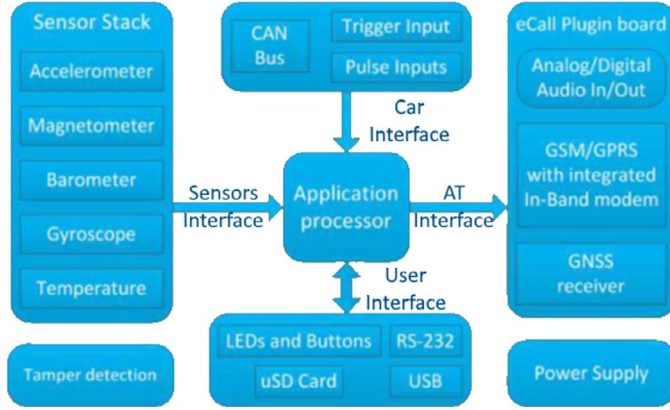## In-Vehicle System Device

Fig. 1. Block diagram of the used IVS-EDR device.

2. EDR device and data specifics

2.1. EDR device compatibility

For the purposes of this research the said IVS-EDR device of TU-Sofia is used. It's block diagram is shown on Fig. 1. From the available data, recorded by the device, for path reconstruction only the measurements of the MEMS accelerometer, gyroscope and magnetometer, and the GPS data are used.

The reconstruction method is compatible with any EDR device capable of providing the same data at reasonably high sampling rate (> 100 Hz), as it highly impacts the reconstruction accuracy. In order to be commercially available the method is developed with the aim to produce reliable results even when using data from low-cost devices.

2.2. EDR data specifics

The specifics of the car's collision path reconstruction are mostly related to the specifics of the EDR recorded data – a factor that both poses difficulties, but also offers some advantages, presented below.

All data is written entirely in the EDR non-volatile memory during the crash and is read and processed subsequently, i.e. non real-time. This allows for the usage of a slower but more accurate algorithm. For instance, a Kalman filter with a smoothing cycle, as well as using the entire data set in the processing.

EDR devices record data the entire time the car is running, but only save a short timeframe when they detect a collision. For instance, the IEEE-1616 standard recommends recording of data in the timeframe -8 s to +5 s around the initial collision – the so called crash pulse [3]. This time limitation, as well as the high probability of the car being in movement in the beginning of the timeframe, is a challenge for the proper initialization of the reconstruction algorithm. To resolve this issue, the IVS-EDR device, used in this research, records additional 5 s of data before the crash pulse. Assuming that at this period the car is in stable motion on a smooth path, we can initialize the attitude using (1) and the position using (2). Where ΔZ and ΔX are calculated from the first 2 s of GPS data.

$$[\varphi \quad \theta \quad \psi]^T = [0 \quad 0 \quad \text{atan2}(\Delta Z/\Delta X)]^T \tag{1}$$

$$[P_X \quad P_Y \quad P_Z]^T = [0 \quad 0 \quad 0]^T \tag{2}$$

Another important input parameter when using a Kalman filter are the noise characteristics of the inertial sensors. From them the error covariance matrices, used in the Kalman filter, are calculated. In inertial navigation this process is usually done as part of the device initialization process, immediately after power up and before any vehicle movement. The solution to this is based on statistic reports, showing that in 93% of the cases of car crashes the vehicle comes to a complete stop in 3 s after the collision [9]. Reflecting on this, the IVS-EDR records
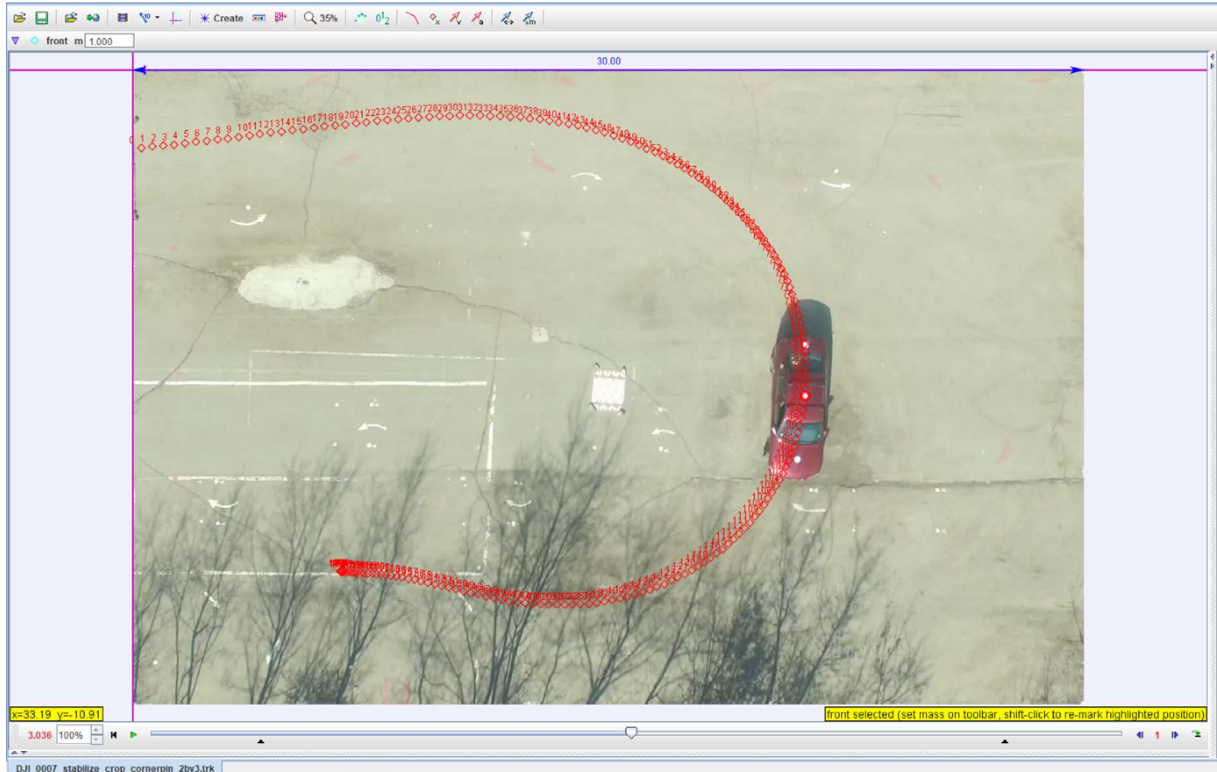

Fig. 2. Visualization from the video tracking software, used to extract the reference path.