ROADROID
CONTINUOUS ROAD CONDITION MONITORING WITH SMART PHONES

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Abstract
By using the built-in vibration sensor in smartphones, it is possible to collect road roughness data at Class 2 or 3 level [1] in a very simple and cost efficient way. Data collection can be done continuously and monitor roughness changes over time. The continuous data collection can also give early warnings of changes and damage, enable new ways to work in the operational road maintenance management, and can guide more accurate surveys for strategic asset management and pavement planning. Data collection with smartphones will not directly compete with Class 1 [1] measurements, but rather complete them in a powerful way. As Class 1 data is very expensive to collect it cannot be done often, and advanced data collection systems also demand complex data analysis and take long time to deliver. Smartphone based data collection can meet both these challenges.

A smartphone based system is also an alternative to Class 4 – Subjective rating [1], on roads where heavy, complex and expensive equipment is impossible to use, and for bicycle roads. The technology is objective, highly portable and simple to use. This gives a powerful support to road inventories, inception reports, tactical planning, program analysis and support maintenance project evaluation.

History:
2002-2006 - Research for the Swedish Road Administration using accelerometers and a PC.
2010 - Technology to measure vibrations was built in to a smartphone.
2011 - First Android app for research of how cars, phones and speed are affecting values.
2012 - User discovery/development with managers for road maintenance
2013 - First end user projects and piloting in different parts of the world.

The Roadroid smartphone solution has two options for roughness data calculation:
1) estimated IRI (eIRI) - based on a Peak and Root Mean Square vibration analysis – and correlated to Swedish laser measurements on paved roads. The setup is fixed but made for three types of cars and is thought to compensate for speed in 20-100 km/h. eIRI is the base for a Roadroid Index (RI) classification of single points and stretches of road.
2) calculated IRI (cIRI) - based on the quarter car formula for a narrow speed gap such as 60-80 km/h. cIRI allows the operator to calibrate the sensitivity to a known reference.

Collected data are digitally transferred to internet maps and can be aggregated in preferred sections (default 100 m), as well as exported to Geographical Information Systems (GIS).

In addition to optimizing road maintenance, the information could be a new kind of input to road navigators and digital route guides. Digital bump warnings can be presented as detected bumps to road navigators through standards for Intelligent Transportation Systems (ITS).
INTRODUCTION
The International Roughness Index (IRI) is a roughness index commonly obtained from measured longitudinal road profiles. Since its introduction in 1986, IRI has become commonly used worldwide for evaluating and managing road systems. Vibrations have been used since early 1900 for expressing road condition and ride quality [2].

The traditional techniques for measuring roughness may be categorized as special built trucks or wagons with laser scanners, bump-wagons, and manually operated rolling straight edges. Special built equipment is expensive, due to heavy and complex hardware, low volume of production and need of sophisticated systems and accessories. Data gathering and analysis are often time consuming. Data collection is typically done during the summer then analysed and delivered to the maintenance management systems in late autumn. It is soon then winter and spring where the road faces continual frost heave/thaw (a very dramatic period in a road’s life with extreme changes in roughness). The IRI values that were “exact” almost a year ago might now not be the same any longer. As it is also so expensive to collect and analyse the data, that many roads are only covered in one lane direction every 3-4 years.

Smartphone based gathering of roughness data, can be done at a low cost and monitor changes on a daily basis. For frost heave issues it can tell when and where it is happening and if the situation is worse than in previous years. It can be used in the winter to determine the performance of snow-removal and ice-grading. It may advantageously be used in performance based contracts or research on road deterioration, various environmental effects (as heavy rains, flooding).

It should be mentioned that smartphone based systems like Roadroid might challenge old knowledge, standards, procedures and existing ways to procure:
- Pavement planners and road engineers know existing inputs;
- Research organisations, suppliers and buyers have existing ways to work;
- Organizations have invested time, prestige and huge amounts of money to develop more and more exact and complex data collection and management systems.

As described in [1] it is necessary to understand the difference between four generic classes of road roughness measuring methods in use:
Class 1 - Precision profiles
Class 2 - Other profilometric methods
Class 3 - IRI by correlation
Class 4 - Subjective ratings

It is natural that scepticism will appear when a Class 2/3 smartphone is compared with a multi-million dollar Class 1 vehicle. But a smartphone can deliver up-to-date good quality roughness data to a web page within 24 hours, in contrast to an expensive software client with the “exact” Class 1 data from last year.

On the other end of the scale – many road inventories and assessments are actually made by Class 4 subjective ratings over large areas using pen and paper.

Smartphone data collection fills a gap between the class 1 measurements and class 4 ocular inspections, and we see some early adopters and notice steps of development in the market.
THE FIRST PROTOTYPES 2002-2006

The Roadroid team has been working with mobile ITS since mid-1990s, particularly with mobile data gathering, road weather information and road databases. During a visit to the Transportation Research Board in Washington 2001, a Canadian project was presented that monitored the speed of timber hauling trucks, simply assuming that where the speed was low the road quality was poor. Our developed idea was to add vibration measurements.

Together with the Royal Institute of Technology, a first pilot scheme was built in 2002-2003. At that time we used a high-resolution accelerometer at the rear axle of a front wheel drive vehicle, connected by cable to a portable PC through a signal conditioner. GPS and GSM were connected through wired serial connections. Two master students built a first prototype using an industrial software system for signal analysis.

![Prototype Image](image-url)

**Fig. 1 From left 1:st prototype 2002-2003 to right 2:nd prototype, developed 2004-2006**

The results were promising and the Swedish National Road Administration financed an R&D project to further develop and validate the prototype with a focus on gravel roads. The system was developed into a C++ software for Windows program, and a GIS tool was implemented for viewing the road quality in different colours.

A validation between ocular inspections and the system’s measurements was performed and presented at the Transport Forum, Linköping, in 2005. 8 segments of 100 m were individually assessed according to 4 road condition classes. Module analysis (experimental analysis of oscillation) was performed on a sample of specific sections of the 4 road condition classes. Regression analysis was then performed with rules based on: 1) amplitude levels for different G, 2) RMS (Root Mean Square), 3) The vehicle speed measured and 4) The length in meters.

The analysis showed that a single test run would classify properly to 70% compared to an average of subjective ocular inspections, while a single ocular inspection varied more from the average than that. The method was considered objective with very good repeatability.

In 2006 the development stalled. The system was considered relatively cheap and simple to operate at the time (~7000 USD). In retrospect, it had several limitations; particularly the sensor mounting and cables exposed in the harsh environment under a car, but also the windows 98 computer and the cable-connected, and a not very accurate, GPS.

FURTHER DEVELOPMENT 2010-2011

In 2010, the ideas from 2002-2006 were reviewed. A major technical development was now the appearance of mobile smartphones. Literally all peripherals that were previously connected by cables were now built into a phone and the limitations of certain components...
were removed by new advances in technology. We knew the answers to some of the questions from 2002-2006, e.g. the basis for signal analysis and the influence of speed. There were however new big questions to solve, such as:

- Was it possible to pick up the signals from inside the car?
- We knew different car models would give different signals and how could we handle that?
- Would a lower sampling frequency be enough (100 Hz compared to earlier 512 Hz)?
- Would the accelerometer sensitivity and the G-scale be sufficient (+/-2G)?
- Would different smartphone models return different values (accelerometer sensitivity).

We developed an Android application and an algorithm using the built-in accelerometer signal. The choice of Android rather than iPhone was made considering the open architecture and hardware price/performance relation. We started to sample data on different roads with different types of vehicles, and over constructed obstacles in 2011.

The obstacles were passed by different vehicle types 5 times in 6 different speeds: 20, 40, 60, 80, 100 and 120 km/h. Data were sampled with different phones, both with our algorithm and in raw 100 Hz. During the data analysis, we then discovered a number of things:

- There are differences between different car models, especially at low speeds. In the 40-80 km/h range, differences are however limited. The tests gave us a model for how to calculate the speed influence of the signal for the 3 different type vehicles.
- There are big differences between different phones, both for the sampling frequency and the quality of the accelerometer data. It is of great importance to know these dynamics to achieve comparable data. A phone calibration procedure is required.
- It is of great importance to mount the phone correctly in a good mounting bracket, preferably in a way that enables the phone’s camera lens to be directed at the road.

Most importantly: the trials during 2011 showed that usable data could be delivered!
We now had an Android app analysing 100 vibrations per second and saving several of the essential road condition values with a GPS coordinate!

The road condition data was divided into 4 different levels for visualization: Green for Good, Yellow for Satisfactory, Red for Unsatisfactory and Black for Poor.

**VIEWING OF DATA**
We now had a tool delivering data, and created a viewer –an internet based map tool to present the data. Data was collected after measurements zipped on the unit, and sent by a file
transfer service to a webserver in the cloud. Data files from different units were imported by a daily routine, mapped to road links/geometries such as Open Street Map (OSM) and using Open Layers on Google map background to present the road condition data on a web map.

The app stored one data value each second, based on a sampling frequency of 100 Hz, but to get an overview in a larger scale it was more convenient to use road links than second resolution dots. Depending on the road database, there will be many opportunities to refine the data and add information such as road width, traffic volumes, etc. Globally we have been using geometries from Open Street Maps.

![Fig 4. A screen shot from Mid-Sweden](image)

**USE OF DATA – AND THE ROADROID INDEX**

We have undertaken studies of the International Roughness Index (IRI) and have developed a correlation between our measured road condition data values and the IRI. We have continually been looking to improve the way we present the comprehensive level of information being collected – flexibility and scalability are key. We wanted to be able to add data from several measurements over time and compare results over time in a flexible way.

We also wanted to automatically generate reports for a road and to compare a road with other roads and within whole regions. The solution was to use a *percentage of each road class* for a road or an area, an index scalable for a part of a road, a whole road, a city or a region.

**Figure 5 to the right:** - How to pick data out from the web tool.
As we want to do continuous monitoring to view development over time we also needed to find a way to produce reports. Data collection can be made by the contractor’s road guards/officers who are doing visual inspections 1-3 times per week, or by other operators such as the local newspaper distributor.

The percentage of each class seemed to be a suitable way to also make reports from the data.

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**Figure 6** – A Road condition change report – for performance follow up.

**ESTIMATED IRI**

We now had a promising and scalable index, but also knew that we needed to correlate this to the IRI. To find the correlation we gathered:

1. our road condition values in absolute terms and matched them to sections in the Swedish road data base
2. average data from Class 1 (laser beam) IRI measurements to the same sections.

By comparing hundreds of sections we established a correlation factor and could now estimate an IRI value (eIRI - usable all the way from our second resolution dots to a road link). The correlation factor (R2) was up to 0.5 which meant that 75% of the classifications were correct.

We have noticed some limitation in speed adaptation, rough pavement surfaces and that minicars are quite more sensitive than our reference small car. Research is continuing by different institutions around the world, as the World Bank, UN OPS, specialized Universities and some large road companies. Throughout 2014 these organizations will report back to inform our developments, and to improve our solution. This will include a calculated IRI (cIRI) and the possibility for an operator controlled calibration.

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**Figure 7:** Left – from our base correlation study / Right - Autostrade Aran comparisons

**CALCULATED IRI**
The cIRI approach is promising and seems to be more dynamic then the eIRI. The quarter car model uses two swinging weights that can be simulated if chassis movement is available as one input. The estimation here is for the chassis movement in a scale 1-10 based on the accelerometer data and. An operator controlled adjustment/calibration. As mobile technologies get more advanced, suitable laser distance devices for distance monitoring between road and chassis might be used in a future.

The needs are different – from operational maintenance on developed road networks to first fact finding in developing countries. Our internet map function is a good way to view data, but demands some basic knowledge of GIS and road databases.

We also developed a data aggregator, collecting date/time, coordinates (X, Y), vertical profile (Z), speed together with eIRI and cIRI in preferred sections 25-1000 m. In the current version, tab separated text files can be generated and imported into other software. By the use of digital spreadsheets, data can for example be adapted for import to Road Maintenance Management Systems.

**Figure 8** – Example - 72 km test run in South Africa – a plot of eIRI, speed and altitude.

As mentioned, we have seen limited IRI-correlation on roads with rough surfaces (as chipseals/brickroads), but at the same time promising results on gravel roads in Afghanistan and Sweden. From what we have seen, it is a mainly a question of filtering the data correctly. We also expect that our operator controlled adjustment of cIRI will facilitate the right levels.

**USE OF THE BUILT-IN CAMERA**

As most phones now have a high quality built-in camera and GPS, we have developed a function to easily take photos and position them on the map as thumbnails. The images are often of acceptable quality, but are subject to mounting and light conditions. This is recognized as very good support for ocular inspections, and can also be used to capture dynamic events, such as certain snow conditions or other maintenance contract issues.
Figure 9 – Use of the phones build-n camera and support on the web tool.

We have also tested GPS high resolution action video cameras (Contour 2+) with good results for more precise and demanding video requirements.

FRICITION MEASUREMENTS

Connected to winter road maintenance, friction is of crucial importance for road traffic safety and to pick up road friction / skidding resistance is simple compared to measuring road roughness.

<table>
<thead>
<tr>
<th>Friction Level</th>
<th>Num Points</th>
<th>% of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>2778</td>
<td>91.1</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>190</td>
<td>6.2</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>57</td>
<td>1.9</td>
</tr>
<tr>
<td>Poor</td>
<td>25</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Mean value: 1.12
Total num points: 3050
Total Length: 36677
Points/meter: 0.98

1) Press friction button
2) Break
3) Friction value saved
4) Data send to server
5) Information on map

Data stored to reports

For an objective dialogue between client and contractor but also for traffic information

Figure 10 – Roadroid friction sampler

The Roadroid app calculates the friction level, using the longitudinal force (retardation) and gives the friction value a GPS coordinate. Data can be sent by the phones SMS if it is an urgent report or transferred with the other data to be shown on the map.
USE ON CYCLE PATHS
The cities of the world are facing more and more traffic problems. Traffic management is optimizing the flow – but far from enough to cope with the car traffic growth. Cycling is one option to commute instead of being stuck in a traffic jam. Modern cities are building cycle highways, with increased demands of quality of the cycle network. Cyclists buy expensive racing bikes with thin wheels – and they drive fast!

The same smartphone based system can be used as a quick and easy monitoring system for cycle roads.

![Figure 11 – Roadroid for bicycle paths](image)

REFERENCES

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