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PHD THESIS

ROAD GEOMETRY IDENTIFICATION WITH MOBILE MAPPING TECHNIQUES

IDENTIFICAZIONE DELLA GEOMETRIA STRADALE CON TECNICHE DI MOBILE MAPPING

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To Eleonora:
my past, present, and future, everywhere.

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Glossary

"Who can say with twenty words what can be said in ten, is also capable of many other evils"
G. Carducci

AGS: The Apollo Abort Guidance System (AGS, also known as Abort Guidance Section) was a backup computer system providing an abort capability in the event of failure of the Lunar Module's primary guidance system during descent, ascent or rendezvous. 29

BIAS: Systematic error 28

CART: Classification and Regression Trees, is a modern flavor of data mining that employs decision trees and can be used for a variety of business and scientific applications. Its advantages include quick insight into database patterns and significant relationships using simple tools such as graphs, charts and reports. 22

CARTOSAT: The Cartosat series of satellites are a type of earth observation satellites indigenously built by India. Up till now 4 Cartosat satellites have been launched by ISRO. The Cartosat series is a part of the Indian Remote Sensing Programme. They were specifically launched for Earth's resource management and monitoring. 25

CCD: A charge-coupled device is a device for the movement of electrical charge, usually from within the device to an area where the charge can be manipulated, for example conversion into a digital value. This is achieved by "shifting" the signals between stages within the device one at a time. CCDs move charge between capacitive bins in the device, with the shift allowing for the transfer of charge between bins. 32

CRF: Conditional random fields are a class of statistical modelling method often applied in pattern recognition and machine learning, where they are used for structured prediction. Whereas an ordinary classifier predicts a label for a single sample without regard to "neighboring" samples, a CRF can take context into account; e.g., the linear chain CRF popular in natural language processing predicts sequences of labels for sequences of input samples 25

D.L.: The Italian "Decreto Legge" is a temporary legislative act having the force of law, adopted in extraordinary necessity and urgency cases by the Government, pursuant to the Italian Republic Constitution, art. 77. 23

ECEF: is a Cartesian coordinate system, also known as ECR ("Earth Centered Rotational"), and is known as a "conventional terrestrial" system. It represents positions as an X, Y, and Z coordinate. The origin is defined as the center of mass of the Earth, hence the name Earth-Centered. Its axes are aligned with the International Reference Pole (IRP) and International Reference Meridian (IRM) that are fixed with respect to the surface of the Earth, hence the name Earth-Fixed 30

FHWA: The Federal Highway Administration is a division of the United States Department of Transportation that specializes in highway transportation. The agency's major activities are grouped into two "programs," the Federal-aid Highway Program and the Federal Lands Highway Program 22

FOG: A fibre optic gyroscope senses changes in orientation, thus performing the function of a mechanical gyroscope. However its principle of operation is instead based on the interference of light which has passed through a coil of optical fibre which can be as long as 5 km. 29

GDP: Gross domestic product (GDP) is defined by Organisation for Economic Co-operation and Development as an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs) 21

GIS: Geographic Information System, is a computer system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. In a general sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps, and present the results of all these operations. 24

GNSS: A Global Satellite Navigation (or satnav) system is a global coverage system of satellites that provide autonomous geo-spatial positioning with global coverage. It allows small electronic receivers to determine their location (longitude, latitude, and altitude) to high precision (within a few metres) using time signals transmitted along a line of sight by radio from satellites. The signals also allow the electronic receivers to calculate the current local time to high precision, which allows time synchronisation. 27

GoPro: Is an American corporation that develops, manufactures and markets high-definition personal cameras, often used in extreme action video photography. They are compact, lightweight, rugged, and are wearable or mountable on vehicles. The cameras capture still photos or video in HD through a wide-angle lens, and can be configured to work automatically with minimum intervention, or remotely controlled 32

GPS: The Global Positioning System is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities to military, civil and commercial users around the world. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver. 24

ICBM: An intercontinental ballistic missile is a ballistic missile with a minimum range of more than 5,500 kilometres (3,400 mi) primarily designed for nuclear weapons delivery (delivering one or more nuclear warheads). 29

IKONOS: IKONOS is a commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. It offers multispectral (MS) and panchromatic (PAN) imagery. 25

IMU: An inertial measurement unit is an electronic device that measures and reports on a craft's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes, sometimes also magnetometers. IMUs are typically used to maneuver aircraft, including unmanned aerial vehicles (UAVs), among many others, and spacecraft, including satellites and landers. 29

INS: An inertial navigation system is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, and spacecraft. 27

MEMS: Microelectromechanical systems is the technology of very small devices; it merges at the nano-scale into nanoelectromechanical systems (NEMS) and nanotechnology. 28

MMS: Mobile mapping is the process of collecting geospatial data from a mobile vehicle, typically fitted with a range of photographic, radar, laser, LiDAR or any number of remote sensing systems. Such systems are composed of an integrated array of time synchronised navigation sensors and imaging sensors mounted on a mobile platform. The primary output from such systems include GIS data, digital maps, and georeferenced images and video. 28

OLS: ordinary least squares or linear least squares is a method for estimating the unknown parameters in a linear regression model. This method minimizes the sum of squared vertical distances between the observed responses in the dataset and the responses predicted by the linear approximation. The resulting estimator can be expressed by a simple formula, especially in the case of a single regressor on the right-hand side. 76

QuickBird: QuickBird is a high-resolution commercial earth observation satellite, owned by DigitalGlobe and launched in 2001[3] as the first satellite in a constellation of three scheduled to be in orbit by 2008. 25

ROV: A remotely operated underwater vehicle, commonly referred to as an ROV, is a tethered underwater vehicle. They are common in deep water industries such as offshore hydrocarbon extraction. While the traditional abbreviation "ROV" stands for remotely operated vehicle, one must distinguish it from remote control vehicles operating on land or in the air. ROVs are unoccupied, highly maneuverable, and operated by a crew aboard a vessel 29

RTK: Real Time Kinematic satellite navigation is a technique used to enhance the precision of position data derived from satellite-based positioning systems, being usable in conjunction with GPS, GLONASS and/or Galileo. It uses measurements of the phase of the signal's carrier wave, rather than the information content of the signal, and relies on a single reference station to provide real-time corrections, providing up to centimetre-level accuracy. 27

SRM: Statistical region merging is an algorithm used for image segmentation. The algorithm is used to evaluate the values within a regional span and grouped together based on the merging criteria resulting a smaller list. 25

TEN-T: The Trans-European Transport Networks are a planned set of road, rail, air and water transport networks in Europe. The TEN-T networks are part of a wider system of Trans-European Networks (TENs), including a telecommunications network (eTEN) and a proposed energy network (TEN-E or Ten-Energy). 23

UTM: The Universal Transverse Mercator conformal projection uses a 2-dimensional Cartesian coordinate system to give locations on the surface of the Earth. It is a horizontal position representation, i.e. it is used to identify locations on the Earth independently of vertical position, but differs from the traditional method of latitude and longitude in several respects. The UTM system is not a single map projection. The system instead divides the Earth into sixty zones, each a six-degree band of longitude, and uses a secant transverse Mercator projection in each zone. 62

WGS84: The World Geodetic System is a standard for use in cartography, geodesy, and navigation. It comprises a standard coordinate system for the Earth, a standard spheroidal reference surface (the datum or reference ellipsoid) for raw altitude data, and a gravitational equipotential surface (the geoid) that defines the nominal sea level. The latest revision is WGS 84, established in 1984 and last revised in 2004. Earlier schemes included WGS 72, WGS 66, and WGS 60. WGS 84 is the reference coordinate system used by the Global Positioning System. 63

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H. Newton

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Introduction

"Dimidium facti, qui coepit, habet"
"Chi ben comincia è a metà dell'opera"
"A good beginning makes a good ending"
Orazio & popular sentences

To guarantee visual recognition, handling, and safety in driving, the road alignment is made of three main geometric elements: tangents, circular and transition arcs. The geometric characteristics of these three elements are designed to create a safe and comfortable driving environment, and to achieve consistency between the geometric characteristics of a road and those ones that the driver that goes along it hopes to find.

Although that road geometrics derives from design decision, and that a great effort is made in terms of calculation and modelling before building a road, the horizontal and vertical alignment characteristics are not often available, do not have the suitable format, are not updated or do not have the required precision. However, studies aimed at the evaluation of the operational effects of road geometrics require having reliable (i.e., accurated and updated) data about the road centerline. Accordingly, a variety of survey methodologies, techniques, and identification methods has been recently introduced to support road engineers in such activities.

A common way to obtain the road alignment, is to collect spatial data points located approximately on the roadway centerline. Such data are then used to back-calculate all the geometric characteristcs of the elements that form the alignment. Surveying and modelling can be carried out referring to several tools, procedures and algorithms.

This research deals with such aspects, and tries to give a contribution to the research implementing an original methodology for the horizontal alignment identification of existing roads. The work has been carried out also focusing on the parameters able to group spatial data points belonging to the same geometric element, and in the development of dedicated algorithm able to back-calculate the geometric characteristics of the same.
This PhD thesis is the summary of three years of field surveys, database construction, programming, and results analysis.

This research's target requires managing innovative techniques and technologies to rapidly acquire information on existing roads, which are generally called *Mobile Mapping Techniques,* and deals with algorithms and models able to extract information like tangents azimuths, curves radii, curves center coordinates, and transition curves scale parameters.
Acquiring information with high efficiency and accuracy is a challenging topic. Even though some technical solutions are already available, they are generally extremely expensive. To overcome this difficulties, this PhD work concerns the use of low cost tools that require significant effort in terms of data treatment and correction due to the quality of the instrumentation in use.

As already mentioned, the core of this research consisted in the study of a recognition algorithm that is able to give back the as-built geometry of an existing road. Part of the work was carried out in the analysis and extraction of the local curvature with different approaches (successive circumferences, local polynomial fitting with different degrees local fitting windows widths), as well as on the study of local deviation angles. A method of identification of the elements that compose the road geometry has been implemented and used in fitting algorithms with various techniques (least squares, robust methods and other).

The document is composed of three main parts:

- the PART A: Theory & Fundamentals) is composed of chapters #1, #2 and #3 and contains all the theoretical and basic models adopted in the research work;
- the PART B: Case study & Applications) is made of chapters #4, #5 and #6, and is specifically focused on the case study of the research work, on programming work, data analysis and conclusions;
- the PART C: Attachments, References & Acknowledgements) reports graphs sets, extended MatLab© codes and detailed information, with the references and the acknowledgments to those who supported this work.

In chapter #1 (*Background*) there is a comprehensive literature background review, starting from road safety issues that represent one of the purposes for road alignment identification and in which the research group of the Politecnico di Torino is particularly involved in:. In fact, many research contributions demonstrate the link between road safety, accident analysis or prevention and road geometrics. Moreover, road safety inspections and any possibile improvement or treatment requires a detailed knowledge of road geometrics. . In the second part of the chapter the main techniques adopted to collect road information with Mobile Mapping techniques but also with aerial images interpretation are shown. A brief excursion of inertial navigation systems, geomatics issues related with mobile mapping and some of the main applications that are available all around the world, in academic institution and on commercial market have been included.

The Chapter #2 (*Alignment identification*) is focused on the two geometric parameters that are generally adopted to recognize the alignment component of an existing road: the local curvature and the local deviation angle. There are several techniques used to extract these parameters from a data point series acquired with a mobile mapping technique or an aerial image interpretation: deviation angle can be evaluated with simple successive azimuth differences or from the local triangle in each epoch of the point set. Some evaluations about the error propagation for both techniques are discussed in the chapter.

The Chapter #3 (*Fitting methods, theories and models*) explores and deepens the main mathematical models, theories and algorithms that are used to extract specific information from a points set. The chapter starts with the least squares methodology with its logical process that leads to all main equations used within this fitting technique . Least squares have also been adapted to the application of the current work, ending up with basic equations implemented to extract desired parameters (curves radii, clothoids parameters, tangent orientation, etc.). Some information has been given about geographical reference systems and coordinate conversions from geographic to cartographic reference systems.
Secondly, the concept of robust fitting and the reason why it is also generally adopted in this kind of application is also presented. A global introduction with the main concept explanation and a general overview of about all the M-estimators available in literature has been included.
After Least Squares and robust methods, a third algorithm from mechanical engineering has been tested in this work. It was proposed by Landau (Thomas & Chan, 1989) to estimate the radius of circular mechanical component surveyed with automatic instruments and pictures. Thomas and Chan improved the target function and made the method applicable with a determined function, avoiding the iterative approach firstly thought and proposed by Landau.

Chapter #4 (*Case Study*) is focused on the case study that has been chosen to pursue the research objectives. It consists on a section of the National Route n.23 that links Turin to Sestriere (Italy), two of the main competition sites for the 2006 Winter Olympic Games. It contains a complete overview of the survey techniques that were used, and the processes of data extraction from aerial images of the investigated infrastructure. A data sampling from the design project of the road was also performed to make some evaluation on controlled data: this is a quite new approach, since generally models and algorithms are applied and calibrated upon road surveys data, while it has been intended to find general correlation without any instrumental/environmental undesired effect.

Chapter #5 (*Database & coding*) is totally dedicated to programming work and database construction. In order to manage a huge quantity of data (directly originated from the survey or from the aerial image interpretation, or

indirectly obtained from the design) an effort in terms of database organization and managing was requested. Also programming process required accurate attention and workload, especially because they have been designed to be successfully implemented in future surveys and case study, so the generalization process has increased the work in terms of volume and time. All the database construction process is explained, as well as the logical structure of each code with comprehensive flowcharts.

Chapter #6 (*Data processing and results*) is a comprehensive exposition of all the results obtained from the data analysis and algorithms application. Detailed information about the behavior of local deviation angle and local curvature is presented, as well as a complete exhibit of results came out from Least Squares, Huber and Landau fitting.
A specific part of this chapter is dedicated to a research on bad conditioning problems on curves fitting.

The final chapter #7 (*Conclusions*) is a brief summary of the main results obtained at the end of this research investigation.