Geomatics as Effective Environmental Monitoring Support

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Abstract. The knowledge of spatial data is critical for environmental studies. Spatial data are object of the geomatics discipline, which becomes an essential support for further analysis having the land as object. Environmental analysis were performed during the IDEM project (Internet of Data for Environmental Monitoring). The aim of the study was the test of an innovative monitoring system of odor air emissions in risky contexts (landfills, composting plants, farms) to improve the environmental conditions, with the connected advantages. Geomatics group in this project dealt with different types of data: some semi-static data, which however, must be periodically updated; some mobile data, which were acquired by sensors installed on bikes and georeferenced by means of different kinds of positioning systems. All the information were included in a geographical information system for being managed and analyzed. Standardization themes, important to the Semantic Web and Internet of Things paradigm were particularly cared.

Keywords. Maps Local Updating, Mobile Mapping, Standard, Open Source, GIS, UAV, INSPIRE, CityGML, Dynamic Data.

1 Introduction

Effective environmental studies must consider the spatial component. The terrain topography, the nature, dimensions and distribution of what is over the land, the distances from specific objects or points, and so on, come into play in the systems that study environmental phenomena. Geomatics is the discipline dealing with the survey of spatial phenomena, being they 3D shape, distributed information through the space or navigation issues. Involving geomatics in the environmental studies and monitoring is therefore essential to improve the analysis performances and results accuracy.

First, it is important to have a reliable cartographic base for contextualizing the other data and for correctly performing modelling operations. The used maps should be correct, accurate enough (caring the needed level of detail), and sufficiently updated. Another problem is to use maps without interruptions or breaks in their continuity. This can be a problem in some border or cross-border areas, where different rules and techniques are used for producing maps [1]. A solution to this problem is provided by the INSPIRE European Directive (Directive 2007/2/EC), which was published since 2007 in Europe for the harmonization and sharing of national cartographic products, in order

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to obtain an available and valid base for performing environmental analysis and developing environmental policies. Also outside Europe some standards are proposed for producing a unique system of unambiguous maps, following the same explicit rules. For example, the international standards ISO/TC 211 [2] are published for managing several aspects of the geometric objects. Other standards are developed by international organizations and consortium of heterogeneous entities with the aim of establishing rules for producing standardized and effective cartographic products. An important example is the OGC (Open Geospatial Consortium), which published languages for managing geographic entities. Another important OGC standard is the CityGML data model; it includes and structures all the data having a role in the urban environment representation. These cartographic standards and open data models were analyzed for effectively representing the project data and for being support to the necessary analysis.

Another essential geomatics issue is the detailed metric survey, for which a number of techniques are developed. They can be employed and chosen following the needed level of detail and the kind of data to be documented. Some of the more evolved methods for geometric survey are LiDAR and imaging methods. Both these techniques can be used from a terrestrial point of view or from aerial platforms. Depending on the width of the surveyed area and the desired level of detail, these can be traditional planes or helicopter or the recently spread Unmanned Aerial Vehicles (UAV). Portions of land were surveyed by UAV images in several cases and for several goals [3,4]. However, the maps produced by each survey are usually considered as a complete product in themselves, without having the problem to be merged in wider contexts or as part of a mosaicked map. The whole new updated map, to substitute the older one, is generally produced. Alternatively, a reduced portion of land (for example when it is produced from UAV data) is surveyed for being used in local analysis. It is unusual to employ local data and wider maps together.

In the IDEM project (described in the next subsection) there was the need of locally updating the existing maps: the general shape of the land remained quite unchanged respect to the situation reported in the available maps, but in the studied sites some differences could be critical in the performances of the analysis and modelling. These changes were documented in the project by UAV survey, then, since the modelling had to be performed on wider areas, the new maps were integrated in the existing ones.

Moreover, the environmental sensors developed by Filippetti S.p.A. need more accurate cartographic data as input.

The performed surveys can also be used for monitoring reasons, when realized in different times on the same object, for verifying the changes of the geometry. In the case of the IDEM project, a landfill was surveyed, so that it is possible to compare the new data with the previous maps to verify the change of the volumes in the landfill, as it is usually made by means of other techniques. Other cases of monitoring activities can be performed on the rivers, for verifying the changes in the riverbed or similar information. Also other kind of environmental phenomena are usually monitored, such as landslides or debris flows [5], the forests growth or fires [6, 7], or agriculture issues [8].

Other kinds of survey can be performed using mobile devices, which produce georeferenced dynamic information along different trajectories, which can vary depending on where the sensor moves. This kind of survey permits to generate maps of different phenomena respect to the geometric objects. For these aims, different types of sensors must cooperate: some navigation sensor (object of geomatics disciplines) and some other synchronized sensor acquiring data about the needed information: image data, thermal data, pollution data, and so on. During the IDEM project some sensors were tested, mounted on bikes, in order to optimize their acquirement for producing georeferenced data useful to enrich maps and monitoring some critical factors (e.g. pollution).

The acquired and processed data must be finally organized in digital maps and Geographical Information Systems (GIS), in order to exploit both the advantages of having the data structured and reciprocally related in a common system for performing queries and automated reasoning and statistics on the data, and the possibilities given by the spatial algorithms integrated in the GIS software tools. For the IDEM data both these functionalities were used. On the one hand, a standard structure was used for organizing the data into a standard database. Then, the GIS tools and algorithms were used to query the information and to perform some important spatial analysis, permitting to generate new knowledge in very short time.

1.1 The IDEM Project

Internet of Data for Environmental Monitoring (IDEM) [9] is a research project funded by POR - FESR (Operating Regional Program of the European Fund for Regional Development) in Piedmont Region (Italy). The main aims regarded the use of interoperable data, produced by connected systems, integrated in order to generate open data, with the goal of the environmental monitoring.

The studied problem was the odoriferous and pollutants emissions by some specific sites and activities, located in Piedmont, Italy. In particular, the test sites were a landfill (SIA S.r.L.) and a composting plant (GAIA S.p.A.). Some more tests of the method and of the used sensors were realized in Turin, in an urban environment, in particular for testing the pollution sensors.

The monitoring system was based on a structure of electronic sensors connected in a smart network, able to measure the data and collect them in a Cloud platform based on Big Data. This was the SmartDataNet platform (http://www.smartdatanet.it/), developed by Piedmont Region to exploit the Internet of Things for environmental monitoring reasons.

The partners of the project were: Politecnico di Torino, Filippetti S.p.A. (www.filippetti.it/), who developed some sensors for measuring odour values and sharing the data in a web platform; ACS S.r.l. (http://www.acs-polito.it/), who made some modelling of the data for forecasting the odour diffusion; CSP S.c.a.r.l. (http://www.csp.it/), who worked on the connection of the project partners' private web platforms and the SmartDataNet, and on the communication of the data; GAIA S.p.A. (http://www.gaia.at.it/home.aspx) and SIA S.r.l. (http://www.siaweb.info/), who were the living lab where to install the sensors and instruments and to perform the tests; and the Politecnico di Torino. The multi-disciplinary Politecnico partners were distributed in three departments: Department of Control and Computer Engineering (DAUIN), the Interuniversity Department of Regional and Urban Studies and Planning (DIST) and Department of

Environment, Land and Infrastructure Engineering (DIATI). The DAUIN developed the research on the pollution measurement sensors. The DIST made an effective Spatial Data Infrastructure (SDI) to include the spatial component in the sharing of the data in the Internet of Things. Finally, the DIATI geomatics group managed the survey and updating of the project cartographic bases, to effectively support the modelling operations and contextualizing the data. Moreover, it supported the georeferencing of dynamic data acquired by mobile sensors, and built a standard data model in order to make the data interoperable and univocally interpreted by any user who wishes to use them. These last activities are described in this paper.

2 Almost-Static Data: Local Updating of the Existing Maps

The maps and cartographic data are generally considered as static data. However they need to be periodically updated, since the represented land changes: new buildings can be built or modified, some vegetation can grow or can be cut, some earth can be moved, for example in case of earthquakes or during the quarries activities, or, as in this case, landfills. Some years pass between the updating of the available maps, generally by means of new acquisitions and new processing. Over this period, some changes obviously happen. They can be irrelevant for the specific modelling to be performed. On the other hand, they can also be meaningful when the scale of the studied phenomena is influenced by the local geometry of the ground and the objects above it. This last option is the case of the spreading of odors in the air: the air can modify its itinerary following the objects surfaces. For this reason, it was fundamental to insert the changes of the test sites in the available maps (which had been produced in 2009): the landfill was filled in a part and a further portion was added respect to the previous representation. Also in the composting plant some changes occurred: it was in fact modified adding a part of building expressly for reducing the odors spreading.

However, for economic and operational reasons, it was impossible to make a new map of the whole region to model, which consisted in a square having sides of 10 km. Therefore, only a local update was performed in the two sites. Expeditious techniques were used to survey the sites with higher levels of detail, and the found new shapes were then included in the existing maps. In particular, the Digital Terrain Model (DTM) and Digital Surface Model (DSM) were produced, as a support for the modelling of the air movement, and orthophotos were mosaicked, for better interpreting the representation and eventually plotting a new digital map.

UAV platforms were employed to acquire the images, which were then processed using digital photogrammetry and Structure-from-Motion software. The data were then merged into the existing maps following procedures that consider both the discrepancies between the data, the reached accuracies, and the updating needs of each site.

2.1 The Processing of the Local Maps

As explained in the introduction, a UAV was used for acquiring the primary data of the sites. In particular, a hexacopter was used for the GAIA composting plant, consisting in a building with the rounding area, and a fixed-wing UAV was used for surveying the SIA area, which was more extended.

In the first case, a Hexakopter by Mikrokopter was employed, performing a flight covering 5 ha with a 60 m flight-height. The advantage of this kind of UAV is the possibility to perform vertical take-off and landing, since there were little open space around the surveyed area to perform a more linear take-off and landing, as needed by common fixed-wing platforms. Furthermore, a lower-distance flight could be performed, achieving a better image resolution (approximately 1.5 cm/pixel Ground Sample Distance - GSD). A Sony Nex 5 was the camera used for shooting the photos. In addition, also further sensors could be installed on this aerial platform: one of the advantages of using it is this high customization potentiality. In fact, in other studies, for example a thermal camera was used in order to survey the temperature gradients, which are critical to be known in some cases. For a continuation of the study, it would be interesting to analyse the odour values measured by the specific sensors and the temperatures of the odoriferous sources or near surfaces.

For the SIA landfill a flight with the fixed-wing UAV produced by Sensefly, the Ebee, was used, with the camera provided with the system, a Canon PowerShot ELPH 110 HS, with known camera parameters. The flight height is bigger in this case (about 150 m), reaching a GSD of approximately 4 cm/pixel. Also these acquired data could therefore be used for a very dense and accurate 3D model.

The images were processed using photogrammetric software, using signalized Ground Control Points (GCP) as reference, whose coordinates were measured with GNSS (Global Navigation Satellite System) – RTK (Real Time Kinematic) technique. These permit the georeferencing of the model and the control of its geometric quality. Basing on the residuals of the GCPs, the accuracy of the two models corresponds to the RMSE of the residual on the measured GCPs, that are: 0.042 m (scale 1:200) in the case of GAIA, and 0,068 m (scale 1:500) in the SIA survey.

The photogrammetric software, integrated with computer vision algorithms, as well known and affirmed in geomatics practices, permit the generation of a 3D model starting from a block of overlapping images [10] using the workflow in Fig.1.

The software used in these cases were: Menci APS, for processing the data acquired by the Ebee, which are directly associated to this software; and Agisoft Photoscan for processing the Hexakopter data. Both these software tools use the photogrammetry theories integrated with some structure-from-motion algorithms, and can reach similar results in terms of accuracy and geometric definition.

2.2 The Maps Local Updating

Once the new products are available, the existing maps were locally updated through the inclusion of the updated map of the test sites in a wider area, for obtaining a 10 km x 10 km map, useful to be used as input for the modelling processes.

For making this operation, some analysis were performed in order to verify that there were no excessive differences in the unchanged areas, which make the products incompatible. For example, the height discrepancies between the DTMs and DSMs were com-

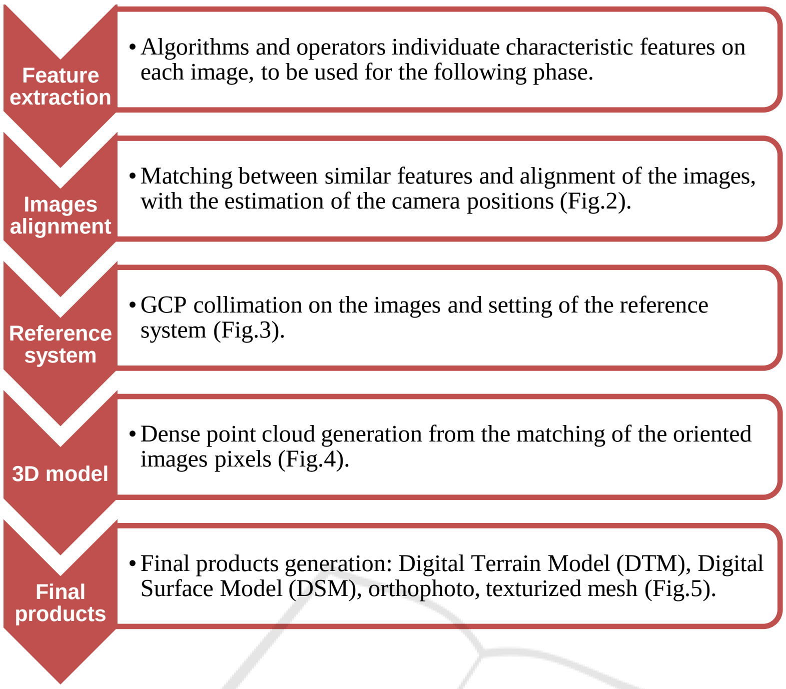


Fig. 1. The structure-from-motion software typical workflow.

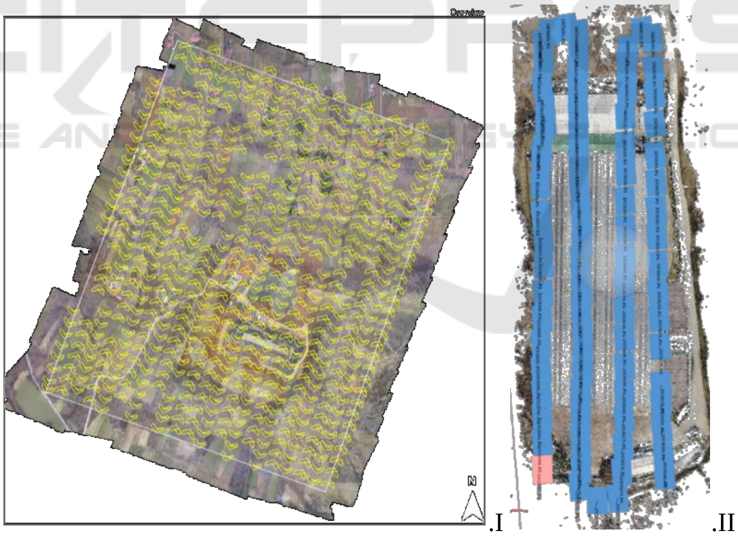
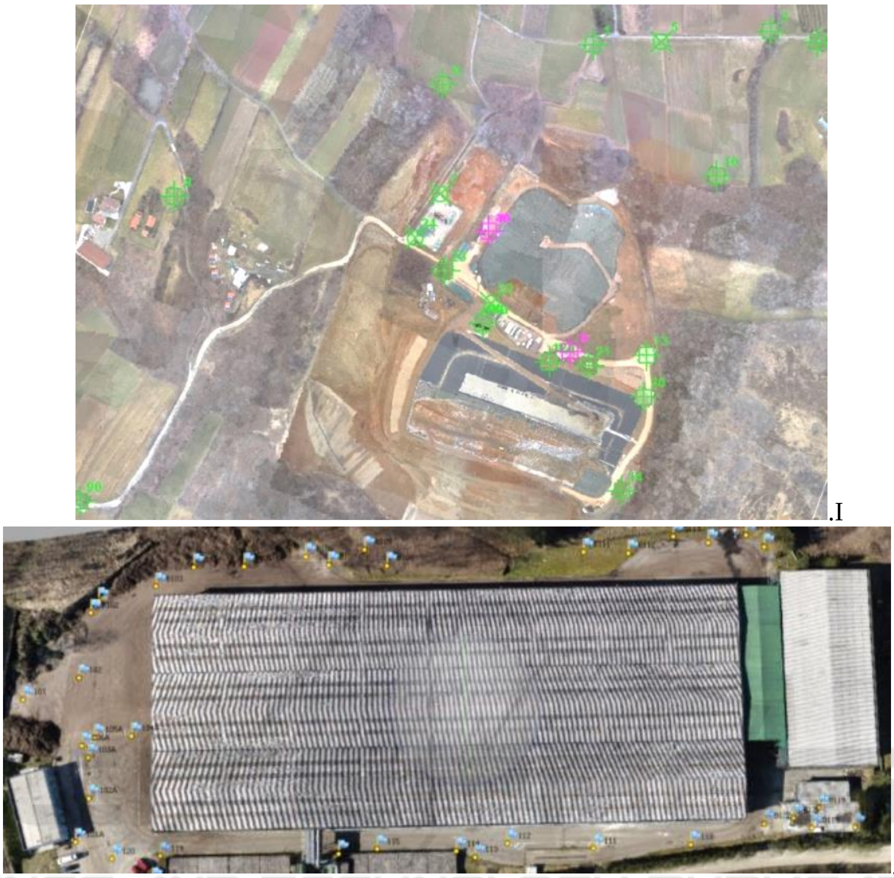


Fig. 2. Schema of the oriented images, acquired on the two sites: SIA landfill (I) and GAIA composting plant (II). In I, the missing of the yellow symbols means that some images were not correctly oriented. The reason of this may be the presence of some wind during the flight, which causes the UAV not to acquire the images with sufficient overlapping to orient them. However, the adjacent images permitted anyway the generation of a continuous map.



.I

.II

Fig. 3. Schema of the measured GCPs distribution in SIA landfill (I) and GAIA plant (II).

Fig. 4. A view of the dense cloud of the GAIA plant.

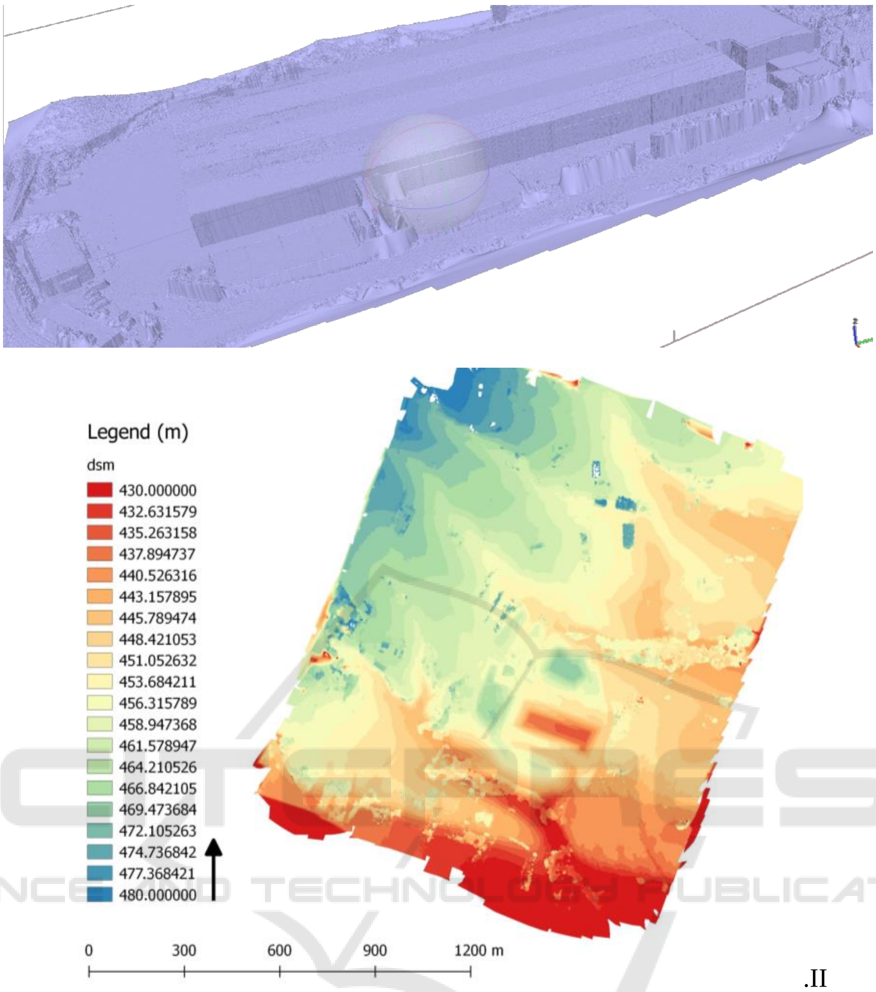


Fig. 5. Some examples of final generated products: a view of the GAIA meshed 3D model (I) and the generated DSM of SIA landfill (II).

puted. Therefore, an area including the changes in its interior and the minor discrepancies on its borders was selected on the elevation models, exploiting the results of the discrepancies between the raster images. A 100 m band was generated as a buffer of the border of this area, and was used for weighing the values of the two images in generating the merged digital elevation model, using the same method used in [1]. The buffer band on the border was translated in a raster containing the distances from the interior to the exterior of the new map, that is, with crescent values starting 50 m inside the new map towards the regional existing map. This was used in the raster calculator tool in a GIS software (QGIS) for generating a digital model band being a transition between the two raster models. In a second step, the three parts (the DTM and DSM of 10 km x 10 km available as regional maps, the band and the new digital models) were merged in a new raster, constituting a "locally – updated" product, generated using little economical resources and expeditious procedures for having a valid map, useful as a support for the modelling activities. The dimension of the grid of this new product is homogeneous with the one of the existing Regional map (5 m).

For the orthophoto integration, the procedure was entirely manual, since it was difficult to use some automatic algorithms for selecting the area with less radiometric differences but including the changes. The changed area was therefore cut from the generated map, preferably following the borders of the cadastral areas, for avoiding evident inconsistencies in the visualization of the map. Some incompatibilities persist on the new orthophoto, since the periods of the acquisition were different: the Regional map uses images acquired probably in summer (the trees have leaves), since the new acquisitions were performed in autumn (the trees have no leaves and the grass is not so green). Therefore, even if this is not meaningful for the geometry being represented, one can notice the new portion in the existing map (Fig. 6).

.I .II

Fig. 6. Ortophotos integration: the existing orthophoto, dating 2009 (I) and the locally-updated orthophotos with the new data (II) in the SIA landfill.

3 Dynamic Data: Mobile Mapping and Almost Real-Time Processing

For another part of the IDEM project, a mobile system was developed and tested for measuring pollutants in the air by means of sensors mounted on bikes.

The DAUIN group of the Politecnico di Torino studied the pollution sensors [11], but the navigation aspects obviously used geomatics issues. Different types of geomatics sensors were used: a further GNSS antenna than the one integrated in the pollution sensor was installed on the bike for defining the exact position of the sensor using cinematic mode positioning, and synchronized with the sensor surveying air pollution.

The used geodetic GNSS antenna, multi-frequency and multi-constellation was a Novatel OEM receiver. The system included an antenna patch, mounted on a ground plate, a little raised on the handlebars, and a data storage unit. This last part was delivered together with the sensor and was specifically customized. For saving space, in more recent application, it was substituted with an Ardulog device. In order to reach better accuracies, a master station was positioned near the surveyed area, to help the positioning corrections. Its position was determined respect to the GNSS permanent network of Piedmont Region. In this case, the employed instrument was a Topcon GRS1. With this system, it is possible to obtain centimetres accuracies (few cm in plan measurements and few more cm for heights). The positions were therefore compared with the ones surveyed by the integrated simple navigational GNSS receiver in the environmental sensors, and its accuracies were established, in order to verify if these measurements can be sufficient for georeferencing the environmental values without the necessity of further integrations (Table 1).

Table 1. Positioning accuracies of the measurements of the GNSS receiver in the environmental sensors.

	ΔE [m]	ΔN [m]	ΔH [m]
mean	1.37	0.56	-0.33
RMS	1.78	2.10	4.22
min	-0.07	-2.81	-6.25
max	3.18	5.21	7.16

It is possible to notice that the reached accuracy is sufficient for georeferencing the environmental values in countryside context, such as the SIA landfill area. Also considering urban environment in a little detailed scale, this can be sufficient. However, whether more detailed analysis would be required, for example considering the pollution distribution in one street, it could be interesting to install the additional geodetic sensors, in order to verify if some differences in the various parts of a street could be meaningful. Furthermore, in urban canyons, the GNSS signal can be even worse than in the case used for the test, therefore the association of further devices would undoubtedly increase the positioning results quality.

Besides the precision problem, another issue is to be considered for these applications: the dimension of the devices. This is crucial when it is necessary to mount the sensors on a bike: foreseeing the installation of the sensors on a number of bikes (for example on bike-sharing vehicles), they have to be space-saving and light enough. Also for this reason the cited sensors were chosen, including the Ardulog as data storage unit. Moreover, all the sensors were installed on the bike, stored in a 3D-printed box and fixed on a rear rack (Fig.7).

The sensors were tested both in the SIA area and in some urban environment in Turin, and, as it is possible to see by the resulting map of the acquired data (e.g. Fig.12) the positioning was accurate enough. In future works some more detailed acquisition could be performed, in order to determine, for example, if there is a difference among

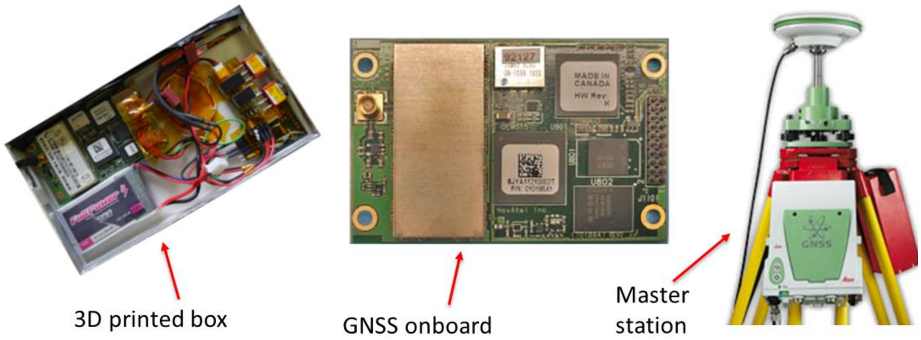


Fig. 7. Instruments composing the positioning system installed on bikes.

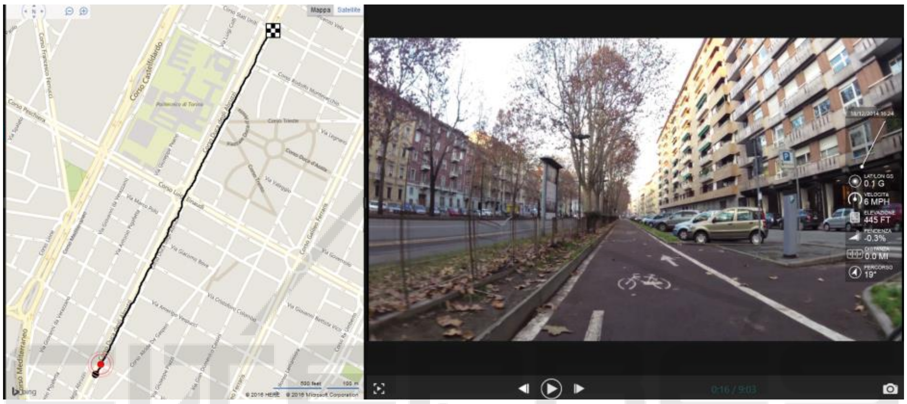


Fig. 8. Synchronous visualization of the video and the camera position on the track on the map.

the various parts of one street and if some factor is meaningful (e.g. the presence of trees or bushes, the distance from the traffic, the presence of a dedicated cycle path, the traffic direction, and so on).

Another sensor mounted to complete the data acquisition is an action-cam. In this case, a GARMIN camera was installed. It also has a simple GNSS receiver integrated in the camera, and a track of the acquisition is available with the data. Specific software can therefore show the georeferenced position of the camera while showing the video (Fig.8). The track has however to be verified, since its accuracies are similar to the ones that characterize the GNSS antennas integrated in the environmental sensors. Also in this case, the values could be eventually improved by using the geodetic cinematic measurements as reference. The GPS time is an effective reference for the synchronization of the data.

The video is essential to contextualize and interpret the data. The images can be support for realizing maps of the city with specific themes regarding the cycling road and path system. The same data can be used for generating 3D city models, which also could be employed for further goals. The advantages of this are obvious when considering the quantity of the data that could be continuously acquired if these devices were installed on a meaningful number of vehicles, such as bike-sharing bikes or volunteers' private bikes. In this way, a large amount of data could be available for processing new information in different areas or for updating the already existing one.

For rapidly and effectively use the acquired data, a system for unambiguously structuring them was developed. Following the proposed standard-based schema (section 4), they can be archived in a GIS (Geographical Information System) and can be retrieved for performing the needed analysis.

4 The Data Archive: A Standard-based Geographical Information System

For correctly managing the information used and produced during the IDEM project, some requirements had to be considered:

- The data to be managed were measured and surveyed by different kinds of sensors, which could be static or dynamic, fixed or mobile, manual or automatic;
- The studied sites should be represented including: digital maps, orthophotos, DTM, DSM, land use and land cover maps;
- The surveyed data by the sensors should be analysed in relation with the site characters;
- The data useful for the study of the odorigenous sources should be introduced, to perform analysis, mapping and modelling operations, and so on, as a support for the planning phases.

The needed entities for these objectives, were organized in a conceptual model, which was reconsidered for being compliant to the existing standards for managing such data. They were mapped to the existing data models, which were in turn extended for being adapted to the specific application. In next subsection the motivations and results of this passage are described.

4.1 Standard Data Models, Ontologies and the SDI Project

The recent developments of informatics and communication technologies made essential to reach some interoperability in the management and sharing of the data, in order to permit a correct interpretation of them and exploit some automatic reasoning procedures deriving from artificial intelligence field [12]. The Semantic web promoters [13] pursue this same aim. A number of standards are published by international organization in order to obtain such interoperability among different-source data empowering the analysis possibilities. Moreover, it is on such exchange possibility and interoperability of the information that the smart city concept is built.

Some basic tools are proposed to reach these goals. The most important ones are the standard languages and formats, and the data models to be used for structuring the data. Such data models are considered ontologies, when having a high degree of generality and including a whole application field. The ontologies permit to integrate in a common frame heterogeneous information, in order to understand, manage and retrieve the data in their very meaning [14], as is, again, the objective of the Semantic web.

The Semantic web (evolution of the World Wide Web) permits to manage the meaning of the data, permitting more accurate searches, based on their nature, and not dependent from the languages and the used word. The data themselves will be managed, instead of the documents, which are at present retrieved in the World Wide Web by means of specific keywords. An essential condition to reach such an objective is to structure the managed data, marking them with their specific semantics [15].

The Semantic Web actors published XML-based languages for structuring and publishing structured data through the web. In the meantime, GML (Geography Markup Language), an XML-based language was developed by OGC (Open Geospatial Consortium) [16] to structure and interchange spatial and geographical data. The geoinformation is essential for smart information retrieval and analysis [17]. And it has to be obviously considered when managing spatial data, as it was required in the IDEM project.

Furthermore, the Internet of Data paradigm is based on the same principles and have these same goals. It was therefore indispensable to consider the interoperability standards and tools in the project of the database.

A first phase of analysis of the existing standard data models and ontologies was realized. The thematic features regarding the air pollution monitoring are included in the SWEET ontology (Semantic Web for Earth and Environmental Terminology). It is developed by the NASA (National Aeronautics and Space Administration) for representing Earth and Environmental Sciences (EES) data and share them through the web [18]. Similar concepts can be found in the European INSPIRE data model [19]. INSPIRE (Infrastructure for Spatial Information in the European Community) is a Directive of the European Parliament (Directive 2007/2/EC) and of the Council (14 March 2007) that establishes rules to realize an infrastructure for spatial information, for supporting the Community environmental policies, and further policies or activities having an impact on the environment. It entered into force on 15th May 2007 and it should be fully implemented by 2019 [20]. The Environmental monitoring is expressly concerned in a part of the INSPIRE data model (Annex III – EF – Environmental monitoring Facilities). Nevertheless the representation scale foreseen for INSPIRE data has to include entities for European policies planning; it needs therefore a low level of detail. The IDEM project studies had a higher definition: therefore, it was important to manage urban data with higher levels of detail. For example, it was also important to include in the analysis the kind of vegetation that are present in the area or near the pollutants sources (conceived both as entire areas and as single tree). For this reason, we considered the open data model, international industry OGC standard, CityGML. Furthermore, also further previous researches effectively used this standard [21]. Its aim is to structure 3D multiscale urban maps; therefore, most of elements of our interest (buildings, vegetation, land use, transports facilities) are already included. Moreover, CityGML presents a mechanism for being extended, in order to adapt the model to further specific application domains, that is the ADE (Application Domain Extension) mechanism. Some ADE examples exists: the CityGML noise ADE or similar ones developed in further projects [22, 23, 24].

Anyway, in further improvements, it would be useful to develop a model including both the proposed ADE for urban levels of the detail and the complex schema given by INSPIRE regarding the Environmental Monitoring Facilities for lower levels of details.

4.2 The AQADE (Air Quality ADE) for CityGML

An application domain extension (ADE) is developed for the CityGML model, in order to include in the 3D city models the data having some influence in the air quality studies. Various CityGML modules are extended by the AQADE (Fig.9), since it is a transversal theme, affecting several urban issues, often reciprocally related. Analyzing the monitored data appropriately structured in the model, that is, in association with their geographic and spatial position in the 3D city model and further parameters (e.g. the traffic at the moment of the survey, the buildings usage, heating periods and so on) it could be possible to define what are the main pollution sources and affected objects. This information would be stored in the model easily providing data for different users: administrators, specialized operators, researchers or simple citizens. For realizing the conceptual model of the extension, as described in [25], the available literature about the application field was analyzed for selecting the needed attributes and entities to be added.

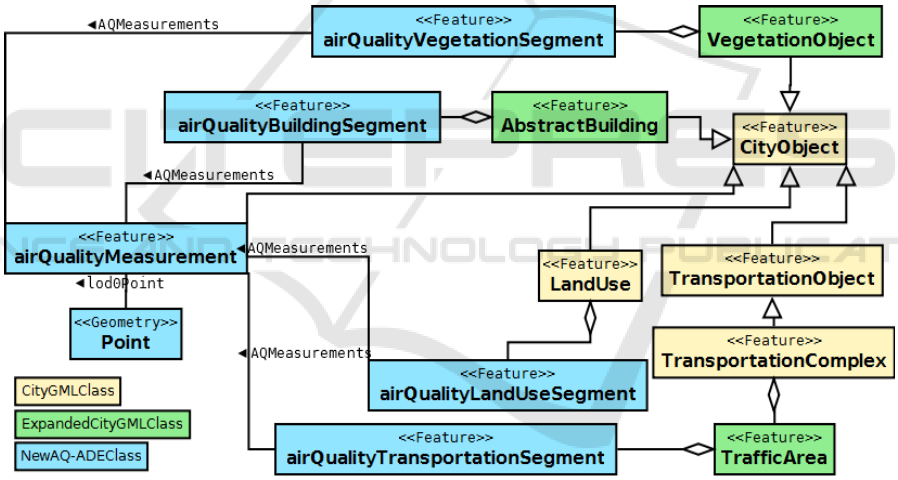


Fig. 9. The synthetic UML schema of the CityGML AQADE.

The ADE was implemented using specific tools. The Sparx Systems software Enterprise Architect was used. Notwithstanding its proprietary nature, it is recommended by the standards documents (for example in the INSPIRE practices). It implements some tools and plugins for managing the conceptual standard schemas in UML (Unified Modeling Language) and translating them in interoperable formats (XSD schemas, OWL, etc.). The CityGML models were extended in Enterprise Architect (EA), and were exported as a GML schema (XSD – XML schema definition) which can be used to structure the data in compliance with the W3C and OGC recommendations. Some problems rest in the translation, since some improvement in the setting files are still needed. Waiting for this progress, some manual editing of the output XSD is necessary. However, using EA procedure, the open and machine-readable structure of the ADE is automatically generated.

4.3 The Model Implementation in GIS

The generated data schema can be implemented in software for really managing the information. Different strategies are possible. In particular, two alternatives should be considered. The more direct one is to use GML data format in order to represent and share the data; the advantage of this is to maintain the object-oriented structure used by the GML models without losing definition in the data complexity. In this case a problem can be the fact that the tools to manage and analyze GML data, especially if they are dynamic data, are still in a development phase, and the resulting datasets could be computationally heavy. Moreover, the available open platforms to share geographic data on the web (as WebGIS, for example georerver.org, which is among the more spread ones) often do not include the possibility to manage the data in GML format.

For this reason, another strategy has been chosen: the model was translated in an SQL database. In the transformation to an object-relational model it is possible to maintain some important relations and, in the same time, to use a simpler model to manage the data, for which a number of affirmed and user-friendly software tools exist. A so-structured database can be shared as a simple SQL statement. The SQL script can be generated from the XSD file by the same Enterprise Architect, or by further software (e.g. ALTOVA XMLSpy or, the open source alternative, Xpad) which are simple XML editors (also a simple text editor, such as Notepad could be effective). The passage through another software is required, in particular, when it is necessary to manually edit the XSD. The datasets produced by filling such schema can be therefore homogeneous and constitute a unique and unambiguous knowledge repository, which can be queried, analysed, inferred and shared.

PostgreSQL-PostGIS [26] was used for managing the produced database, and QGIS [27] was used as a GIS software tool. It was employed both as a graphical interface for querying and viewing the data and as analysis tool. Alternatively, also other GIS platforms can be used, for example, ESRI ArcGIS was employed for performing some interpolations and analysis of the mobile data, as explained in section 5.1.

5 Results and Analysis in GIS

The tables (containing both the thematic and geometric data) can be filled in and managed in the GIS (in this case, QGIS) interface. Here, they can be visualized and queried, symbols can be applied in order to produce thematic maps, statistics can be automatically computed on the data, and they can be analyzed for obtaining useful information (Fig. 10-11).

Fig. 10. GIS layout showing a possible spatial analysis of the dynamic mobile data acquired in the area of the Politecnico in Turin: the average of the values measured in a 50 m buffer of a building can be calculated and associated to the selected building. This can be useful to understand if the activities realized in that building, or its heating / cooling system, and so on, could pollute.

Fig. 11. GIS thematic map of the streets rounding the Politecnico in Turin (entities "TrafficArea") showing the measured PM10 values. This can be related to the traffic present in each street at the moment of the acquisition for understanding, for example, possible relations with the traffic intensity and vehicles velocity. The points represent the positions of the surveyed values by the sensors.

5.1 Dynamic Maps Generation in GIS

It is important to analyze the mobile data also for foreseen the map of the surveyed data in the areas neighboring the travelled path and between one surveyed data position and the following one. This is usually done by means of advanced techniques. Various factors are considered in the methods for modelling the pollutants dispersion. They are complex and include the movement of the air, the terrain topography, the geometry and nature of the objects above it, and so on. Dedicated specific software and methods exist [28, 29].

Despite this, an expeditious procedure for rapidly using the measured data, in order to share even a simplified result with reduced processing times was proposed. The aim was to potentially obtain processed information in almost-real time, once the process would be automated. This could permit to use this information also for supporting rapid decisions tools. For this goal, the interpolation tools implemented in GIS software tools were tested.

Two main methods were tried. The first and simpler one consisted in a plain spatial interpolation of the measured and georeferenced values, by means of different interpolation methods: nearest neighbour (NN) [30]; inverse distance weighted [31] with power value 1 (IDW1), and with power value 2 (IDW2); and the function “topo to raster” in ESRI ArcGIS (TtR), which uses thin plate spline [32].

The tests were performed on the data measured in three sites: two in the city of Turin (urban context, with buildings, heavy traffic, and so on) and one near the landfill SIA, in the countryside, so that it was possible to compare the results (difference in urban canyons presence and the topography complexity). In all the three cases, the IDW2 method results to be the more accurate one, as verified on the checkpoints values. The checkpoints are measured points, having therefore known values and coordinates, which are not considered in the interpolation, but are used as a reference for testing the interpolation accuracy. The discrepancies between the checkpoints values and the interpolated raster were obtained using automatic statistics computation tools in GIS tables. The results show how the estimated values by the interpolation have accuracies (RMSE) that are always in line with the precision of the measuring instrument. There are not systematic errors (since the average values are smaller than the RMSE) and the best interpolation method results to be the IDW2. This method will be used in eventual automatic on-line processing services implementation, since this method is suitable for obtaining a rapid processing, the regularity of the results and a limited approximation, avoiding excessively hypothesised values.

A more complex method employed a multivariate linear regression taking in account some factors influencing the dispersion (temperature, humidity, bike speed, luminosity, terrain height, curvature, slope and solar radiation) [33]. However, the results on the same checkpoints underlined how this method is not useful to improve the quality of the interpolation, although being more complicated. The further parameters are therefore to be considered in a more complex context, but for having a simplified and expeditious indication, the first spatial interpolation was sufficient and more accurate.

6 Conclusions

Geomatics was an essential support to the environmental monitoring activities performed during this project. The spatial and geographical reference is fundamental for the environmental studies.

Geomatics issues were employed for three kinds of data (static, dynamic and mobile), to respond to three kinds of problems: the correctness of the reference site geometry, the precision of the surveyed mobile values positions, the use of these known data in geographical information systems (GIS). This last activity permitted their sharing (through a standard-based data model), their management by means of GIS software tools and their spatial processing for obtaining further data. The so-managed data became unambiguous and therefore they can be effectively called “information”. The reference to the standard ontologies also assures the semantic precision of the shared knowledge.

Besides guaranteeing the metric accuracy of the produced and analysed data, the performed activities permitted the expeditious updating of the known data and the rapid availability of the produced information. This could be fundamental for performing any kind of analysis or, for example for delivering some particular service.

These activities could play a fundamental role also in building the smart cities infrastructures.

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