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# Using smartphones as a very low-cost tool for road inventories

S. Higuera de Frutos *, M. Castro

*Dept. Transportes, E.T.S.I.C.C.P., Universidad Politécnica de Madrid, C/ Prof. Aranguren s/n, 28040 Madrid, Spain*

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ABSTRACT

Road inventories are a key component in the planning of road networks as they allow for efficient management and a better return on the investment. Current techniques for carrying out road inventories are expensive and entail long planning processes and data post-processing. Furthermore, these inventories are only useful to those parties interested in designing and building road networks. This study presents a new method for create road inventories based on the use of the latest generation cellular phones, also called *smartphones*. This paper describes the use of several mobile apps developed for this project that were implemented during the different stages of road inventory process. The results indicate that the data processing speed, its low cost, and the ease of implementation from any type of vehicle validate the proposed procedure as an invaluable tool (1) to do inventories of all types of road networks that are not accessible to cars; (2) to manage the routine maintenance of small road networks; and (3) as a basis for future research projects on road design and outline.



## 1. Introduction

The efficient management of any road network requires a detailed description of its characteristics with the aim of easing the decision making process and getting the best return on investment. In order to achieve these goals it is necessary to create a road network inventory that includes both road characteristics and road maintenance conditions.

The purpose of a road inventory is to provide a management tool for the different parties that are involved in the planning and exploitation of road networks. Road inventories are based on the physical and geometric characteristics of each road section.

The current method used to create road networks inventories involves high costs, requires a broad range of instruments and detailed preplanning. These requirements prevent a quick implementation of this method. This is crucial to consider when, for example, making inventories after natural disasters or in recently recovered areas after military operations. Since the vehicles used in this procedure are specialized for taking measurements on paved roads designed for standard car widths, it is very difficult to use them for other types of roads. This is the case in cycling paths, forestry and mountain roads, hiking trails or touristic paths.

The goal of this research project is to develop a series of software programs for smartphones that provide a low-cost, efficient and adaptable option for the inventory of different types of roads. This article presents both the apps and their implementation in two rural roads in Madrid, Spain.

* Corresponding author.
*E-mail address:* shiguera@mercatorlab.com (S. Higuera de Frutos).

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## 2. Literature review

### 2.1. Road inventories

Film inventories are a fundamental part of current road inventories. They can be created either by taking photographs of the road at specific distance intervals or by video-taping the routes. High-quality digital cameras are used for this purpose. In general, panoramic formats are used with a viewing angle of at least 120°. Photographs are stored in JPEG graphic formats, which allow for adding metadata to the images (Joint Photographic Experts Group, 2013). Resolution types differ depending on the instrument used. In some cases, vehicles are also equipped with mechanisms that automatically correct the camera orientation while taking curves.

In order to define the road centerline points, global positioning systems by satellite, such as GPS and DGPS, are used. Methods to enhance the accuracy of GPS data have been developed by integrating information provided by inertial sensors, such as the accelerometer. Jiménez uses the initial location provided by the GPS and calculates the maximum distance that can be covered by integrating the trajectory before having to retake the GPS position (Jiménez, 2010). In a recent study, Martí et al. develop algorithms that combine the information from DGPS devices with information from an IMU (Inertial Measurement Unit) and propose to apply their results to the development of automatic driving systems (Martí et al., 2012). One of the problems associated with using GPS for road inventories is its low accuracy while measuring altitude. For this reason, Boroujeni et al. have recently tried to complement the altitude data provided by GPS with the atmospheric pressure data from a barometer. Specifically, Boroujeni et al. use data from a low-cost GPS equipped with barometric altimeter to calculate the average grade of a road (Boroujeni et al., 2013).

A road's horizontal geometry is defined by the radius of curvature in each of the centerline points. There are different methods to obtain the radius of curvature. The most accurate method is the topographic surveying of the curve. The radius of curvature can be also inferred from the axis points coordinates, previously obtained by means of GPS devices, digitized aerial pictures and other methods. To determine the radius of curvature, mathematical procedures that estimate the geometric properties of the centerline points are implemented, such as methods based on approximation by splines (Castro et al., 2006; Cafiso, 2008), on approximation by least squares (Tong et al., 2010) and on azimuth variation (Gikas and Stratakos, 2011).

Inventory vendors typically use similar techniques and equipment to collect data and calculate curvatures. This equipment, known as *Mobile Mapping Systems*, incorporates gyroscopes, odometers, and GPS units. Data are continuously registered while the vehicle goes over the road using high-sensitivity gyroscopes to calculate the vehicle's lateral and longitudinal inclination. These measurements are then synchronized with those obtained by means of an odometer and a GPS. The data collection frequency differs depending on the speed, the required accuracy and the equipment used. The equipment currently used can provide data at intervals of a few centimeters (Saura López et al., 2008).

Findley et al. have compared different methods to calculate the radius of curvatures. Their study compares five procedures used to calculate the radius of curvature: on-site surveying, GIS software, inventory data, project design data, and with the help of the data provided by three vendors. The average error of these methods is 35%, and the average error of the vendors is 30%. The same study analyzed the error observed in defining the curve length: while the methods had an average error of 25%, the three vendors showed an error of 21% (Findley et al., 2013). In a former study dedicated to compare roadside data collected by manual methods to data collected by manned data collection vehicles, Findley highlights the need for crystal clear specifications before embarking on a mobile data collection program (Findley et al., 2011).

These *Mobile Mapping Systems*, which are generally used to make road inventories, are expensive and not very suitable to inventory roads in emergency cases or for roads that are narrow, for pedestrians or of difficult accessibility. For these reasons, in recent years, international organizations have been promoting the use of low-cost equipment to make road inventories in developing countries. In this context, it is important to highlight the project carried out by Kayondo et al. The goal of this study was to do a preliminary evaluation of roads conditions in Uganda by using two video cameras mounted on both sides of a 4WD. One of the cameras takes real color pictures while the second camera takes infrared images (Kayondo et al., 2011). Likewise, Youssef et al. use a video camera mounted on a car dashboard to do a preliminary evaluation of side slopes with the highest risk of landslides in the roads of Missouri. The results were meant to establish baseline standards in maintenance work. Based on measurements done by means of the videos, they calculate several parameters, including their angle or their height (Youssef et al., 2007). In both cases, the vehicles had GPS equipment and at least a personal computer, in addition to the video cameras. These methods can reduce by ten times the real cost of making road inventories.

### 2.2. Smartphones

Mobile phones known as smartphones are equipped with a series of environmental and motion sensors that turn them into very low-cost mobile sensor platforms. Currently, a high-end smartphone costs around 500 euros and includes GPS, light sensors, sound, magnetic field sensors, accelerometer, gyroscope, barometer, photo camera and video camera. They can also be connected via Bluetooth, Wireless or Internet. Furthermore, they have high computational capabilities, which are much better than the functionality of computers available a few years ago. Because of all this, smartphones can be used as powerful tools to develop all types of apps, particularly new and exciting opportunities are emerging with regard to the transport sector.