Proceedings, International Cycling Safety Conference 2014
18–19 November 2014, Göteborg, Sweden

Using Smartphones to Monitor Cycling and Automatically Detect Accidents - Towards *eCall* Functionality for Cyclists

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ABSTRACT

Automatic crash notification to the nearest emergency center in case of a traffic accident will through the EU initiative *eCall* improve the safety for cars on European roads. *eCall* functionality could also increase the safety for vulnerable road users such as cyclists, but there is no technical implementation agreed upon for this purpose. We propose to use smartphones due to their widespread availability and no need for extra hardware. Today's high-end smartphones are equipped with both GPS functionality and movement sensors. The aims of this study were to explore if smartphones can be used to collect cycling data of sufficient quality and to design and evaluate a crash detection algorithm (CDA) for cycling accidents. A Google Nexus 4 smartphone was chosen for the study. This device is equipped with a combined accelerometer and gyroscope chip. Over five hours of "normal" cycling data, i.e. without accidents/incidents, was collected. Six crash tests were performed using a simplified crash test dummy. In order to achieve a realistic user scenario the smartphone was allowed to be easily carried as in everyday use, i.e. the users were not required to fix it to the body. We used the total acceleration based on the sum of square of each direction to obtain a measure independent on smartphone orientation. For normal cycling this measure was found to momentarily be as high as 50 $\mathrm{m\,s^{-2}}$. High levels were often due to handling of the smartphone. This prompted that an acceleration threshold alone is not sufficient for an accurate CDA. A marked rotation during a short time interval was found to be an important predictor for crashes. An accurate CDA was designed based on a combination of sensor data such as acceleration and rotation. The CDA detected all crashes and was subsequently evaluated in several hours of normal cycling without any false positive alarms.

Keywords: automatic accident detection, *eCall*, smartphone.

1 INTRODUCTION

eCall is an important EU initiative that by making automatic crash notification mandatory will save lives and mitigate injury on European roads. In case of an accident involving a car the vehicle will automatically initiate a call to the nearest emergency call center and send a predefined (minimum) set of data including the exact location of the vehicle, which will cut the emergency response time and enable severely injured patients to receive treatment faster. It is estimated that *eCall* will save hundreds of lives and reduce severity of injury for tens of thousands of cases every year [1]. The deadline for implementation of the first version is likely to be by the end of 2017 or beginning of 2018 [1].

A limitation with *eCall* as of today is that vulnerable road users (VRU) such as cyclists are not adressed. The injury statistics for cyclists clearly show that it is an important group to target since it makes up a large and increasing proportion of killed and severely injured [2]. Furthermore, studies show that single accidents are by far the most common [3], and many case reports tell stories about injured cyclists that are found many hours after the accident with aggravated injuries. This indicates that *eCall* functionality for bicyclists will be a valuable tool to make sure that the accident is noticed and that the injured person receives help as soon as possible.

There are many challenges with implementing *eCall* for cyclists and reach a wide user-base. There is typically no power source that can feed electronics mounted on the bike, and there is no mandatory yearly control of bicycles such as for cars that could be used to assure proper functionality of a device mounted on the bicycle. It may also be argued that it is more relevant to monitor the movement of the person using the bike than the movement of the bike. Furthermore, the cyclist may not be willing to pay for the extra safety *eCall* would provide if it is based on expensive hardware.

We propose the use of smartphones for implementing *eCall* functionality for cyclists (Figure 1). If it would be possible to use the built-in sensors in the smartphone to automatically detect an accident a smartphone implementation could potentially solve many of the above mentioned challenges. No extra hardware would be needed. No external power source would be required, as long as the smartphone application would be sufficiently power efficient so that the smartphone battery will not be quickly drained. The smartphone would also focus on the movement of the cyclist. By using a smartphone it is also easier to establish a communication link to a suitable receiver via the owner's data plan.

Automatic crash notification has reached wide implementation in the US through systems such as General Motor's OnStar [4]. Pioneers in trauma care of traffic accident victims have even developed algorithms that can assess the probability that any passenger has been severely injured in a crash by using data from accelerometers etc. [5–7]. The information from a smartphone such as speed and accelerometer/rotation could possibly also be used to indicate the severity of an accident (Figure 1). Automatic crash notification implemented on portable devices and smartphones have been presented by others [8–10], but to our knowledge there has previously not been presented a possible solution specifically aimed at cyclists and using a smartphone alone.

The first challenge to overcome for implementing *eCall* for cyclists on smartphones is to assess whether smartphones are adequate to record cycling data of sufficient quality so that it could be used to distinguish "normal" cycling, i.e. without accidents or incidents, from a crash/incident. In this study we have developed a smartphone application for logging cycling data from the embedded sensors. This has been used to collect many hours of cycling data, and crash data using a simplified crash test dummy. From these data a crash detection algorithm (CDA) was developed.

Figure 1. The principle of *eCall* functionality for cyclists implemented on a smartphone.

2 MATERIALS AND METHODS

Different smartphones were evaluated based on hardware specifications and tests regarding the quality of the motion-tracking sensors. Google Nexus 4 (LG Nexus 4 E960, LG Electronics Inc., Yeouido-dong, Seoul, South Korea) was chosen for the main development and tests in this study. This smartphone has a combined six-axis accelerometer and gyro chip (InvenSense Inc. MPU-6050, San Jose, CA, USA). An in-house developed application was used to monitor movements of the cyclist. The recorded data was acceleration (three axes), rotation (three axes), position (GPS) and speed sampled at 100 Hz. The total acceleration was calculated from the three axes according to Equation (1):

$$|Acc| = \sqrt{{Acc_x}^2 + {Acc_y}^2 + {Acc_z}^2}, \tag{1}$$

where Acc = acceleration $[\mathrm{m\,s^{-2}}]$, and x, y, and z are the coordinate system axes. In addition, normal data was collected using in-house developed applications for iPhone 4 and iPhone 5s (Apple Inc., Cupertino, CA, USA).

The “normal” data, i.e. without any crashes or incidents occurring, was collected both during regular commuting to work and during tests that assessed specific types of cycling that may produce high values of acceleration/rotation such as the cyclist standing and spurting, passing over high/sharp edges (e.g. pavements and tram tracks) at high speed, cycling with many stops and on a variety of surfaces. Furthermore, smartphone placement was varied, e.g. in different pockets on the rider, in backpacks and in saddle bags. City, racing, hybrid race and fixed gear bikes were used. No electric bikes were used. Approximately 5.5 hours of normal data was collected.

Tests using a simplified crash test dummy were performed to gain knowledge of typical movements during a crash. An anthropomorphically shaped exoskeleton built from PVC pipes, fenders, chicken wire and duct tape was filled with sand, giving it a human-like weight of approximately 40 kg (Figure 2). The dummy was mounted on a bicycle with a posture mimicking that of a cyclist and the Google Nexus 4 smartphone was put in a pocket on the dummy's chest (Figure 2). Different crash situations were then modeled by pushing the bicycle until it reached a realistic cycling speed, and then let it overturn or hit a rigid obstacle. Six crashes were performed, chosen to represent overturn/hit object for both soft and hard surfaces (Table 1).

A CDA was developed to differentiate the crashes from normal cycling data. The CDA is proprietary and will therefore not be described in detail.

Figure 2. An illustration of the simplified crash test dummy showing the exoskeleton of PVC pipes and the fenders used as legs. For the crash tests the upper body skeleton was added more weight to using sand.

Table 1. Descriptions of the six simulated crashes.

Crash number	Description
1	Dummy overturned at low speed on soft surface
2	Dummy overturned at medium speed on soft surface
3	Dummy crashed into rigid object at low speed and overturned on soft surface
4	Dummy overturned at medium speed on a hard surface
5	Dummy crashed into rigid object at low speed and overturned on a soft surface
6	Dummy overturned at very low speed on a hard surface

3 RESULTS

Figures 3, 4 and 5 show the distributions of the measured acceleration, rotation and speed for normal cycling. Note that since one of the purposes of this study was to study situations where acceleration/rotation/speed may be relatively high, the data collected for this study may not be fully representative for cycling in general. Figure 6 shows a representative example of the acceleration and rotation for the crashes. In this test the crash dummy was brought up to speed starting at 80 s and the crash occurs at approximately 97 s. At the crash large spikes in both acceleration and rotation were observed. This result is representable for all the simulated crashes, although the magnitudes of the signal spikes at the moment of crash varied.

Through comparing normal data to crash data acceleration and rotation thresholds indicating occurrence of a crash were identified and used as input to the CDA. The CDA evaluates different criteria of the recorded acceleration, rotation and speed that all have to be fulfilled for an alarm to be triggered. The CDA detected all six crashes and generated no false positive alarms for the normal cycling data. The CDA was in addition evaluated on several hours of cycling whose data was not recorded and thus not part of the input for constructing the CDA, without generating any false positives.

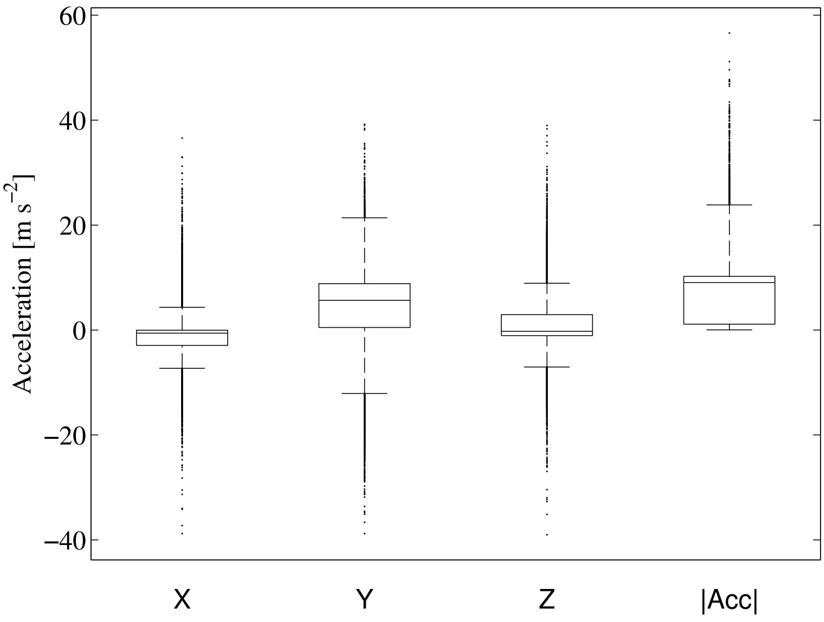

Figure 3. The distributions of acceleration for normal cycling. The line in the middle of the boxes shows the median, and the bottom and the top of the box show the 25th and 75th percentile, respectively. The whiskers extend to 1.5 times the interquartile range away from the top or bottom of the box, or to the furthest observations from the box. Data points outside the whiskers are plotted individually.

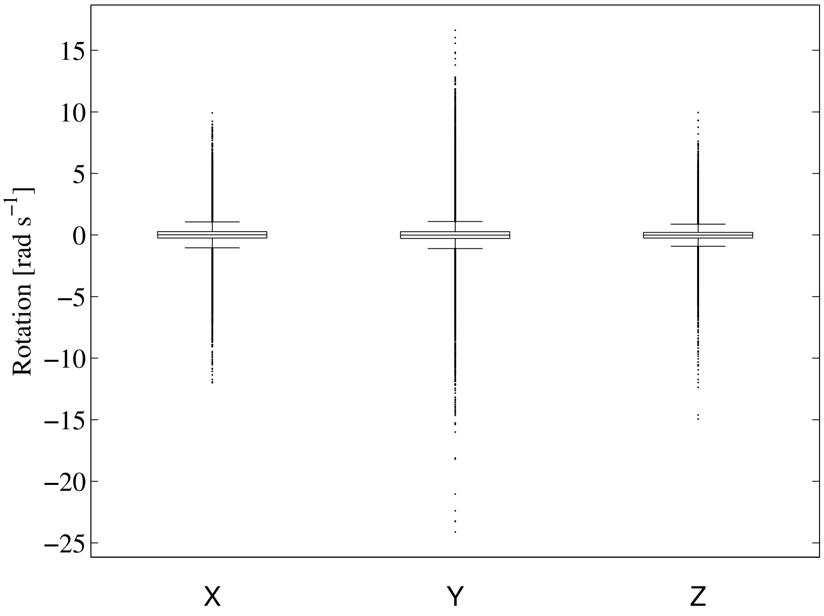

Figure 4. The distributions of rotation for normal cycling. The line in the middle of the boxes shows the median, and the bottom and the top of the box show the 25th and 75th percentile, respectively. The whiskers extend to 1.5 times the interquartile range away from the top or bottom of the box, or to the furthest observations from the box. Data points outside the whiskers are plotted individually.

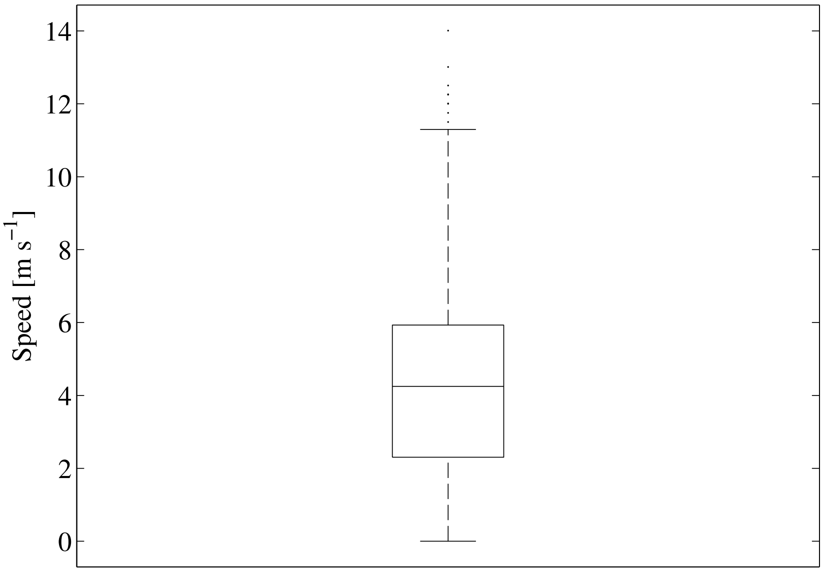

Figure 5. The distribution of speed for normal cycling. The line in the middle of the box shows the median, and the bottom and the top of the box show the 25th and 75th percentile, respectively. The whiskers extend to 1.5 times the interquartile range away from the top or bottom of the box, or to the furthest observations from the box. Data points outside the whiskers are plotted individually.

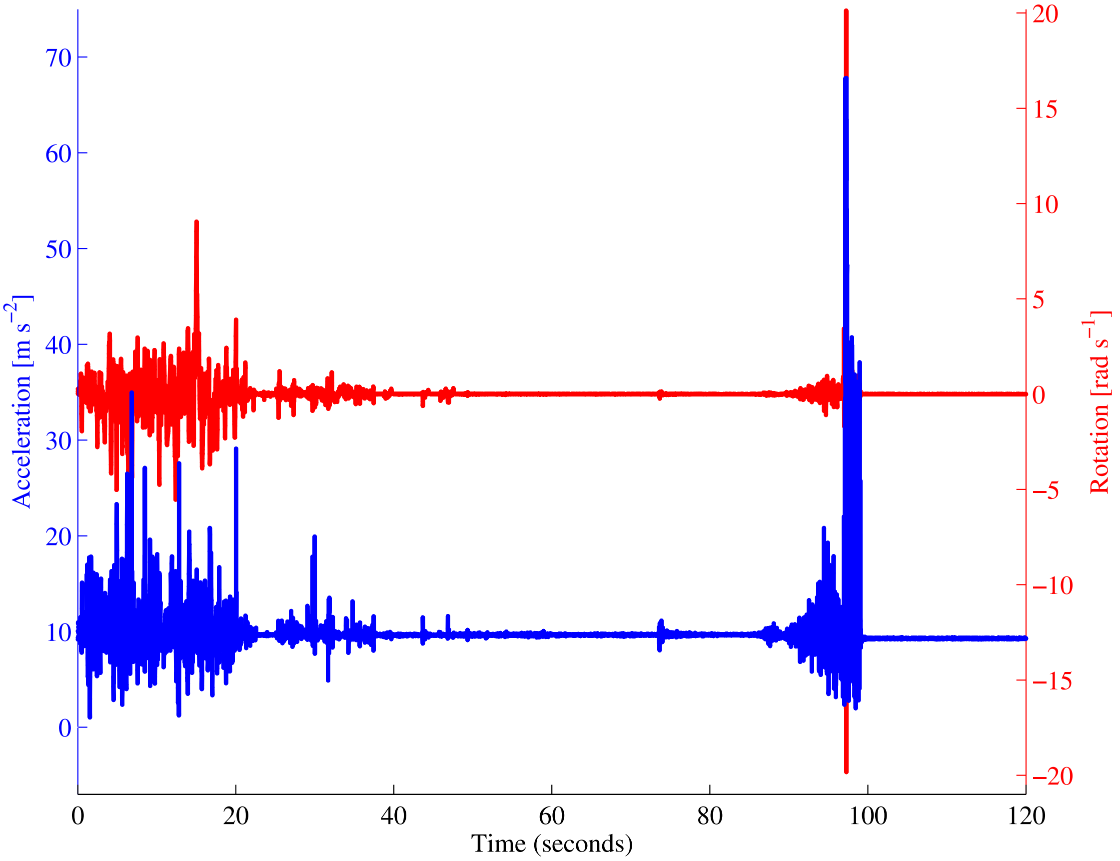

Figure 6. Total acceleration (blue) and rotation (red) of the smartphone (the x-axis which showed the most prominent rotational motion in this crash) for one of the crashes. The signal fluctuations from 0–40 s represents the preparations and the handling of the smartphone when it was put into the chest pocket of the crash dummy.

4 DISCUSSION

In this study we have shown that smartphones may be a good solution for developing an *eCall* function for VRU such as cyclists. An important result that emerged from the study was that it seems indeed possible to create an algorithm for real time motion analysis and crash detection, without restricting the user to carry the smartphone tightly fixed to the body.

Comparing the distributions of acceleration and rotation (Figure 3 and 4) during normal cycling to a typical crash (Figure 6) we see that the prospects for developing a CDA with high accuracy are good. Our experience is that high values during cycling most often occurs as the user interacts with the phone. For example putting the phone in a pocket will generate relatively high acceleration/rotation values. However, handling of the phone still generated considerably lower values than the crashes in general.

The main limitations of this study are that the data sets are limited and that the crashes are modeled in a simplified way. For the normal data we have so far collected 5.5 hours of cycling. However, the normal data were carefully collected so that many scenarios were covered: different users, different types of bikes, different surfaces, different placements of smartphone, etc. Six test crashes have been performed so far, and our opinion is that the way that crashes were modeled and the limited amount is the most important limitation of the study. Crashes are difficult to mimic to their nature. The simplified crash test dummy used in this study will obviously not behave as a human during a crash. Furthermore, the smartphone was only placed in the chest pocket of the dummy. A realistic crash model accurately describing more accident scenarios is needed. In upcoming studies we plan to use/develop more advanced laboratory/simulation crash tests.

5 CONCLUSION

Modern smartphones with good hardware sensors can be used to monitor cycling and automatically detect a fall or accident and issue an alarm if this happen, thereby providing an *eCall* functionality for cyclists. The CDA developed in this study needs to be verified in a large-scale cycling study with realistic crash tests.

6 ACKNOWLEDGEMENT

We acknowledge Jalp Systems AB for supplying the crash detection algorithm.

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