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Monitoring Road and Traffic Condition using Smartphone Devices

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ABSTRACT

Keeping roadways in good condition is challenging, because of normal wear and tear and unexpected traffic load. A ubiquitous monitoring system is required to inform drivers about unexpected road anomalies. Detecting these anomalies will lead to reducing traffic jams and road accidents. Most of the current road monitoring systems install dedicated sensors on the roadside or in dedicated vehicles such as inductive loops, traffic cameras, doppler radar, and laser sensors. These systems are expensive and infeasible to be ubiquitous since they are limited to the number of sensors deployed in the system.

Smartphones have transformed from being basic devices into advanced tools comprising various communication channels, capable computational hardware, and reachable to a diverse set of sensors for interacting with the surroundings. Smartphones come with rich embedded sensors (e.g., GPS, accelerometer, and gyroscope) as well as built-in radios (e.g., Bluetooth, Wi-Fi, and Cellular), which both enable users to gather data and share them in the surrounding at any time or location. These capabilities enable the realization of mobile crowdsensing systems.

In this thesis, the problem of monitoring road conditions using smartphone sensors is studied. We propose a complete mobile crowdsensing framework for road surface condition detection. In this framework, various modules along with typically utilized techniques and algorithms are discussed. The framework addresses various modules including task management, data fusion, reputation scoring, incentive awarding, security, and privacy. The proposed framework confirms the feasibility of utilizing the smartphone sensors in a real-time ubiquitous monitoring system for road surface conditions.

Moreover, we focused on utilizing machine-learning techniques to detect road anomalies using smartphone sensors. An android application is developed to record sensor readings while driving the car. Using this app, a dataset of four trips on Cairo roads is constructed, consisting of a total duration of 80 minutes and about 50K records. To automatically label these records, two clustering techniques (K-Means and DBSCAN) are evaluated to identify the ground truth for the sensor readings if they represent road anomalies or normal road surfaces. It is noticed that DBSCAN can more accurately cluster sensor readings than K-Means can do. Once the dataset is labeled, a classification model is built to allow a smartphone to classify sensor readings and identify the surface quality of unseen roads. An accuracy of 96% can be obtained from the built classifier confirming the effectiveness of the adopted methodology in evaluating the road surface quality in Egyptian roads.

List of Publications

- El-Kady, A., K. Emara, M.H. ElEliemy, and E. Shaaban. Road Surface Quality Detection using Smartphone Sensors: Egyptian Roads Case Study. in 2019 Ninth International Conference on Intelligent Computing and Information Systems (ICICIS). 2019. IEEE.

- Emara, Karim, El-Kady, Aya Mamdouh,shaaban, Eman,ElEliemy, Mohamed Hamdy. MOBILE CROWDSENSING FRAMEWORK FOR ROAD SURFACE QUALITY DETECTION. International Journal of Intelligent Computing and Information Sciences, 2021. 21(3): p. 95-10

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LIST OF ABBREVIATIONS

AD	Arbitrary deadline
API	Application Programming Interface
BLISS	Budget LImited robuSt crowdsensing
CFS	Confocal White Light Sensor
CMM	Coordinate measuring machine
DBSCAN	Density-based spatial clustering of applications with noise
DTRPP	Dynamic Trust Relationships aware data Privacy Protection
EEW	Earthquake Early warning
Eps	Epsilon
E-R	Experience and Reputation
FFT	Filter and Fast Fourier Transform
FIFO	First-in first-out
FN	False Negative
FP	False positive
GPS	Global Positioning System
IoT	Internet of things
IRI	International roughness index
ITS	Intelligent Transportation Systems
KS	Kolmogorov-Smirnov
MCS	Mobile Crowdsensing
MCSC	Mobile Crowd Sensing and Computing
MESS	Minimum Energy Single-sensor task Scheduling
MGRS	Military grid reference system
OVO	One-versus-one
PBPM	Probe-based Pavement Management
PD	Potholes Detection
PR	Profile Reconstruction
PA	Parking Availability
PAYG	Pay as you go
PAYM	Pay monthly
QnQ	Quality and Quantity

RE	Roughness Index Estimation
RF	Random Forest
RMS	Root-mean-squared acceleration
SFFS	Sequential Forward Floating Search
STDEV(Z)	Standard deviation of Z-acc
SVM	Support vector machine
SWT	Stationary Wavelet Transformation
TN	True Negative
TP	True Positive
UAV	Unmanned aerial vehicles
VDC	Vehicle dynamic control
WHO	World Health Organization
WOM	Word of mouth
WSN	Wireless Sensor Network

Chapter 1 INTRODUCTION

This chapter gives a background of road surface quality detection showing the motivation, problem statement, and objectives of the thesis. It also discusses briefly the smartphone sensors and their operation.

1.1. Background

In June 2021, World Health Organization (WHO) declared that approximately 1.3 million people die every year as a result of road accidents, and between 20 and 50 million more people suffer non-fatal injuries, with many incurring a disability as a result of their injury [1]. Road traffic injuries cause considerable economic losses to both individuals and nations as a whole. Road traffic crashes cost most countries 3% of their gross domestic product. Poor road conditions such as bumps, potholes, and broken pavement can cause traffic congestion, vehicle damages, and accidents as shown in Fig. 1.1. Many road anomalies do not have visible labels or are even visible, especially at night. Therefore, a ubiquitous monitoring system is required to inform drivers about invisible and unexpected road anomalies. Most of the existing methods for monitoring road conditions like radar, cameras, and ultra-sonic detectors are expensive and cannot be adopted to cover the whole road network, but they are deployed or used in a small portion of the system for main roads.

Smartphones have transformed from being basic devices into advanced tools comprising various communication channels, capable computational hardware, and reachable to a diverse set of sensors for interacting with the surroundings. Smartphones come with rich embedded sensors (e.g., GPS, accelerometer, and gyroscope) as well as built-in radios (e.g., Bluetooth, Wi-Fi, and Cellular). These sensors can be used in measuring several characteristics around the user context, including road conditions. Using their built-in communication modules, smartphones can share gathered context information to the surrounding at any time or location. Nowadays, smartphones and tablets are used everywhere and used by most people which can realize a ubiquitous monitoring system without significant overhead.

Figure 1.1 Traffic congestion due to pothole accident

The road condition detection based on smartphone sensors is cost-efficient as it does not need complex and costly deployment for special devices in the vehicles. It depends on the driver's smart device and the service provider infrastructure where the crowdsourced real-time sensor data are collected and processed. We envision the overall system to have a mobile application for collecting data while the driver navigates in the city and a cloud where data is processed, and road conditions are detected and delivered to users.

The smartphone's wide usage has come up with both mobile crowdsensing (MCS) and crowd computing concepts. Mobile crowdsensing is a new sensing model that makes use of the huge adoption of mobile devices equipped with sensors, to gather data from the surrounding environment. Mobile crowdsensing often depends on a large number of participants for sensing the environment using their smart devices. Mobile sensing can be very helpful in sharing daily information and spreading knowledge to improve lifestyle. Mobile crowdsensing development can be used in a wide range of applications usually categorized into three types: *infrastructural*, such as detecting road anomalies, *environmental*, such as monitoring noise, and *social* such as tracking the movement and exercises of participants. Mobile crowdsensing (MCS) relies on collecting data from various users using sensors in their smartphones to improve the quality and reliability of data. Based on the involvement of participants in sensing actions, mobile crowdsensing can be categorized as participatory and opportunistic [2]. Participatory sensing requires the active participation of each user in collecting sensory data in order to result in a large-scale phenomenon, which cannot be easily measured by single participation. For example, delivering an intelligent traffic congestion report where many users provide their speed and location information while being in transportation is considered participatory sensing. On the other hand, opportunistic sensing accepts sensory data collection in a fully autonomous way without active user interaction. This type of application runs in background mode without any user intervention in the actual sensing, such as continuous location notification or ambient sound recognition.

1.2. Smartphone Sensors

Most smartphones have different types of sensors that are used in collecting data for various purposes. Fig. 1.2 shows different types of smartphone built-in sensors, including ambient light, GPS, proximity, accelerometer, microphone, gyroscope, and camera sensors. Light sensors are used for adjusting the screen luminosity. Light and proximity sensors enable the device to achieve simple forms of context recognition linked with the user interface. The GPS permits the device to localize itself as well as enable location-aware searches, navigation, and mobile social networking applications [3] [4]. By obtaining information from satellites in space, it can detect the sensor's accurate location. Gyroscopes and compasses can identify direction and orientation and how fast the sensor is moving. Compasses measure the orientation to the earth's magnetic pole. They also improve location-based applications that depend on the GPS [5]. The accelerometer has a dissimilar function. It measures vibration and motion through the conversion of physical movement into an electrical signal. It measures the acceleration force in meters per second in the three directions (x,y,z) which is the rate of change of velocity of the body. This force can be static, as the force of gravity, or dynamic to measure the motion and vibration as in most smartphones. It is applicable to gain information from the accelerometer as the object tends and vibrates. Accelerometers are used in many fields including industry, science, transport, biology, and engineering. They are used in computers and digital cameras so that images on screens are displayed straight. They are also used in unmanned aerial vehicles to help in-flight stabilization. They can be used to define several activities such as walking, standing, and running.

Figure 1.2 Smartphone sensor

Relying on the physical accelerometer sensor, various virtual sensors can be derived. Gravity and linear acceleration are examples of derived virtual sensors. Linear acceleration is the acceleration derived from the accelerometer sensor excluding the gravity measures. The gravity sensor provides a three-dimensional vector indicating the direction and magnitude of gravity. In the android operating system, virtual sensors are available for developers to be accessed in a similar as the physical sensors.

The camera and microphone are the most popular and global sensors and can be found in all smart devices. The front camera of the phone can be used for conventional tasks such as tracing the eye movement of the user to activate contextual actions.

Sensors can be fused to be used in the detection of different events. For example, accelerometer readings can be aggregated with the GPS locations so that the user activity can be deduced (e.g., driving a car, riding a bus, or even walking or running) [6]). Fused data obtained from these sensors can come up with new applications in different fields, such as healthcare which uses an accelerometer in measuring the user's activities [7], environmental monitoring which uses the GPS sensor and microphone, and social applications [3].

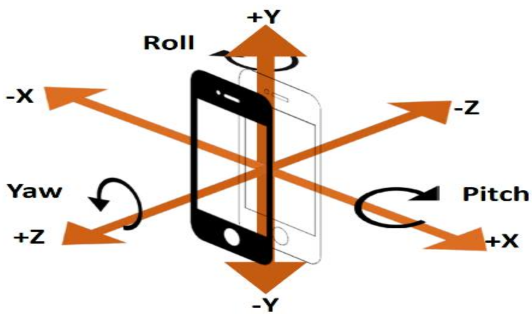

Figure 1.3 Android 3-axis standard coordinate system

The expansion and growth of mobile devices have often been related to the presentation of various new sensors. For example, accelerometers have become more common after being used in enhancing images captured by the phone camera and after utilizing it in the graphical user interface [5]. Sensors are used to automatically determine the orientation of the mobile phone screen and use that information to switch the display between landscape and portrait orientation or properly orient the taken photos.

Android uses 3-axis standard coordinate system to show values for built-in sensors like accelerometer sensor, magnetometer, and gyroscope sensor. Fig. 1.3 shows the 3-axis standard coordinate system that is used by Android devices to show the values of smartphone sensors accelerometer sensor, magnetometer, and gyroscope sensor. When the phone is positioned up, the X-axis is the horizontal one, Y-axis is the vertical, and Z-axis points outside the screen.

1.3. Motivation

The already existing road condition monitoring systems have some limitations such as the deployment cost. For example, installing devices on vehicles to increase sensing density is very expensive, consequently, the number of participants in the system will be limited to the vehicles where sensors are mounted.

Nowadays smartphones are considered an essential device that people carry wherever they go and whatever they do. This encouraged utilizing these devices by using their built-in sensors in monitoring road conditions.