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RESEARCH ARTICLE

VGI in surveying engineering: Introducing collaborative cloud land surveying

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Abstract: Volunteered geographic information (VGI) has enabled many innovative applications in various scientific fields. This paper introduces a new framework called "collaborative cloud-based land surveying" (CCLS) that uses VGI principles for data sharing among surveyor engineers to boost the productivity and improve the quality of their applications. A cloud-based spatio-temporal data repository is presented, aiming to facilitate the sharing of VGI among surveyor engineers. A fully-functional distributed software application has been developed and used to apply CCLS in a large-scale land surveying project run by the Greek Ministry of Culture, which involves the mapping of the historic center of Athens. Results from the data analysis of hundreds of measurements indicate a substantial (30% to 60%) error reduction and also a significant productivity raise ($\sim$22%). The collected measurements are shared in an online database, accessible by professional surveyors who can in turn contribute their own data to further enhance the CCLS system.

Keywords: volunteered geographic information, engineering applications, spatial data and service sharing, collaborative cloud land surveying

1 Introduction

Information sharing and reuse on the internet has largely revolutionized many human activities ranging from research to daily life activities over the past few years [1, 25]. Global geo-spatial mapping applications currently available on the internet, enable the development of communities that share all kinds of geographic as well as geo-referenced data, organized in collections [20]. The term "Volunteered geographic information" (VGI) was introduced in 2007, as "a special case of the more general Web phenomenon of user-generated content" [8, 10, 13], and has been widely used in various fields including navigation and mapping.

Two of the most successful and popular projects that follow the principles of VGI are OpenStreetMap (OSM) and WikiMapia, both of which aggregate mass geo-referenced data collected and assessed from various sources, in collections that one can freely access and process in order to deliver new geo-spatial products or services (OSM counts over 3.1 million users and 5.4 trillion GPS points uploaded at the time of writing [24]).

Often VGI is wrongly related to crowdsourcing because of their common "sharing" property. Latest studies indicate that crowdsourcing and VGI differ by information clarity, purposes, abilities to control collection and reusability with VGI referred as geographic information collected with the knowledge and explicit decision of a person [15].

The quality of the VGI data is certainly affected by the volunteers. In fact, Coleman et al. [3] discuss that the contributors of VGI information are categorized into five overlapping classes ranging from users that have no background (i.e., neophyte, interested, amateur) to those that have high expertise in a subject (i.e., expert amateur, expert, professional, and expert authority). Doing so, Coleman has set the basis to evaluate the quality of a VGI project's datasets since the contributor's capacity defines the potential usage of geographic data collections.

There are many international examples towards a professional-wise VGI concept. A typical one is the ESRI that hosts the Community Maps Program and provides the means to geographic information creators to share their authoritative content with the global GIS community while still retaining their intellectual property [11]. Also, national map agencies of various countries try to implement as much as possible VGI data into their products but there are constrains regarding data precision due to the "importance that the mapping agencies place on maintaining their reputation for high quality products" [23]. Generic governmental usage is also challenging but Johnson and Sieber [16] have discussed that whilst there is resistance to the acceptance and use of VGI a more formalized VGI collection process, with a focus on data quality and strict controls to contribution, and crowdsourced verification may prove beneficial. Also, Spielman indicates, "the critical question is how to ensure that the collection of contributions is high quality; this may or may not be contingent on the quality of individual contributions" [33].

VGI systems, regarding community participation, provide access to two categories of users, namely contributors and consumers. In the contributor side, there is the "expert" restriction factor that does not allow massive citizens participation as seen in typical cases. This generic approach is not new in VGI applications. Linda et al. [31] has recently identified "high level data sharing websites contributed by experts" in the corresponding study, in a ratio of four over 100. On the other hand, VGI consumers spread horizontally over operational, research, and educational contexts. The corresponding geographic information accuracy is better than any other VGI system, thus it is expected to have a direct impact on both extending existing and developing new use-cases.

A scientific field that benefits significantly of information sharing is that of engineering surveying. This is because surveyor engineers traditionally work in the field, collecting data in order to determine with high accuracy the shape of areas and the positions of points on the earth's surface along with features of interest [19]. The basic surveying measurements of angles and distances are obtained with high accuracy measuring instruments (total stations). However, such types of data often remain private and isolated within the context of the project that were produced in. The surveying engineering community has not yet exploited the enormous potential of sharing data, which can significantly improve the productivity and reduce the cost of the field measurement process.

This paper explores the perspective of using the VGI concept in the scientific field of land surveying. A community made by surveyor engineers and generally spatial related scientists that would contribute their data to a well defined, standardized VGI system, can bring many benefits with shared high quality field collected measurements and produced geographic data. Such an approach would also fit well into governmental and mapping agencies' workflows regarding data collection and sharing.

1.1 Collaborative cloud land surveying (CCLS)

This paper introduces the "collaborative cloud land surveying" (CCLS) concept, which is a specialized methodological framework focused on implementing VGI in surveying engineering applications. Focus is placed on land surveying applications using total stations for data collection, as this is the most common practice in routine surveying. Other methods like GNSS (Global Navigation Satellite Systems) as well as techniques based on image processing (photogrammetry, remote sensing, etc.) that are also used in surveying applications are out of the scope of this work.

It is very common in the surveying profession that when the final results are delivered the raw data are practically rendered useless, stored in digital files without any standard structure or metadata that could make these useful to future users. The same stands for other related data types that support mapping processes, such as digital photos or relevant public records. The above remark is of special interest considering that surveying of a particular area can be performed several times by different teams, for different employers, projects, etc. However, the re-usability of measurement data is of major importance as it would offer multiple benefits, such as:

- Productivity boost and cost reduction due to the reuse pre-existing and validated available information;
- Accuracy improvement due to additional data that will be made available for processing;
- Detection of erroneous observations or measurements;
- Possibility for temporal analysis of data for the same geographical area; and
- Enabling of new applications that can make use of the data, possibly together with other VGI openly available for the same geographical area.

The objective of the CCLS introduced in this paper is to provide a methodology, and specialized VGI data processing framework to achieve all of the above. To meet the needs for surveying engineering applications and accuracy requirements a data structure and format, is proposed, to facilitate the sharing of VGI information among surveying engineers. The equipment networking and measurement processing will be described, using data casting technologies and portable processing units along with integrated Web-GIS services, as a new methodology for land surveying. This methodology can largely benefit from applying the above concepts that combine in the field measurements, processing, sharing, and validation in real-time. The core of the proposed approach is found in the VGI behavior concept for geo-data sharing and exchange.

It is emphasized that CCLS refers only to "Expert Amateur", "Expert Professional," and "Expert Authority" contributors. This is because research with focus on VGI data quality and especially in comparison to corporate authoritative data, has indicated that corresponding datasets can be comparable if not better regarding quality and completeness [14, 18]. Elwood, Goodchild, and Sui acknowledge that through VGI, "a vast amount of data is becoming available through this mechanism and that these data are a rich and immediate source of information for a variety of purposes" [24]. However, data coming from citizens without appropriate knowledge have not yet proven to meet the standards of topographic base projects [4].

This paper is structured in six Sections. In the second section, an early prototype of a fully functional system developed and used to apply the proposed methodology is presented and potential use cases of the proposed system are discussed in Section 3. Section 4 presents the case study. The case study of the proposed methodology involves a large scale surveying task using networked total stations for the mapping of the historic center of Athens under the auspices of the Archaeological Cadastre project of the Greek Ministry of Culture. Section 5 provides a discussion of the results and analyzes the method's benefits. Finally, Section 6 gives the conclusions of the work.

2 Method and architecture

Manufacturers of surveying equipment such as total station work integrating in the field computational tools. Most of these implementations are currently limited in off-the shelf total stations providing mainly transformations of coordinate reference systems and visualizations of points of interest. Lately, efforts are made in integrating connected portable devices with total stations in order to upgrade their capabilities at a minimum cost adding visualization, image overlay and field data file sharing with the office [26]. Clearly, there is a need to unify measuring and processing tasks in the field. The drawback is that every commercial product of this category follows its own standards and do not target or allow creating a community that would share measurements and GI in general outside of an individual or company context. The evolution of cloud computing enables the creation of a system for sharing surveying measurement data for engineering applications [30]. The ability to share data over the internet provides many advantages, such as real-time measurement, processing synchronization, and dynamic interaction; in the field accuracy estimation and erroneous observation detection; and access to online shared data both for downloading and uploading measurements. Also, multiple synchronized total stations sharing data can speed up the on-field measurement progress and collaboratively achieve the detection of critical measurements that are missing. Important aspects are also the in the field metadata collection and sharing, visualizations of the processed data, real-time progress monitoring, and dynamic work reorganization. The proposed method aims to integrate the acquisition and processing of surveying-accuracy data, and also to provide access to shared data captured by other Surveying Engineers.

The synchronization of raw measurements allows for real-time data flows from and to any connected total station, while project overview and progress indicators are also available to authorized clients. There are two main types of actors: "Data collector" that refers to all types of activities that capture measurement data in the field, and "data manager," that allows users to process collected data. After discussing these entities, a database schema for storing all data is presented; finally the main in the field functions are reviewed. Figure 1 illustrates an overview of the proposed architecture. The data collection equipment interacts with portable processing units (tablet, smart phone). These units handle the equipment, get the observation information, synchronize with available data in the shared database, and execute all required processes. The central measurement database contains information from past measurements and synchronizes with multiple data collection units at the same time. Data management units are system clients that connect to the database and make use of more advanced services, like project overview, final measurement filtering, observation processing, etc. The system components are further analyzed in the following paragraphs.

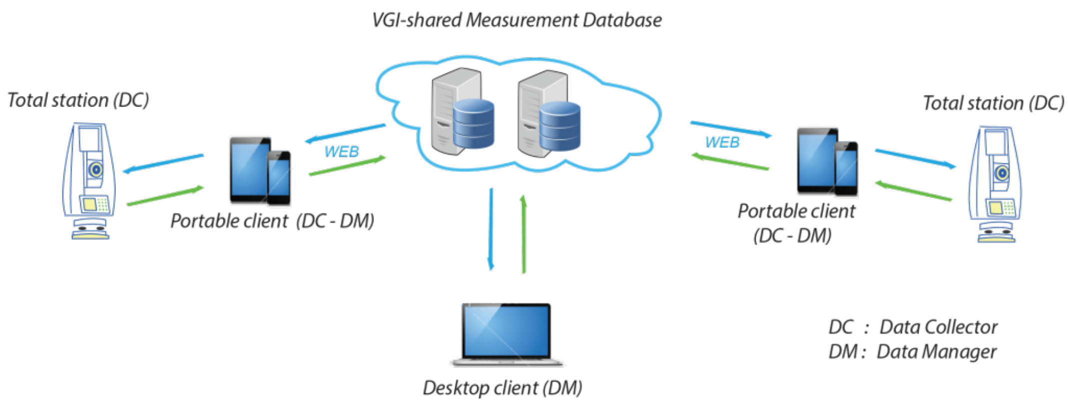


Figure 1: Networked measurement stations, VGI database, and data contributors.

2.1 Data collection

Every device that is used to acquire data in the field is referred to as a data collector. The essential data collector is a total station with data communications functionality and network access. Every record of data contains the following fields: slope distance, horizontal angle, vertical angle, and target height. By using as a reference the total station position coordinates, along with the above information, the position of any point can be determined. Notably, except from models that natively support wireless communications, most total stations that allow serial communications for data and command processing can be used together with some aftermarket serial-to-wireless adaptor.

Total stations for routine surveying applications do not allow network and visualization functions, nor do they offer any programming framework in order to develop the software required. On the other hand, powerful handheld portable devices provide processing abilities at very low cost, especially since the introduction of the Android ecosystem. Therefore, any Android tablet or smartphone doubles as a great tool for data management. In the case study to be discussed in the sequel, a Nexus 10 tablet (10′ screen, 2 core 1.7 GHz CPU, 2 GB ram) and LG G2 mobile phone (5.2′ screen, 4core 2.2 GHz, 2 GB ram) have been used, connected via Bluetooth to a total station. The software that has been developed uses the Bluetooth connection to send the appropriate commands and waits for measurement data to be received back (slope distance, sd; horizontal angle, hz; vertical angle, vz). Thus, the software takes over the handling of the measurements. The total station receives the commands and responds by supplying the measurement data (i.e., hz, vz, sd) as seen in Figure 2.

Additionally, other portable units can be configured to capture attributes of objects, metadata, and tagged photos and further manage network data flows. Given that total stations with limited programming capabilities can also be used, the portable devices become the mediator for routing data to a cloud-hosted geo-database, via a mobile data network.

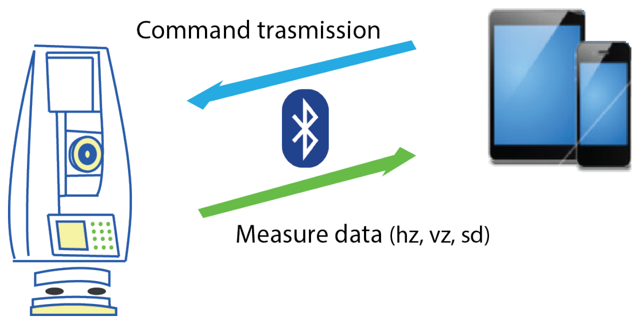


Figure 2: Portable device total station communication.

2.2 Data modeling

Geographic information is intended to be stored in a cloud-hosted database as surveying engineers upload measurement data, according to CCLS. The data model of this database should overcome the information heterogeneity issue, using a global modeling approach over collected data [9]. This project integrates Open Geospatial Consortium (OGC) standards in order to serve spatial interoperability and also extends selected objects where additional modeling is required.

The two main object types used, that are of interest to this project and OGC has provided standards for, are "Observations and measurements" and "Simple feature." Observations and measurement (OM) standards define a schema for observations and features involved in sampling environmental quantities using the appropriate sensors [22]. In surveying engineering, these are angles and distances [19]—vertical angle [V_A], horizontal angle [H_A], slope distance [S_D], feature height [H]—acquired by total stations (Figure 3) and possibly photos and GNSS coordinates.

The above fundamental observable quantities are extended to model spatial entities: geometries (points, lines, polygons, etc.), and also include metadata and additional attributes needed to fully describe both the physical and abstract objects [21,32]. Along with feature geometry, the reference system object defines the globally absolute position through the selected coordinate system. In this work, the "reference system" database object is defined according to the standards of Geodesy Subcommittee of the IOPS Geomatics Committee. The dataset model developed and implemented in this work is discussed in Section 2.4.

Figure 4a shows the "LS_Process" class that is an extension of "OM_Process" class of OM OGC standard. Each discussed attribute is implemented so that the "LS_Process" object can effectively describe the actual Land Surveying process. Additionally, Figure 4b depicts the "LS_Observation" class. Other classes are introduced to define and integrate

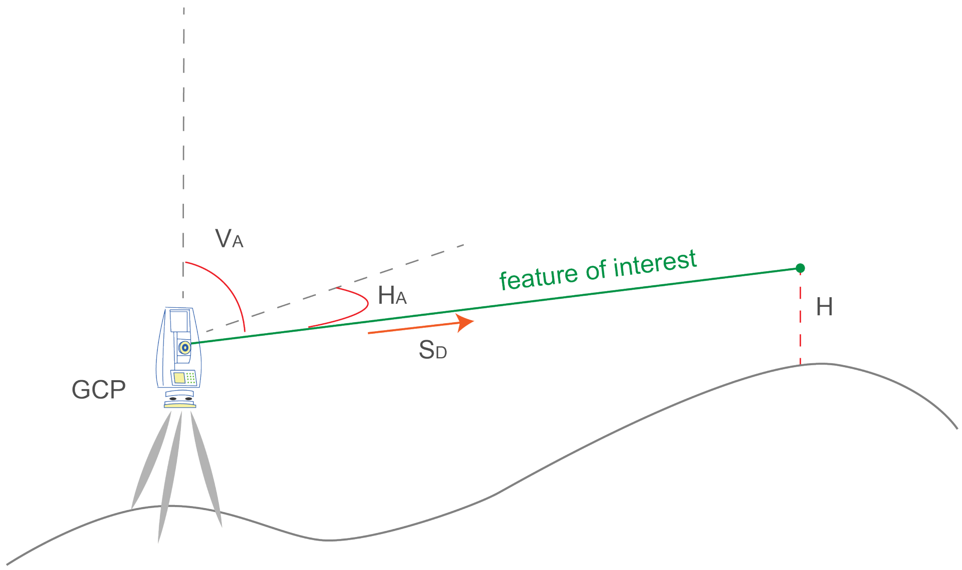


Figure 3: Illustration of observable quantities using total station equipment.

into the model the required entities of operator, total station, accuracy, and ground point instance.

"Control points" (CPs) are the main entities that are used to put the observation set in a coordinate reference framework. Their position is usually defined by using measurements of distance and angle relative to other, known control points. They form networks (reference networks) and are used as the basis for computing all other points' positions. In a national level, control points are managed usually by authorities responsible to maintain and provide information about their position. Such authorities are the Military Geographical Service and National Cadastre for Greece. Land surveying applications require a denser network than the national, so surveyors use one or two national control points as a starting point to establish their own. However, this new network is later unusable, as there is no access provided to other surveyors. This fact indicates that a new network should be re-established in the same area, though the same could be used if there was such an option. The goal is to make the surveyor engineers' established control points reusable, which means that anybody can have access to their data.

A typical workflow includes the establishment of the reference network, the acquisition of raw measurements in the field, as well as the post-processing of measurement data, either by software embedded in instruments or by desktop software. Whatever the case, this process is based on the following concepts: (a) every measurement station is an autonomous "data creator" and (b) the measurement workflow consists of two discrete steps, executed sequentially: measurement acquisition and processing. Regardless of whether the processing of measurements is performed by total station software in the field or in a post-processes mode in the office, there is no dynamic interaction between the acquisition and the processing of measurements. In this context as "dynamic interaction" is considered any decision-making activity that can impact either the measuring workflow (e.g., decision on what to measure next), or the validation of the measurement accuracy using mathematical

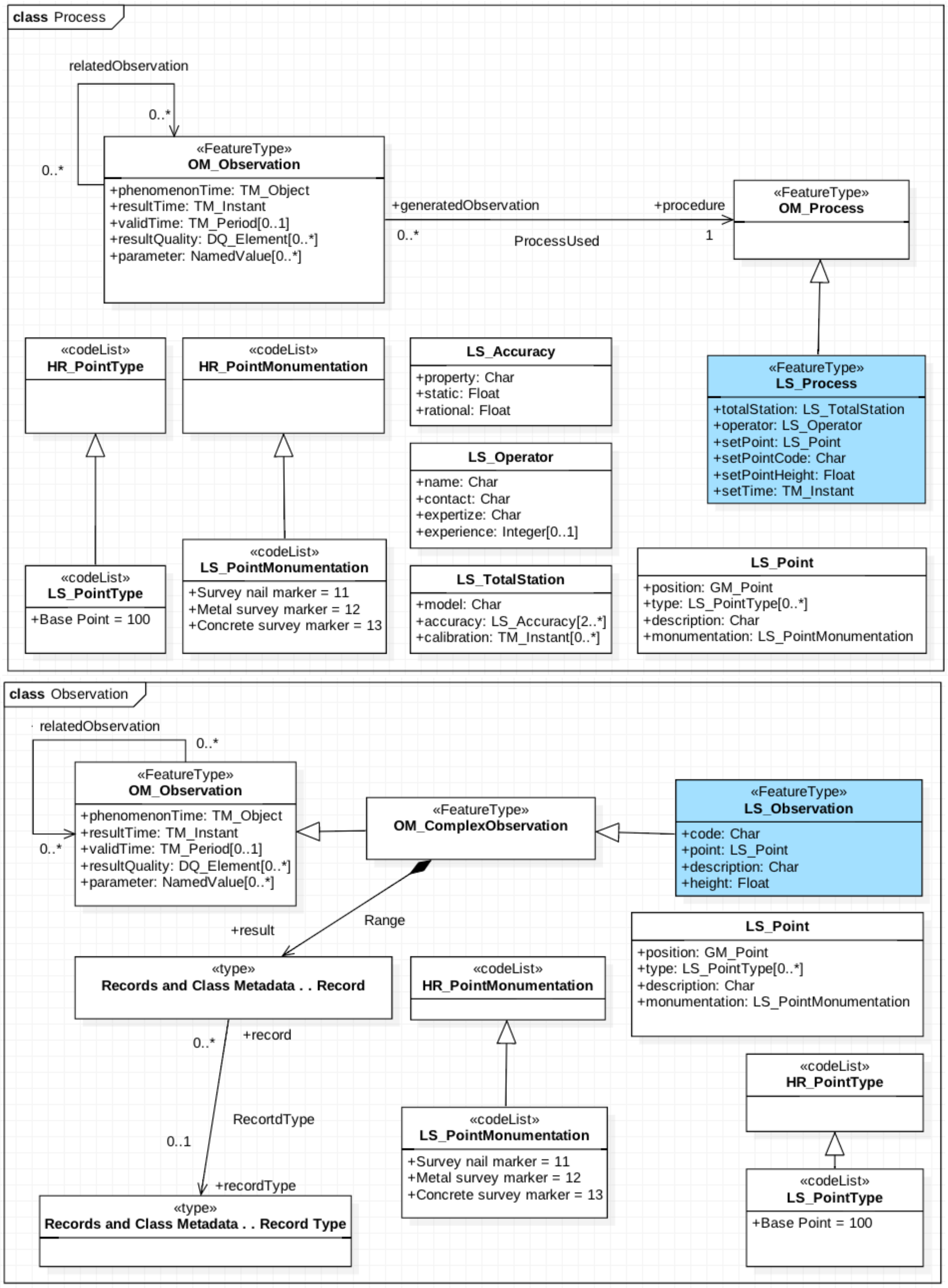


Figure 4: a) OM inherited process model, b) OM inherited observation model.

calculations. As a result, errors discovered during post-processing can only be resolved by back-tracking, which in some cases means re-visiting the field for new measurements.

A control point has the following attributes: description, feature (location, accuracy), time, and creator. Every time a total station is set over a control point for measuring purposes, the recorded raw measurements are grouped into sets of data that share similar properties. This is achieved using the object "Measurement_Set," which is the core entity. As the raw data come from the total station, an instance of measurement class is created. Basic attributes include the horizontal and vertical angles, slope distance, target height, and metadata. The above objects are the minimum required to define the model. Additionally, timestamps and other relevant metadata that refer to spatial resources' description extension [7] could be used in order to define an ontology-based approach to describe each point [12, 29]. Currently these extensions are not included in the software but will be considered in the future.

As the position of measured features on the earth's surface could change over time (e.g., sidewalk reconstruction, building movement after earthquake, or infrastructure network reform), the proposed approach allows for temporal management of measurements to track phenomena of such nature. Figure 5 describes different cases of determining the position of the same control point (CP0). There are approaches like multi spatial (when CP0 is determined by different control points), multi user (when different users determine the position of CP0), and multi epoch (when CP0 position is determined over different timeframes) [5, 6, 27, 34]. This fact allows for the determination of the accuracy of user equipment as well as for the detection of time-based changes.

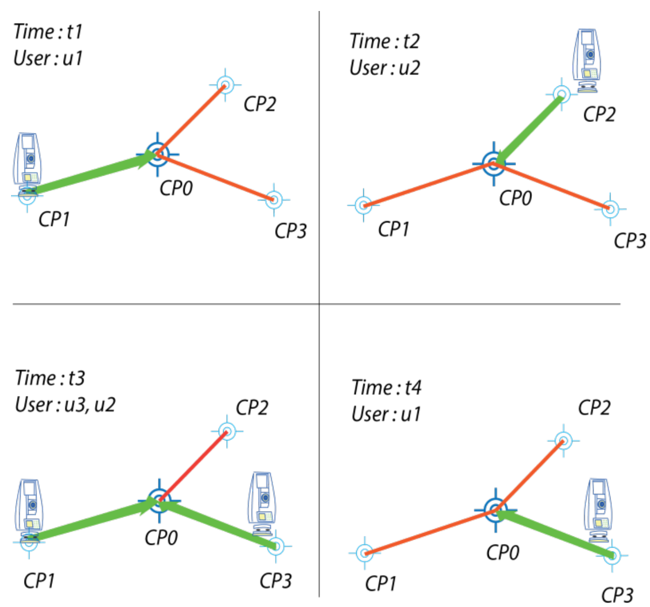


Figure 5: Multi user / time position control point definition.

In Figure 5, the objective is the spatial definition of CP0 by acquired observations. Different users (u1, u2, u3) contribute in the definition of the control point, over the four illustrated cases (multi user approach). Multi-spatial definition refers to the definition of CP0 by different control points (CP1, CP2, and CP3). Finally, definition over variant time (multi epoch) is obvious as there are four cases of observations that take place in different time instances (t1, t2, t3, t4).

2.3 Data management and processing

Data management and processing are procedures that both must be executed in real-time, to allow access to all available information in the field as well as in the office. In this work two types of system clients, namely portable (in the field) and desktop (office) have been developed. Each client type receives and offers distinct functionalities using appropriate tools and functions, which are discussed in the following sections.

2.3.1 Portable client

The portable devices, as described in Section 2.1, interact with the total station, in order to receive raw measurement data. Together with the data collection, the devices are employed for three more important tasks: data routing, data processing, and information visualization. Appropriate software for this project has been developed in Android OS that enables all the above operations to be executed.

a) Portable client: Data routing The portable clients perform the data routing, since total stations have limited functionality. The first step is the control of the total station over Bluetooth, which is followed by the measurement data response. The developed software gathers the raw measurement data that may be enriched with other types of data (e.g., photos, metadata, spatial attributes) essential to extent geometry and enhance potential usability [17, 28]; these data are stored locally in order to have offline access, and are also sent to the system server over a wireless internet connection. The final goal is to achieve data synchronization both on user request and real time when possible.

b) Portable client: Data processing One of the main advantages of the proposed architecture is the real-time data processing during data collection in the field. This allows the surveyor to validate the collected measurements, detect erroneous observations, verify the integrity of measurements by eliminating a possible lack of measurements—as the real-time processing can detect missing information, and integrate all available data. In order to make this possible, computations of the positions of the entire control point network are triggered upon any new measurement data entry. In this way, whenever the local device or any connected network device provides new data, the network control points positions are updated (if the user selects to integrate all measurements available). The user can continually evaluate the full dataset easily by having any conflicting measurements highlighted, prompting for a review.

c) Portable client: Data visualization Portable devices are equipped with high definition flat panel displays capable of providing an advanced visualization experience. The developed software displays both raster maps and vector generated data. Geo-referenced maps, web map service (WMS) tiles and orthophotos of the area of interest are preloaded on the device and used as a background for overlaid vector data. In the project described in this work, orthophotos provided by the National Greek Cadastre Service are used as a background, providing 20 cm accuracy level over urban areas, allowing for gross error detection and removal (every measurement that contributes in over 20 cm position error of measured point is immediately recognized). Regarding vector information, there are multiple cases of spatial data usage. Preloaded vector files can be projected over the project workspace, in order to be compared with the collected data (KML files have been used for our case study). Every time the system recalculates a feature's position, it gets drawn over the raster images and the available layers containing the vector information. As mentioned above, this results in the detection of erroneous observations, which are highlighted on the screen. Figure 6 and 7 give examples of visualization modes as developed and used in the current implementation.

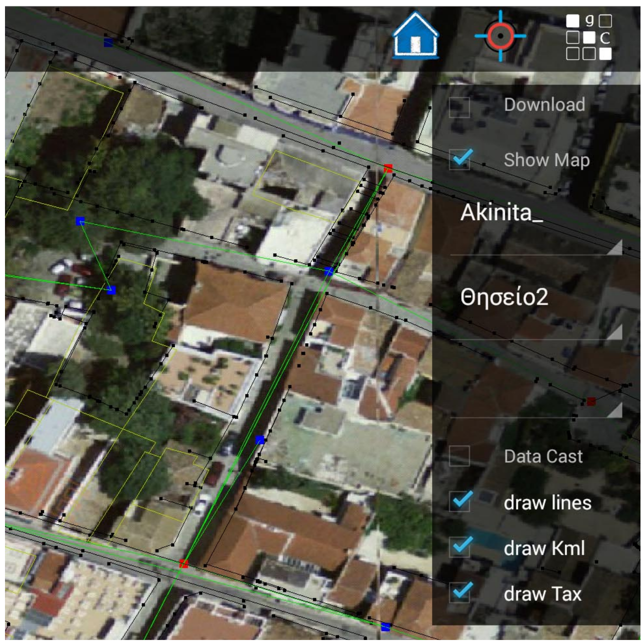


Figure 6: Portable client WMS visualization.

2.3.2 Desktop client

Project administration overview (including the field work monitoring) is also possible via dedicated software. The desktop client developed for this project runs in a web browser environment, enabling the project management and granting administrative rights (project creation, global variable setting, grant user access, set available layers, etc.). Also there are several functions provided additionally to those of the portable clients, such as project creation, project edit, progress overview, computations finalization, report export, and quantitative tools for the purposes of this research. Moreover, as the web application has been developed in JavaScript, HTML, and PHP programming languages, it is possible to hand out the system functionality through an application program interface (API), which will allow further extensions by the community, according to the current trend in platform-independent collaborative software development.

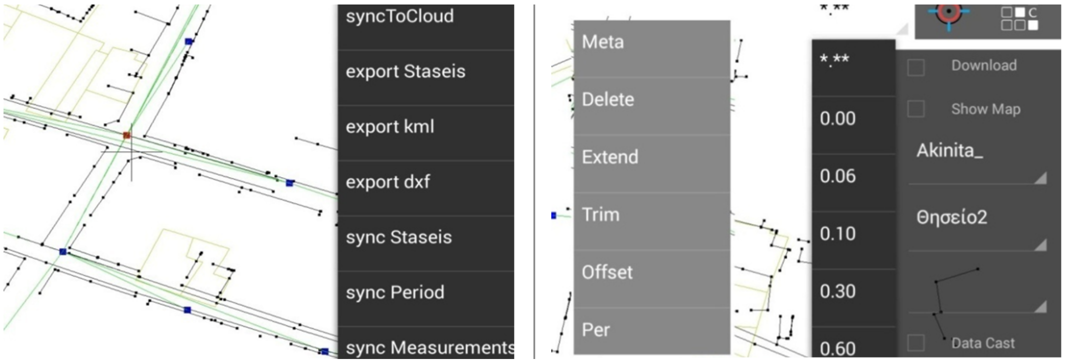


Figure 7: Portable client vector visualization.

2.4 Client-server software

Centralized data management requires a database. Through the selected database management system (DBMS), the developed software can implement data management functions such as input, storage, and retrieval, while ensuring both data integrity and security. The current implementation uses MySQL, an open source DBMS, on a typical Linux distribution (Ubuntu).

The client software, on the other side, is developed for Android 4, using the Java Eclipse IDE. The portable devices are able to offer the appropriate functionality deriving from modified calculation algorithms to match the project needs. The software for this project has been developed in Android OS, which is an open OS, and also is the most popular platform of the majority of tablet devices. Research on Android usage in the field has been already in progress [26].

2.5 Data quality

One of the most fundamental concepts to be discussed is the management of measurement quality. Precision estimation and processing is of critical importance to the community of land surveying engineers, as high accuracy specifications have to be met. This requirement sets quality as a factor to be exploited in order to define the necessary data flows, tools, and services to achieve an effective management of precision and error. This section discusses three types of measurement evaluation data sources, namely a priori, statistical, and user provided.

2.5.1 A priori (equipment specifications)

Land surveying measurements are acquired using special equipment (laser distance meters, total stations, GNSS) that provides information regarding the precision of observation procedure (precision specifications). CCLS database registers this type of information so that every measurement provided can be retrieved along with both the equipment precision specification and information regarding calibration activities. This ensures that users that have access to provided datasets can evaluate the compatibility to their project's requirements.

2.5.2 Statistical

Every measurement collection is typically used to compute the coordinates of features of interest. This process benefits from advanced computational workflows that make use of statistical models and algorithms that manage error metrics and estimate a posteriori observation errors along with coordinate errors. For example, if the sum of three angles of a triangle is greater than 180 degrees, the difference is assigned as error. Accordingly, statistical error estimations that refer to distances are produced during the same process but also final position uncertainty (x, y, h error estimators). All the above error values can be attached to the observation, so that multiple quality indicators can be available to any consumer of the data repository.

2.5.3 User feedback

One of the most important factors that will ensure the quality of the available information is the user themself. The user can provide feedback regarding the observation quality in many aspects:

- Repository measurements are available in the field, enabling this way the user to verify them in comparison to his observations. When a measurement is indicated as erroneous as the difference from the repository version is over the accepted threshold, the operator repeats the measurement verifying this way the correct value. This piece information is a continuous observation error watch mechanism that ensures the quality as more measurements are available; and
- The processing of measurements results through supervised filtering most of the times, where user goes through iterations in order to achieve the best possible result. This workflow requires the user to add or remove measurements accordingly until he reaches the best result. The information of ignored observations can be a valuable indicator that can also be attached to the measurement entity.

Every "operator-equipment" entity that provides a number of observations to the described system, also generates multiple error estimators according to the above discussion. The total of these measurements can be used to generate an observation quality index that is attached to every measurement.

3 Use cases

The previously described architecture introduces new tools and concepts that can be used in land surveying, allowing specific use cases to take place and meet specific needs. In this section, parameters that define the context of a project's execution are used in order to categorize its requirements and define the appropriate process, which will help users to achieve the targeted work optimization. Figure 8 illustrates a classification diagram by capacity of the measuring crew, used to determine the required methodology adaptation.

The first parameter is the dataset density and reliability that CCLS data repository provides to authorized users. In Figure 8, DB content is categorized into three states of dataset availability, pictured as radial zones. The vertical axis is used to define a project's requirement for productivity/accuracy balance, as these attributes are generally competing to each other. The Horizontal axis denotes the capacity of measuring crews, ranging from "beginner" to "expert."

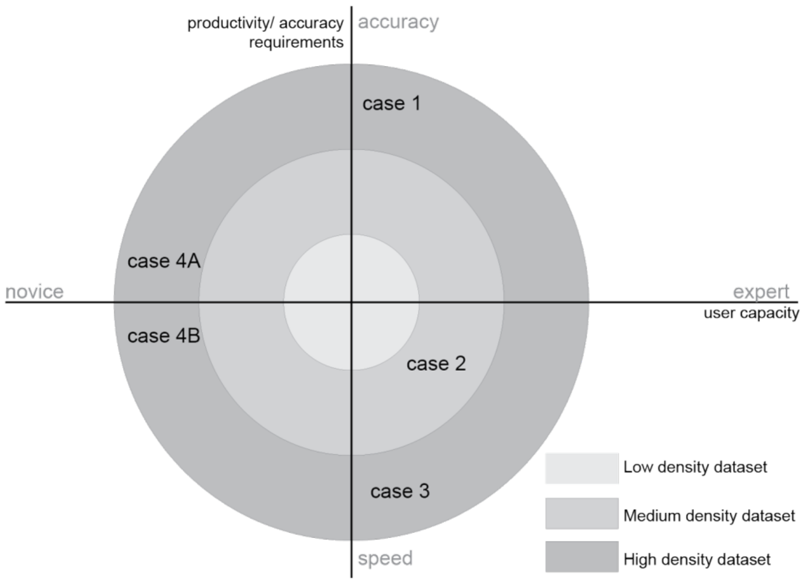


Figure 8: CCLS use case classification.

In the indicated segments of this circle, the above factors define a specific requirement combination as the context of a use case. "Case 1" area describes a project that is specified by high accuracy demand, executed by expert users, while the CCLS database provides a high density dataset. These attributes match projects that collect high accuracy data. "Case 2" and "case 3" segments refer to projects where time is critical, executed by experienced users and data availability is of medium and high density respectively. Finally, "case 4A" and "case 4B" require high density, validated datasets available on the cloud in order to grade beginners in situations of high accuracy and limited time availability. These are described in the following.

3.1 Case 1: Feature movement monitoring

In projects that require monitoring of features or infrastructure networks, high accuracy measurements are collected and compared to past data in order to detect possible movements. Such tasks are executed by experienced surveying engineers while the availability of temporal spatial data by CCLS is of critical importance. These types of projects combine all of the above specifications while CCLS set the framework that ensures execution optimization. Figure 9 shows the UML use case diagram.

The proposed methodology provides the data store and access tools that are capable of managing spatio-temporal data. The project manager has access to the full dataset contain-

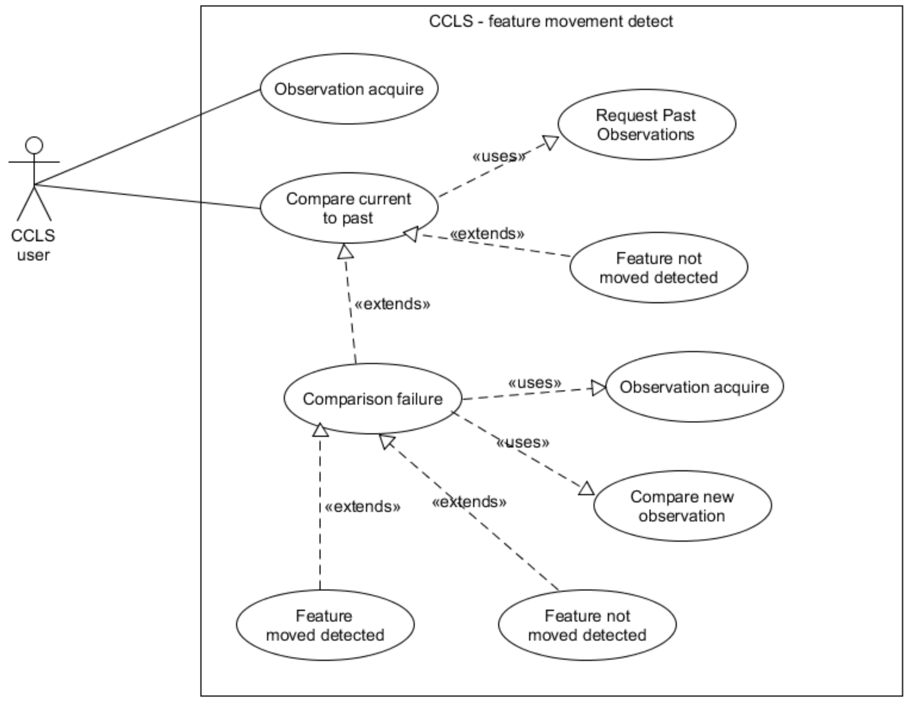


Figure 9: CCLS feature movement monitor use case UML diagram.

ing both their own team's collected data and other available measurements. On-the-field access to available data ensures that real time observation divergence detection is possible; this is a unique feature of CCLS, which enables a significant measurement accuracy improvement as is discussed in Section 4. The above functionality automatically triggers measurement repetition requests; once executed, either an error has been corrected or a feature movements have been detected.

3.2 Case 2: Multiple stations

Time can often be a critical factor in land surveying projects, especially in large scale projects where multiple land surveying groups collect data simultaneously. Problems that usually come up in organizing such tasks include group area overlap, control points naming conventions, and complementary observations on area bounds

The CCLS framework uses the concept of a real-time collaborating total stations network (total stations that exchange data over the Internet in real time). Multiple total stations populate the CCLS cloud-hosted database with observations that become immediately available to the rest of the total stations working on the same project and area, allowing each user to overview the progress of the whole project in real time. Users who collect data in adjacent areas have immediate access to all the measurements and features that have been already surveyed by others, which is useful in detecting both errors and missing measurements. Figure 10 shows UML use case diagram.

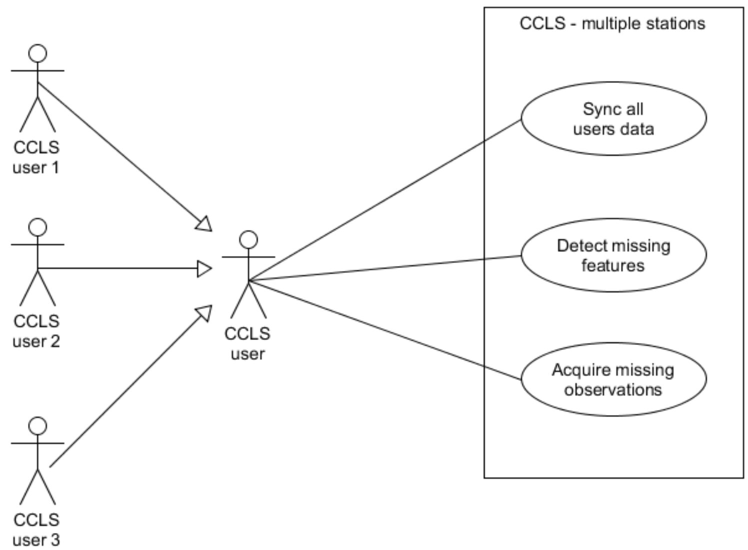


Figure 10: CCLS multiple stations use case UML diagram.

3.3 Case 3: Fast track

Another type of project where time is of critical importance is defined by areas where data exists in the CCLS data store at a medium-to-high density. In such projects, users of the CCLS approach can maximize the reusability of information. CCLS provides the context of data sharing, access, and reuse. Surveyor engineers can evaluate existing information accuracy by re-measuring a sample of the provided dataset, verifying that it can be used as is. Any missing measurements for their specific project can be re-measured, which will be also contributed to the cloud-stored database. Figure 11 shows a fast track UML use case diagram.

3.4 Cases 4A 4B: User capacity grading

There are cases where high density verified spatial information are available and there is the need to evaluate how the land surveying process is applied by novice users, such as trainees. This case can be part of a teaching process. Cases 4A and 4B (cf. Figure 8) consist of high density, validated datasets, which according to CCLS are made available to novice users in conditions of both high accuracy and short execution time limitations, respectively.

The typical teaching methodology has been found inappropriate to help students exceed the three bottom educational cognitive levels of Bloom's taxonomy (remember, understand, and apply). The main objective of land surveying education can be considered

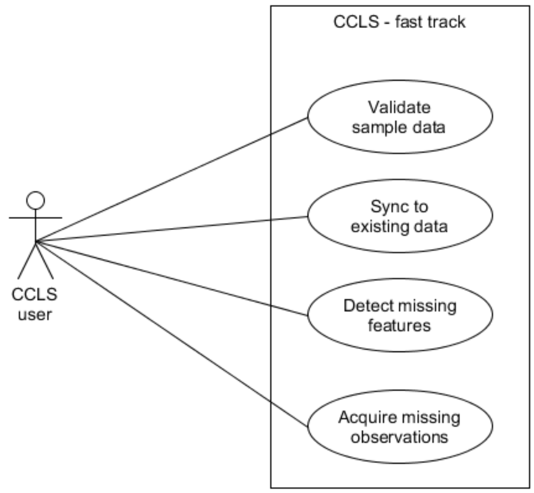


Figure 11: CCLS fast track use case UML diagram.

to be dealing with measurement error management through spatial procedures and algorithms. It is not possible to detect error sources or trace the propagation of the error through applied data processing algorithms due to restrictions such as:

- Predefined site study area. In university campuses of surveying engineering schools, there are usually areas used by students of land surveying courses in order to exercise their skills. These areas are used every year and observations are repeated by different users.
- Lack of error detection directly in the measurement procedure.
- Lack of "true" values of measured quantities. The traditional Surveying Engineering teaching process compares the final product (2D plans) to validated datasets in order to evaluate the skills of novice Surveying Engineers. Errors can be detected, but information of failure source cannot be extracted.

Figure 12 shows the UML use case diagram.

On the other hand, CCLS can grant novices access to validated data to improve this process. Every collected observation can be evaluated in the field in real time so as to trigger repetitions of measurements where needed. If this is part of a learning process, the measurements can simply be stored without notice and be used to create an "observation error" profile that specifies weaknesses in each student's practice. Teachers can use this analysis to improve the teaching process and provide personalized corrections and instructions to each learner. If this process is applied in different conditions (high accuracy, short execution time) then students can develop and evaluate quality skills over multiple land surveying work profiles. Implementing CCLS in land Surveying teaching has the capacity to access the three top levels of Bloom's taxonomy (analyze, evaluate, and create) [2].

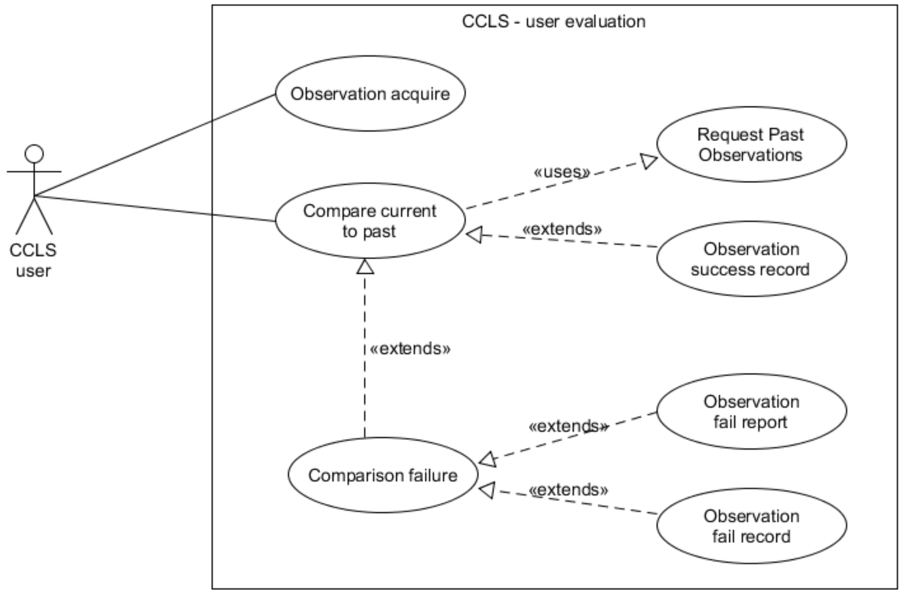


Figure 12: CCLS user evaluation use case UML diagram.

4 Project case study

In order to test and validate the functionality of the proposed approach, it was used in a real project of the Greek Ministry of Culture. This project is about the mapping of the historic center of Athens including all the archaeological sites, monuments, and private real estate property, as part of the Archaeological Cadastre. As a result, mapping of the area should provide spatial information of places of interest. The study area is about 460 000 m^2, 60% of which is urban area of high density.

This project is a great fit for the CCLS because is a large-scale application giving the opportunity to collect and manage large amount of measuring data coming from multiple work groups at the same time. Figure 13 visualizes the boundary of work area over OSM and satellite image.

An important aspect within the project's scope is the equipment cost. The case study described, was based on a low priced Kolida KTS-442RC total station (angle accuracy 2″, distance accuracy of ±(5mm+2ppmxD) for non prism and ±(2mm+2ppmxD) with prism). Total stations of medium to low end currently do not support wireless data transfer in their vast majority apart from RS-232 communication. In order to allow total stations for routinely surveying applications to be used, a Bluetooth to serial adaptor can be integrated to enable wireless data transmission and command execution.

During the field work, the Android application developed for this project was used as data collector and data manager. Bluetooth adapter were used to establish connections between total stations and tablets. Tablets manage commands to the total stations, as well as data synchronization. Also, all computations were executed and visualized in real-time.

(a) (b)

Figure 13: Boundary of project area over Open Street Map (a) and satellite image (b).

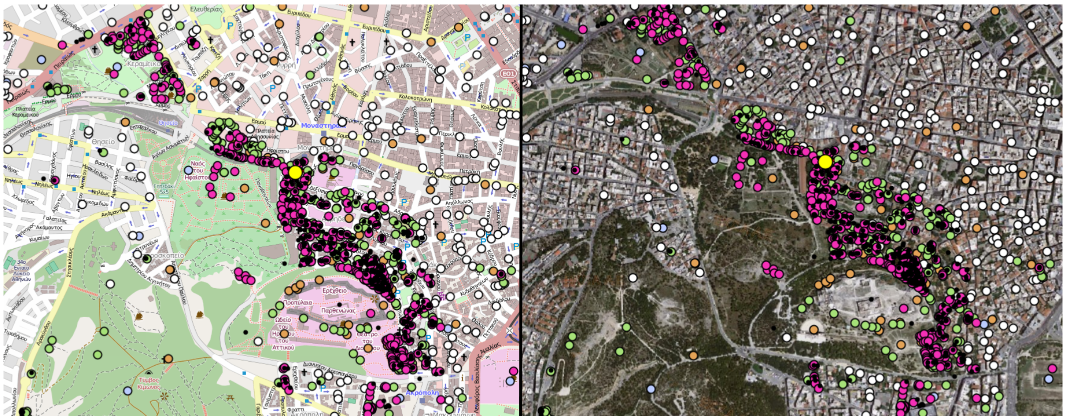
Multiple data collectors/total stations collected the project data that were processed and displayed simultaneously by all clients (Figure 1).

During a 4-month data collection period, 8 surveyor engineers and several archaeologists worked together in mixed teams and at least three groups were measuring with total stations in the field simultaneously. The participants' working experience during the data collection varied from zero to 20 years. In order to compare the proposed approach, it was requested that some groups used the proposed system during the measurement process, and some others worked in the field using the classical surveying workflow.

At an initial level, the approximate point position for each property and archaeological monument, was located using the existing address along with the Google Maps search service, so that the field work would have approximate reference points (Figures 14a, 14b). Furthermore, datasets for some properties were available containing non validated information (such as older topographic maps). Finally the Greek National Cadastre and Mapping Agency WMS provided background maps of 20cm accuracy used to overlay both existing and measured data.

Up to the time of writing, the reference network consisted of 270 control points covering about 60% of the total project area. After filtering out inaccurate data (measurements tagged as erroneous and repeated on field), 41,515 observations that refer to 10,379 features of interest, acquired in the field have been used. The control points and reference network density are shown on Figures 15 and 16, respectively.

Figure 17 depicts part of the created geometries as the desktop client overlays on an OSM map. The user interface (UI) allows to select applicable backgrounds (OSM, cadastre WMS) while thematic layers can be turned on and off by checkboxes on the main bar. There are also multi type control points that are shown as points with different colors and sizes in order to be able to distinguish property type on site. The sidebar on the left is used to view data of selected properties and set attributes (e.g., state, description, and other information). Finally images taken in the field can be uploaded and viewed through the current interface.



(a) (b)

Figure 14: Position of points of interest over (a) OSM and (b) satellite image.

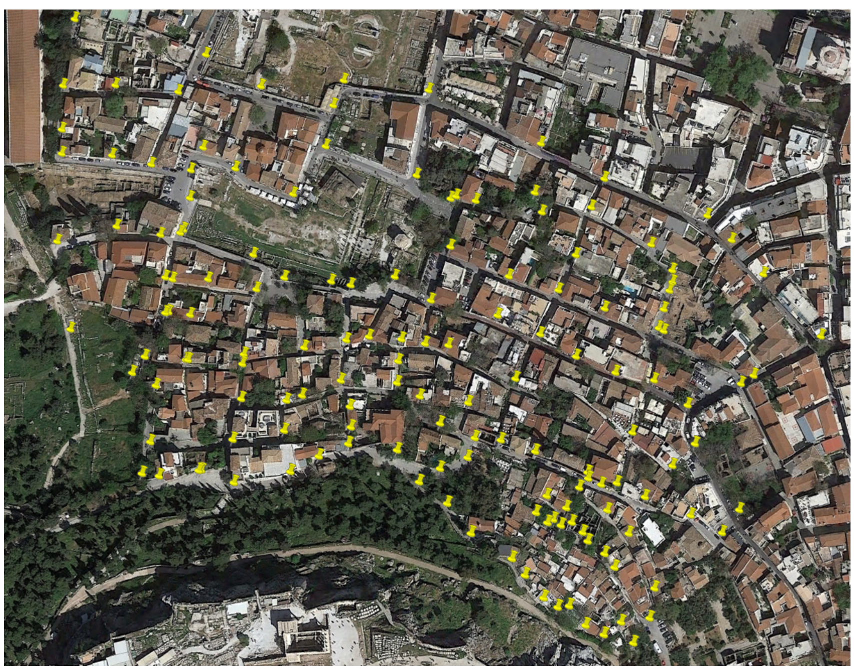


Figure 15: Control points over satellite image.

5 Results

After the processing of the collected measurements from the reference network, a comparison of the results was made between the classical surveying methodology and CCLS. The main comparison refers to traverses (branches of reference network, consisting of several control points), which were measured using both the typical approach and CCLS.

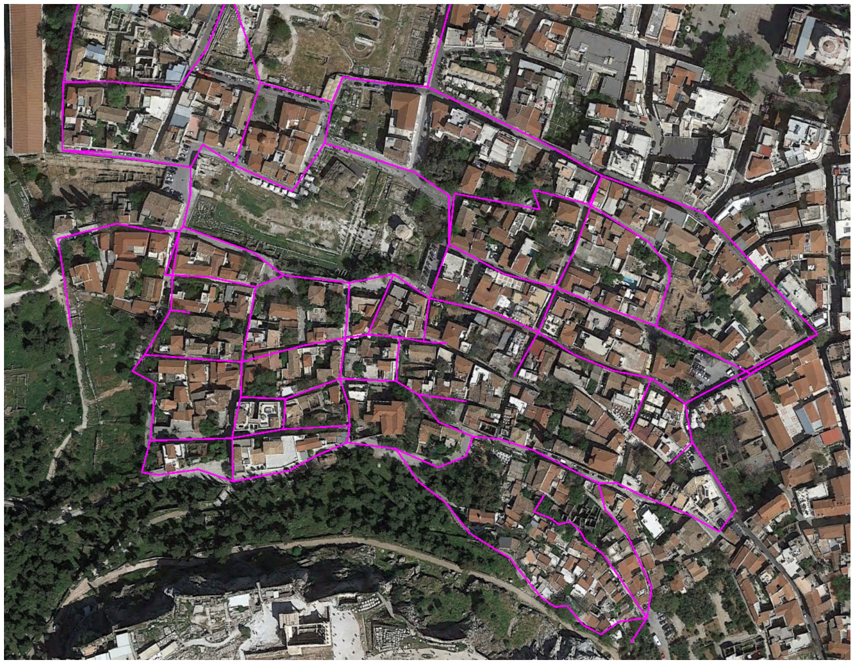


Figure 16: Reference network over satellite image.

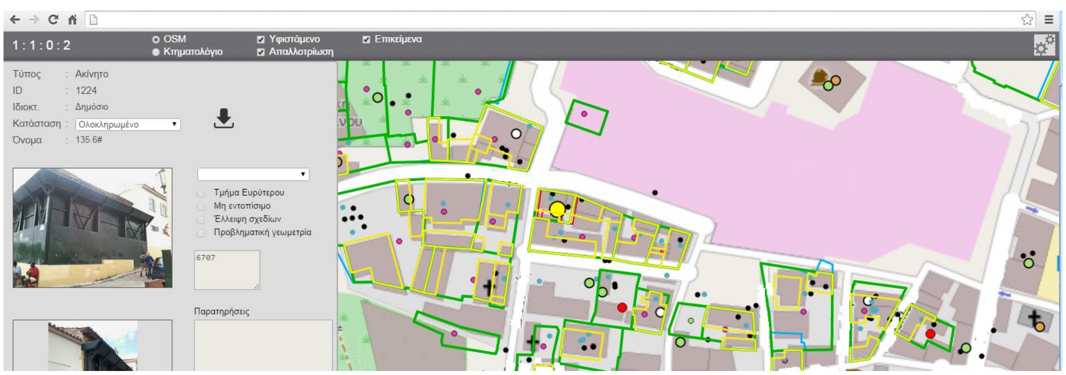


Figure 17: Created geometries as desktop client overlays on OSM map.

In the process of traverse or closed loop solution, the angular and linear errors are estimated by comparing measurements to known geometric information. The angular error is defined as the divergence between measured angles and known geometries, and the linear error as the divergence between computed and known point coordinates (start and end point of traverse are known and loops end on the starting point). For example, the sum of a triangle's angles should sum to 180°. The difference to that is identified as measurement error, which is distributed to each control point by applying least square adjustment. The traverse computations can be found in any standard surveying textbook [19].

Table 1 provides an example regarding a number of baseline traverses and their error information using the CCLS and the classical surveying method. Columns 2 and 3 show the angular and linear solution error respectively of each traverse. Columns 5, 6, and 7 refer to measurement method of control points, while columns 8 to 11 distribute the total error to the two different methods used. For example, record 5 analyzes traverse S58-33-116, consisting of 10 control points, 6 of which were measured using classical surveying and 4 using the proposed system. The traverse angular error was computed equal to 0.0178 degrees (0.0107 deg for classical surveying and 0.0071 deg for CCLS) while the linear error was 0.102 m (0.061 m for classical surveying and 0.041 m for CCLS). After normalization by dividing the sum of errors by the number of control points in each case, both the average angular and linear errors per control point for each method are shown. These results indicate that by following the CCLS approach, the angular error has been reduced by 61% while the linear error has been reduced by 29%.

Traverse	Error		Traverse length	Control Points			Angular error		Linear error	
	Angular deg $\times 10^{-3}$	Linear mm	m	Total	Surveying	**CCLS**	Surv. deg $\times 10^{-3}$	**CCLS**	Surv. mm	**CCLS**
S41-S47	7.0	18	207.47	5	1	**4**	1.4	**5.6**	4	**14**
S44-S46	0.7	9	74.59	2	2	**0**	0.7	**0.0**	9	**0**
S48-S60	17.8	75	118.97	4	4	**0**	17.8	**0.0**	75	**0**
S58-116	1.1	99	725.54	15	3	**12**	0.2	**0.9**	20	**79**
S58-116	17.8	102	311.14	10	6	**4**	10.7	**7.1**	61	**41**
S58-116	1.1	85	99.59	16	0	**16**	0.0	**1.1**	0	**85**
S73-S86	14.3	61	99.59	3	3	**0**	14.3	**0.0**	61	**0**
S78-S68	19.6	100	170.93	5	5	**0**	19.6	**0.0**	100	**0**
S80-S93	24.6	9	212.52	7	7	**0**	24.6	**0.0**	9	**0**
S101-S106	17.9	69	134.51	4	4	**0**	17.9	**0.0**	69	**0**
S112-ST65	24.9	55	316.03	18	18	**0**	24.9	**0.0**	55	**0**
SG10-SG67	15.4	79	257.80	4	0	**4**	0.0	**15.4**	0	**79**
SG11-SG24	16.1	17	308.22	8	0	**8**	0.0	**16.1**	0	**17**
SG13-SG56	5.8	21	175.72	5	0	**5**	0.0	**5.8**	0	**21**
ST65-S131	23.3	29	141.13	11	11	**0**	23.3	**0.0**	29	**0**
SG52-S150	0.1	40	1085.50	17	5	**12**	0.0	**0.1**	12	**28**
S31-S245	4.2	58	248.19	7	7	**0**	4.2	**0.0**	58	**0**
S246-S147	3.1	66	460.28	4	4	**0**	3.1	**0.0**	66	**0**
			Total	145	80	**65**	162.7	**52.1**	628.0	**364.0**
			Average				2.0	**0.8**	7.9	**5.6**
			Average error reduction					**61%**		**29%**

Table 1: Computations: error estimation (angular units-degrees $\times 10^{-3}$, linear units-mm).

Another interesting result is the productivity boost. For the same work time in the field, there were 80 control points needed to be set by the teams following the classical surveying approach, while only 65 control points required by those who followed CCLS. The field groups that followed the classical surveying approach consisted of three members, while on the other hand only two were needed for the proposed method. Classical land surveying required one additional member to draw sketch, identify control points and do tasks that the proposed system could automate and pass to the total station operator. It can be deduced that there is a cost/productivity benefit of the proposed method by $[(65/80) \times (3/2)\text{-}1] \times 100 \approx 22\%$.

The distribution of the linear and angular measurement errors is shown in Figure 18 (a and b). It is seen that across the scale of error classifications (x axis), more measurements acquired by the CCLS method have lower error values compared to the number of measurements taken by the traditional surveying methodology. Considering that the participating surveying teams in this project had no previous experience in applying the proposed method, the productivity and accuracy are expected to improve even further. Completion of the project will provide more data to analyze further the results in order to get more feedback.

After the completion of the field work, users were asked to give feedback on user experience provided by the new data collection procedure. The total response set included many interesting remarks from the user's point of view that can be classified into three generic benefit categories, namely:

- Rapid area awareness. The combination of selective dataset overlay (WMS, vector files, etc.) along with real time feature drawing provides immediate space orientation and identification.
- Observation certainty. The fact that errors were indicated on site for existing features, along with the real time drawing, made the users feel more confident on observation execution. For example, the use of non prism distance observation method was used more than normally would, because reflections on environment obstacles (tree leaves, wire fence, etc.) could be immediately detected. Also, real time network computations and drawing provides awareness on missing observations that ensures a complete collection session.
- Overall working time reduction. The users responded that the preparation time before field work was minored, as most of the information were available on the CCLS portable unit UI (control points, other measurements, raster maps) and most of the preparation work was overridden (existing control point identification, project progress review, map printing, etc.). This fact along with the previous two reported benefits, led to overall working time reduction for the same amount of observation acquisition, as users indicated.

6 Discussion

At this point, some benefits that came up through the process should be noted. During the production of the final topographic plans, there were several cases where need to revisit the field was essential in order to confirm the dimensions or other missing information. None of these cases had used CCLS, which further indicates the effectiveness of the approach. Moreover, during the field data collection, there were cases where more than two control points had been set within few cm spacing by different users over time, making difficult to determine the correct one. These cases are considered as error sources, so users had to measure all control points, in order to be sure not to miss the correct one. Afterwards, during the post-processing procedure, each of those control points had to be used separately in the solution in order to detect which one is the correct. Alternatively, groups that followed the proposed approach were automatically notified of the measurement and the respective solution error.

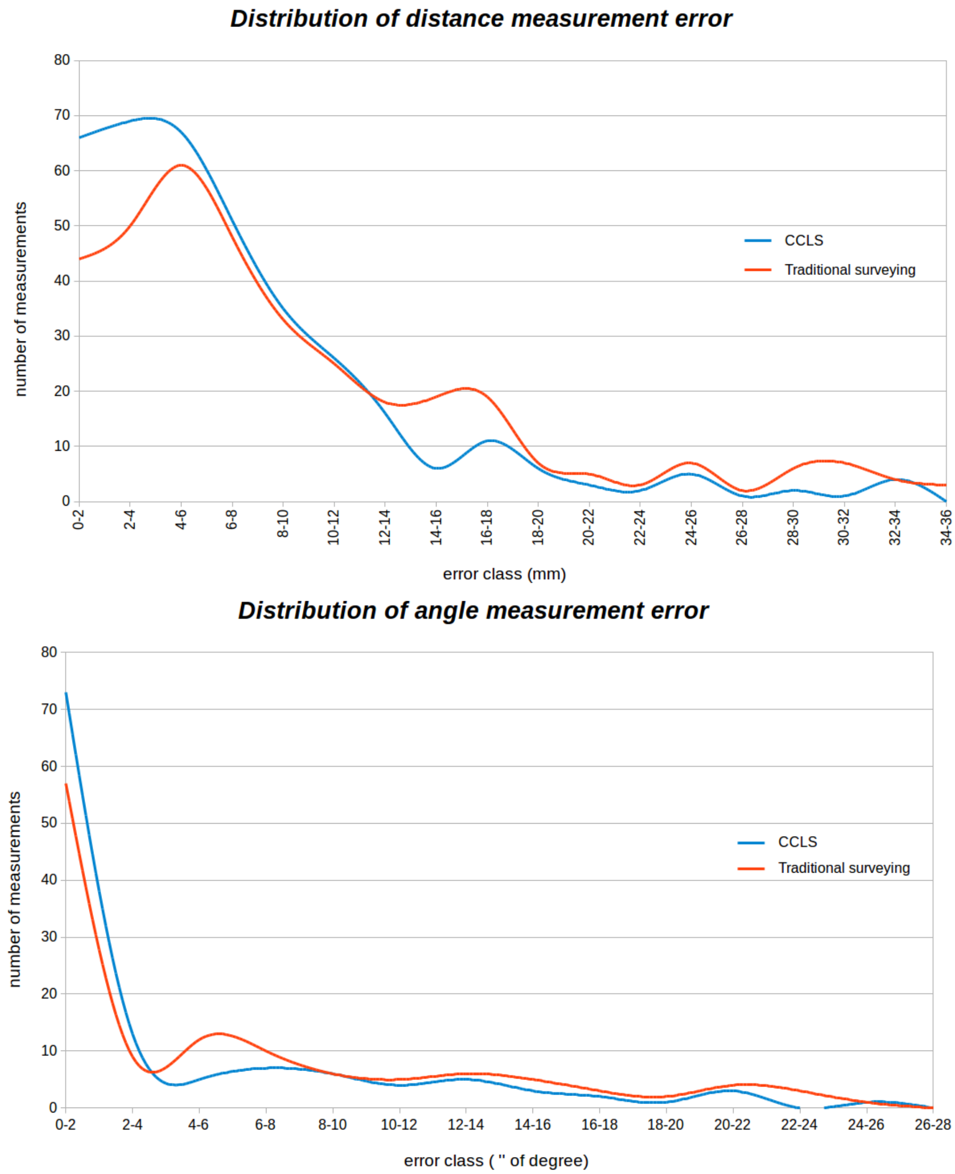


Figure 18: Distribution of the distance (a) and angle (b) measurement error.

Considering that all the measured and computed information will be stored in an online repository, allowing reusability by authorized users, the dataset is expected to grow rapidly as CCLS will be adopted in the surveying engineering practice. This kind of data feed creates self-expanding and continuously self-improving networks, like reference networks, power stations, hydrographic networks, etc. Common VGI data coming from citizens without appropriate knowledge have not yet proven to meet the standards of topographic base projects [4]. By using the proposed approach, the area of "social surveying engineering" (a term defining scientific behavior of sharing raw surveying measurement data by specialized users) can be expanded thus enabling the development of VGI projects of special interest and high accuracy demands, allowing for the first time the re-use of large-scale spatial information of Engineering-level accuracy.

Property	Benefit	Description
Data-recycle	cost reduction	use existing data, speed completion time
Field process	- accuracy improvement - detect erroneous observations - spatiotemporal feature tracking - large scale multiple station approach - interactive network ontology data approach - direct availability	continuous comparison to existing data, real time model solution

Table 2: Potential benefits.

Aspect	Surveying	CCLS
Work flow	2 step flow, data collect (field) data process (office)	data collect / process unification
Total station topology	isolated working node	part of an interactive network
Data form	distance-angle station dependent, data files	structured database modeling spatial information along with metadata
Time frame	static, time fixed object description	multi epoch data collection, temporal measurement repository
Project overview review	time dependent incoherent project overview after every data collect / data process cycle	real time project progress / overview, continuous remote review
Data flow	field data collection saved to local media	real time data route from and to CCLS database
Data access / reusability	limited access / availability, hard to integrate due to lack of modeling	real time open access through web service, easy to integrate, structured information

Table 3: Key differences.

Production cost should decrease by both productivity raise and equipment upgrade. The application developed for this project, has been set on Android OS and requires only a total station with basic serial interface that accepts terminal commands. This transforms low budget, high accuracy equipment, to a networked device accessing multisource / multi type data instrument with up-to-date processing power and abilities, which can improve the surveying methodology. Table 3 summarizes the differences between classical surveying and CCLS. Table 2 provides the main advantages of the proposed approach with reference to corresponding property of CCLS. The provided option to recycle available data is expected to reduce overall cost of land surveying procedure. On the other hand, provided field functions and tools will help increase quality and speed of corresponding processes but also enable new use case application flows.

Finally, another aspect of the proposed framework that should be mentioned is the legal nature of the items to be identified. In this context, it is important to clarify two major attributes of the observed items. The first important notice refers to the responsibility owner for data accuracy. By default, responsible for the accuracy of the final product, is the Engineer that has been assigned to execute the procedure of land surveying. This fact remains as is in the proposed approach. The land surveyor that has been granted access to CCLS repository data is responsible of evaluating the provided information and decide which data subset is appropriate for use. The second consideration that should be taken into account refers to the boundary lines. It is important to distinguish the property nature of a boundary line, to that of its geometry. CCLS refers to the geometry instance of observed items as this is observed by different users. It is a totally different thing to estimate and identify the property boundary (that could be mismatched to existing geometries) and it is not currently discussed as an objective of this work.

7 Concluding remarks

This paper has introduced CCLS, a methodology that challenges the classical topographic surveying process by using VGI along with modern collaborative network-based concepts. CCLS initiates novelties in the way data are collected and processed, unifying both these processes. It introduces field networking for total stations while a central data store is used to synchronize all the connected devices that now have access to the full dataset that is available while in the field. The concepts of CCLS can be implemented also in the collection and processing of other types of geospatial data.

The case study presented has applied the proposed method and the results indicated a substantial error reduction by 61% on angular measurements and a linear error reduction of 29%. Additionally, a productivity raise of 22% (as computed and indicated in Section 6) during the corresponding measuring period has been achieved, regarding both the quality and quantity of collected data.

This work sets a new framework for land surveying, integrating volunteer geographic information that users provide through appropriate services. Current technological achievements allow the creation of a system that would provide such functionalities, while at the same time data networks allow information sharing in real time. Benefits of this new concept have been analyzed and results show that accuracy and productivity increase significantly.

There are many open questions regarding issues such as dataset development / sharing / usage evolution in this specific scientific area. Such architectures that would enable geographic information integration are currently under research [20]. Globally, interest is focused on community-created, yet quality-evaluated content that offers multiple benefits. Surveying engineering evolves this way, as recent trends have proven to be enabling new approaches.

Based on the development of CCLS, the authors have addressed a series of issues and considerations to be exploited. One of the open issues that are subject of future work, is the extension of developed data model in order to define an ontology-based approach to describe each point and also include other types of topographic measurements, such as photographs taken for photogrammetric calculations and raw GNSS observations. Additionally, an extensive discussion on educational applications that implements CCLS, with reference to students' cognitive skills based on Bloom's taxonomy [2] is under development.

Measurement sharing in the context of the described approach is the critical, yet optional, requirement of CCLS. Information that data contributors think is not advisable to provide, will not be shared (though position only could be provided in such cases). Adoption of CCLS will depend on several factors including the mentality of the surveying engineering community, dealing with which is out of the scope of this work. The results obtained so far are more than promising, which is a clear indication of the value of this approach that exploits and specializes the VGI concept into a discrete engineering domain. Future work will integrate the full dataset of this project as soon as measurements are available for the whole area of interest. Updated results shall complete this stage of evaluation and provide further comparisons regarding accuracy and productivity. Moreover, future projects that integrate currently collected information will allow over time reusability and enable spatiotemporal data processing, revealing the potential of geographic information sharing among surveying engineering community members.

Acknowledgements

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