International Journal of Engineering Education Vol. 37, No. 6, pp. 1716–1729, 2021
Printed in Great Britain

0949-149X/91 $3.00+0.00

Using Geodetic Infrastructure to Teach Geomatics Engineering and to Promote Scientific Research*

MARÍA S. GARRIDO-CARRETERO[1,2,3]**, MARÍA J. BORQUE-ARANCÓN[1,2,3], MARÍA C. DE LACY-PÉREZ DE LOS COBOS[1,2,3], MANUEL AVILÉS-MORENO[1,2] and ANTONIO J. GIL-CRUZ[1,2,3]

[1] Research group RNM282, University of Jaén, Campus Las Lagunillas, 23071 Jaén, Spain.
[2] Center for Advanced Studies in Earth, Energy and Environmental Sciences (CEACTEMA), University of Jaén, Campus de las Lagunillas, 23071 Jaén, Spain.
[3] Department of Cartographic, Geodetic and Photogrammetric Engineering, University of Jaén, Campus de las Lagunillas, 23071 Jaén, Spain.

Teaching and research are two basic functions of a University, and both have to be integrated into students' learning as well as in their initiation into the scientific research. Geomatics Engineering has evolved in recent years, supported by continuous technological and methodological development and the students need updated learning approaches. This paper describes an innovative experience carried out at the University of Jaén (Spain) to promote the initiation in scientific research within the framework of a research group of Applied Geodesy and shows how active learning environments may be designed with all their components acting congruently to support deep approaches to learning. Three case studies located at different academic levels and with six participating students are presented. These show how the geodetic infrastructure is a valuable tool for introducing students to applied scientific research. This approach provides research opportunities to undergraduate and graduate students, it is sustainable in collaboration with a consolidated research group, and it promotes the dissemination of research results by peer-reviewed papers and scientific publications with students as co-authors.

Keywords: active learning; engineering education; geomatics engineering; scientific research; case-studies

1. Introduction

Teaching, learning and research in higher education are topics for research in themselves and the relationship between them has been the subject of analysis [1–4]. In the field of engineering, many organizations worldwide have promoted research into engineering education: UNESCO, the World Federation of Engineering Organizations, the International Council of Academies of Engineering and Technological Sciences, the International Society of Engineering Pedagogy, etc. [5]. In Europe, the European Society for Engineering Education (SEFI) has contributed to the development and research into engineering education. It also promotes cooperation between engineering higher education institutions and international scientific centers. Engineering is a practice-oriented profession, thus technical skills must be taught in the technical context in which they will be used. Due to the socio-technological challenges, engineering education must anticipate and adapt to changes in the engineering practice [6]. This is especially true in Geomatics Engineering. Geomatics is a relatively new term that deals with the three-dimensional acquisition, processing and application of geo-information. Geomatics Engineering focuses on the sciences and technologies related to positioning and navigation, mapping, measurements and sensors as well as on spatial intelligence. It has evolved rapidly in recent years, supported by several international scientific and academic organizations such as International Association of Geodesy (IAG), International Cartographic Association (ICA) and International Society for Photogrammetry and Remote Sensing (ISPRS), to name a few. At global level, the United Nations initiative on Global Geospatial Information Management proposes guidelines for the development of geospatial information and the promotion of its use to address global challenges. In Europe, the importance of Geomatics is recognized under the Infrastructure for Spatial Information in Europe (INSPIRE) Directive [7]. In addition, organizations such as the European Space Agency (ESA) provide and promote the cooperation among European States in space research and technology and their space applications, to be used for scientific purposes and for operational space applications systems [8]. In connection with this, Europe's approach to Global Navigation Satellite Systems (GNSS) begun with the European Geostationary Navigation Overlay Service (EGNOS). This experience has helped Gali-

** Corresponding author: mgarrido@ujaen.es
ORCID corresponding author: 0000-0001-8914-9431.

* Accepted 27 July 2021.

leo, Europe's Global Navigation Satellite System. In addition, ESA is developing a new family of satellites (Sentinels) specifically for the operational needs of the Copernicus Earth observation program, an initiative headed by the European Commission in partnership with the ESA.

In this context, geomatics engineering education needs appropriate learning approaches. As shown by [9] the competencies that students develop during their engineering program should be aligned with their professional practice. The higher-education field faces a challenge to modify the traditional learning to a more student-centered direction [10]. Two approaches that force student to take responsibility for their learning and to ensure deep and active involvement are problem-based and project-based learning. Over the last years, the acronym PBL has been used for both project-based learning and problem-based learning to unify the learning principles [11]. However, providing appropriate "active-research-based learning" environments that allow independent learning and innovative practical experiences while making state of the art research insights available is quite challenging. As shown in [12], active learning is effective in improving student learning and performance in STEM (Science, Technology, Engineering and Mathematics) disciplines such as Computer Science, Engineering, Physics, etc. This type of research-based learning engages students by applying the methods, instruments and geodetic infrastructure as a form of active learning in Geomatics. In addition, this approach creates opportunities to put students into real contexts in research, dealing with problems where they need to link theory to practice.

Learning and research based on geomatics engineering involves a combination of technical and transversal competencies that provide opportunities for the development of professional skills. Within this context, students develop technical and transversal skills, and the learning process becomes more motivating and meaningful for them. Students recognize the importance of research at the University and understand why it is important for their future as geomatics engineers. This article shows an educational innovation approach based on active learning environments. The geodetic infrastructure at the University of Jaén (Spain) is applied in the introduction to scientific research of the students of Geomatics Engineering. Considering this framework, students learn geodetic concepts, methodology and instrumentation and their application into Geomatics Engineering as well as they begin in research tasks on applied Geodesy. The three case-studies presented show experiences in which students from different academic levels use this local geodetic infrastructure as a valuable tool of active learning and illustrate the advantages for the students' curriculum vitae.

2. Background

2.1 The Role of Geodetic Infrastructure in Geomatics Engineering

Geomatics Engineering is a very active field of applied sciences that works with multi-resolution and multi-temporal geospatial information in all kinds of scientific applications. Based on the scientific framework of Geodesy, it uses terrestrial, marine, airborne, and satellite-based sensors to acquire spatial and other data. From its origin, Geodesy has been the foundation for high accuracy positioning. Over the past two decades, geodetic technology has developed rapidly, however, many current geodetic technologies require ground infrastructure. Advancements in technology combining with updated geodetic infrastructure open up new opportunities for Geomatics Engineering learning and research. An example is the Global Geodetic Observing System (GGOS), which works together with the IAG Services to facilitate the production of geodetic products and to provide the geodetic infrastructure for monitoring the Earth system and the global change research [13].

Modern Geodesy involves a wide range of geodetic techniques, including Global Navigation Satellite Systems, that are used among others to monitor the precise locations of a set of reference stations around the world. This global reference frame can be used to determine the position of other points and to establish regional and local reference frames. Providing the infrastructure to maintain these reference frames is the way Geodesy underpins the navigation devices that are ubiquitous in our society [14]. In recent years, multi-constellation GNSS have revolutionized navigation and surveying. The reliability and accuracy of the GNSS technology will continue to increase, especially due to the number of available satellites. Nowadays, many static and kinematic surveys are supported by local or regional networks of Continuously Operating Reference Stations (CORS). A CORS includes a GNSS receiver and antenna installed over a monument that collects GNSS data, 24 hours a day, every day of the year, in order to support 3D positioning activities. Geomatics surveying engineers, as well as other scientists and professional users use GNSS data for post-processing, for real-time accurate positioning or to model physical phenomena, among other applications. The design of a CORS network includes a data center for quality checking, processing, distributing and archiving GNSS data files and real time data streams that are used to support stationary or mobile applications. Considering CORS, users reduce the cost of instruments for GNSS data acquisition. Today there are numerous CORS networks throughout the world, which have been established to support applications in engineering, surveying, agriculture, environmental science, etc. Examples of CORS networks as the basis for research projects can be found in [15–18].

A CORS network is the result of endeavors involving governmental, academic and commercial organizations that have made contributions to the geodetic infrastructure. In Europe, the European Reference Permanent GNSS Network (EUREF) is operated under the umbrella of the IAG Regional Reference Frame sub-commission [19] and there are many national active networks available that complement this regional geodetic infrastructure. In Germany, the SAPOS HEPS (Hochpräziser Echtzeit Positionierungs-Service) was one of the first network with real time positioning services [20]. In Portugal, RENEP (Rede Nacional de Estações Permanentes GNSS) and SERVIR (Sistema de Estações de Referência GNSS VIRtuais) coexist in order to support real-time high precision positioning applications [21]. Other examples of active networks in Europe can be found in [22] and [23]. In Spain, the ERGNSS national network provides GNSS data for post processing and differential corrections for real time

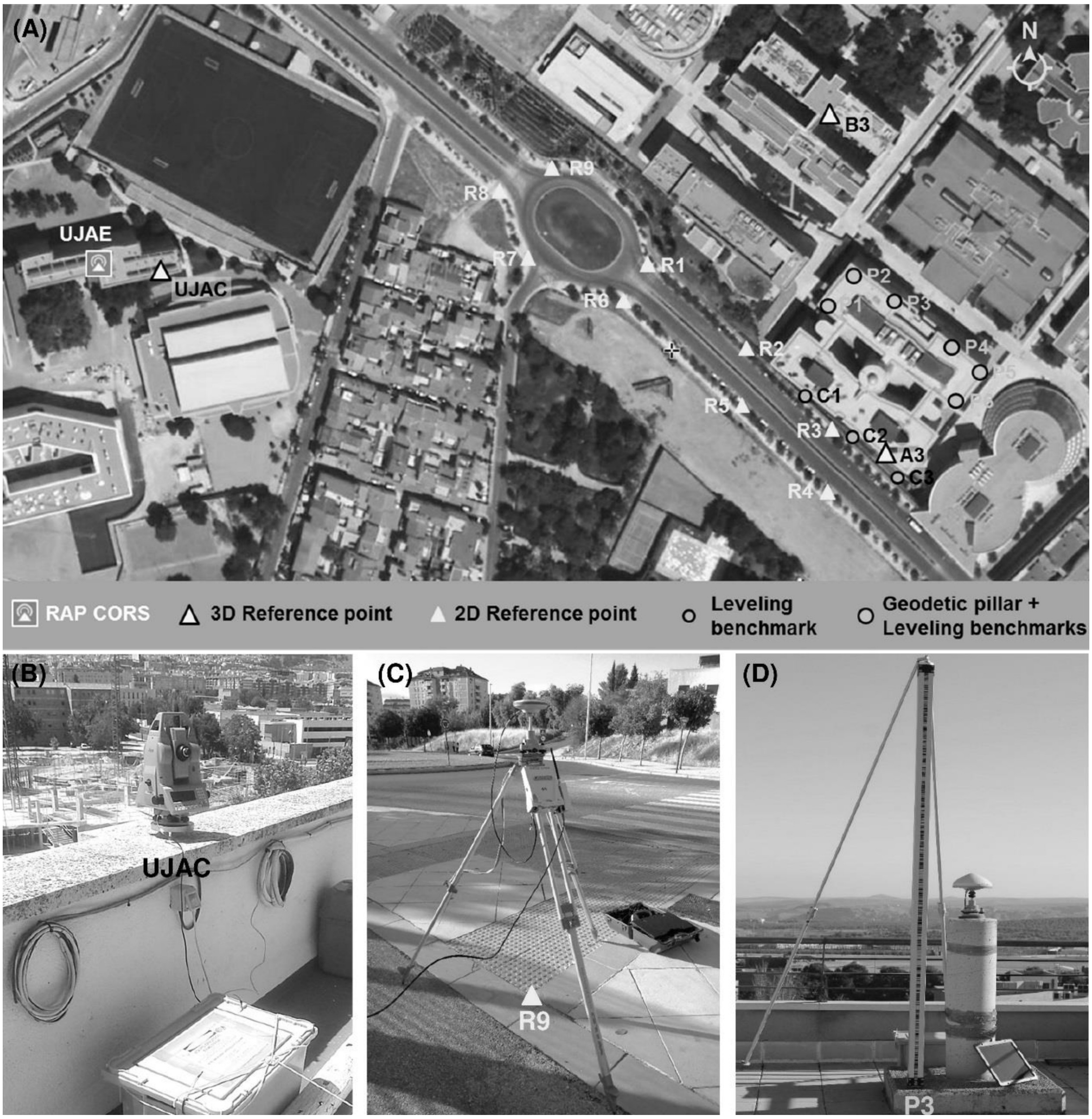

Fig. 1. Active and passive geodetic infrastructure at the University of Jaén (Spain) (A) and examples of 3D reference point (B), 2D reference point (C) and 3D geodetic pillar plus 1D leveling benchmark (D).

positioning [24] and almost all Spanish regions have an active network to support accurate real-time positioning. An example of this is the Andalusian Positioning Network (RAP) [25] with 22 GNSS reference stations, among them the CORS UJAE at the University of Jaén.

2.2 Local Geodetic Infrastructure: Technical Description and Specific Applications

At the University of Jaén (Spain), the local geodetic infrastructure includes active (CORS UJAE) and passive (geodetic pillars, leveling benchmarks and reference points) elements that provide support to teaching and research in Geomatics Engineering (Fig. 1).

This infrastructure supports research in specific areas where the geomatics engineer has the professional expertise to conduct studies related to assessing the accuracy of surveying techniques, spatial measuring or deformation monitoring, providing a pragmatic approach to data interpretation and contributing to the definition of precise local reference frames.

The RNM282 research group in collaboration with the Department of Cartographic, Geodetic and Photogrammetric Engineering of the University of Jaén, established and maintains several local high-precision geodetic networks designed with scientific and teaching goals. In 2000, this research group promoted the installation of a CORS at the University of Jaén (UJAE) to support teaching and research tasks. A CORS requires a correct monumentation over a geodetic pillar or other stable structure, a good electrical environment to reduce the multipath and an enclosure to house power supplies, batteries, computer and telecommunications equipment. GNSS receiver should be able to track multiple constellations, collecting data simultaneously from the GPS, GLONASS and Galileo systems among others (Fig. 2).

In 2007, this CORS was integrated into the RAP active network. In addition to the main application of a CORS, to support relative positioning, this CORS has contributed to the advance of research in multidisciplinary applications, including GNSS positioning and navigation, multipath studies, atmospheric studies or deformation monitoring, as shown [26–28].

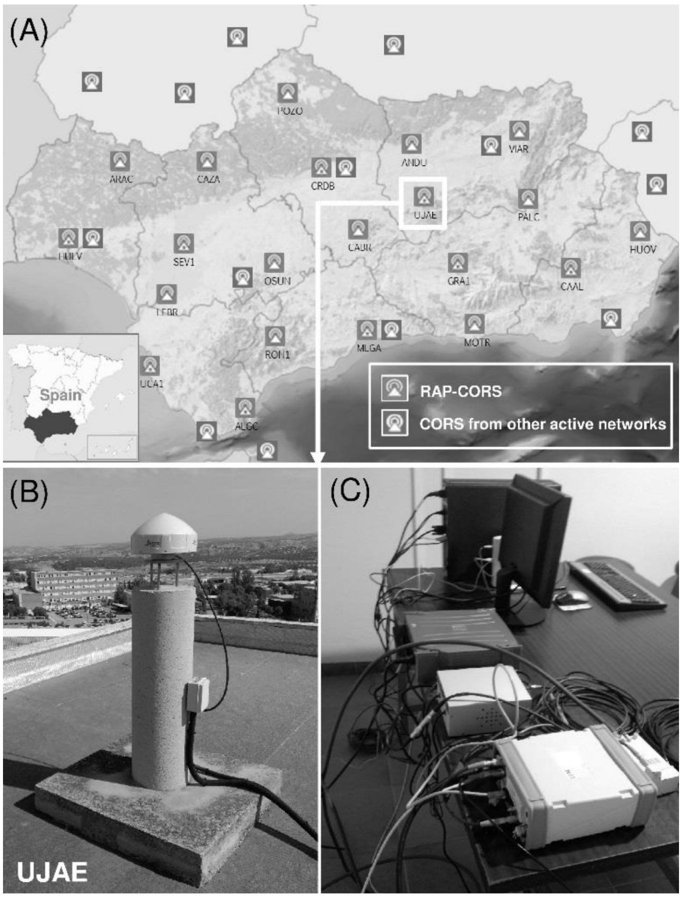

Fig. 2. (A) RAP active network (Andalusia, S Spain), (B) Site monumentation of CORS UJAE with GNSS antenna LEIAR25 LEIM and (C) Details of GNSS receiver LEICA GR50, uninterruptible power supply and PC at UJAE.

The passive geodetic infrastructure at the University of Jaén comprises geodetic sites, reference points and leveling benchmarks organized into 3D, 2D and 1D networks. The reference points of the 3D network are materialized by a brass pillar plate that is designed to be screwed into concrete. The main use is the establishment of a local reference framework as well as the installation of non-permanent GNSS reference stations at the Campus. Furthermore, there are six geodetic pillars in the terrace of the Science and Technology building. Each geodetic pillar is composed of a cylinder 1.20 m high and 0.30 m in diameter supported on a concrete base, with a reinforced center to ensure accurate and stable placement of geodetic instruments or GNSS antenna. Their main use is the establishment of a local reference frame at the building, however other specific applications are as reference points for the quality analysis of the RTK positioning or as control points for the estimation of measurement uncertainties of topographic-geodetic instruments. The 2D network is materialized by brass markers that allow the installation of poles and tripods for surveying instruments (total stations, GNSS antennas and receivers, etc.). The 1D network is materialized by leveling benchmarks that are made of brass or aluminum and are installed vertically. These benchmarks are used for the establishment of an altimetric reference frame and for the vertical monitoring of the building structure as well as for the determination of collimation error, the largest potential source of systematic error for leveling even using geodetic-quality levels.

2.3 Bachelor's and Master's Degree Programs in Geomatics Engineering at the University of Jaén (Spain)

For two decades, Spain has been immersed in the transformation of its higher education system along with other European countries in order to create a European Higher Education Area. Its objectives are to standardize both the grading system and the unit to measure academic performance and to guarantee the recognition of the qualifications, in order to increase student mobility and facilitate the integration of graduates into the European labor market. In line with the European Convergence of Higher Education, the study programs at the University of Jaén include Bachelor's degrees and Postgraduate studies. The aim of the first is to provide the students the basic education together with subjects oriented towards the professional needs of the students (3–4 years and 240 ECTS-European Credit Transfer and Accumulation System). Postgraduate studies are committed to a more in depth teaching in specific aspects of the subjects, together with the preparation for the professional application of the student's knowledge. This cycle is divided into the Master's degree (1–2 years) and the Doctoral degree (3–4 years). Through the different academic levels, the students can benefit from a practice selection process and gain work experience. Thanks to the collaboration with companies, institutions and research groups, the University offers students a valuable tool, contributing to their integral training and facilitating immersion in a business reality in which they can apply the knowledge acquired and development of a series of competencies that will improve their employability. In addition, this practice favors innovation, creativity, and entrepreneurship, and at the same time, implies a first contact with the research carried out at the University.

The research-based engineering education approach requires students to experience the reality of Geomatics Engineering throughout several stages in their formation. Engineering learning can be more effective when it is developed in contact with a research group through technical and scientific challenges of real engineering situations. This study focuses on the Bachelor's degree in Geomatics and Surveying Engineering, on the Master's degree in Satellite Geodesy and Geophysics Applied to Engineering and Geology and the Engineering Practice Program of the RNM282 Research Group. The Bachelor's degree in Geomatics and Surveying Engineering has been taught since the 2010-2011 academic year. The Master's degree in Satellite Geodesy and Geophysics Applied to Engineering and Geology was first offered in the 2015-2016 academic year supported by the University of Jaén and the Centre for Advanced Studies of Earth Sciences. The practice program of the Research Group RNM282 is active since 2017.

Through active-research-based learning, generic competencies and skills, such as understanding contexts of engineering practice, developing effective solutions to specific problems, understanding organization behavior, working effectively as a member of team or communicating effectively are acquired. These competencies are complemented by basic, general, transversal and specific ones developed in the Bachelor's degree in Geomatics and Surveying Engineering [29] and in the Master's degree in Satellite Geodesy and Geophysics Applied to Engineering [30]. These titles were approved by Spanish Academic Agencies. All competencies and skills achieved by the students by means of the corresponding pedagogic methodologies are included in the academic guides of the courses conforming the titles. It is important to underline the Bachelor's degree in Geomatics and Surveying Engineering was verified by the Eur-

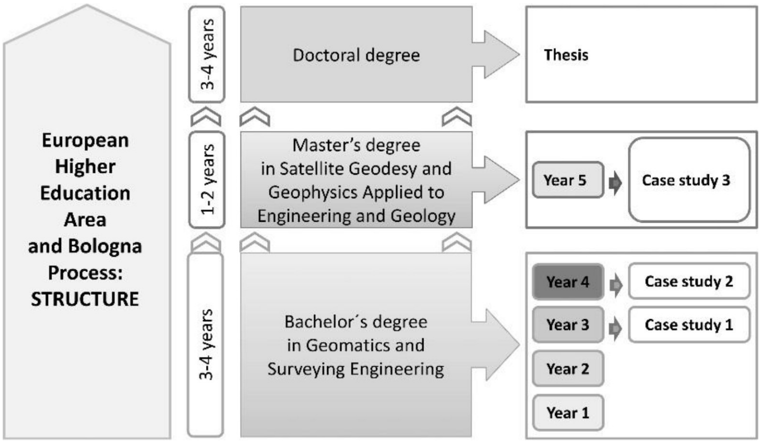

Fig. 3. Location of case studies through the different academic levels.

opean Network for the Accreditation of Engineering Education with the International Quality STAMP EUR-ACE. The integration of the students within the framework of a research group also allows the development of competencies and skills to understand the research lines, to review the existing knowledge and research literature, to formulate scientific questions, to design and to use appropriate methods, to collect, review and analyze critically the data and to present the results and conclusions in a specific context. The way to evaluate these competences is based on the daily work developed by the student and the oral presentation of the Bachelor's Thesis and Master's Thesis. In order to have a valuable feedback of the strengths and weaknesses of the developed activities, the Service of Planning and Evaluation of the University of Jaén sends a questionnaire to the students and supervisors at the end of the activities. The results of this questionnaire is sent back to academic commission of the titles to establish improvement actions. Furthermore, the titles have an internal quality commission to guarantee the quality of their activities. The academic commission of these studies elaborates an annual report analyzing strengths and weaknesses found during the academic year. This report is sent to the Andalusian Direction of the Evaluation and Accreditation. This agency emits an annual verification report suggesting improving actions according to the reports elaborated by the academic commission.

3. Case Studies

The aim of this approach is to incorporate the applied research associated with the geodetic infrastructure into the student curriculum at different academic levels and at increasingly earlier stages. The geodetic infrastructure presented has been applied in several PhD thesis and their results have been published in [31] and [32].

Several proposals have been designed and offered to undergraduate and postgraduate students. They have the opportunity to approach the theoretical framework of investigation, to recognize research objectives, to participate in projects supervised by researchers, to know what the scientific activity consists of and to awaken their research vocation as well as to disseminate their experience.

Three case studies, identified as case study 1, 2 and 3, are presented (Fig. 3). Case 1 focuses on students belonging to the third year of the Bachelor's degree program for a period of 6 months. The number of participants is four. Cases 2 and 3 are respectively associated with the realization of the Bachelor's Thesis and the Master's thesis for an approximate period of one year and two participants per year. The next section describes the research framework, the strategies used at different academic levels to facilitate students' initiation to applied research, the main results achieved, and the competencies acquired through this approach.

3.1 CASE STUDY 1: Proposed research for Bachelor's degree students (3rd year)

3.1.1 Framework and proposed research methodology

Nowadays, the most advanced global observation systems are available. However, phenomena to study occur on different spatial and temporal scales and in most cases it is convenient to collect local data to monitor them. The GNSS use satellites and ground-based receivers to determine the location on the Earth's surface. At a local scale, GNSS techniques have been applied to monitoring civil structures or buildings. In addition, precise measurements of height differences help to identify vertical movements. Continuous deformation monitoring of a building enables verification that it meets the structural assumptions defined in the project. Once the building is in use, unexpected structural responses can help to detect current and future problems. As shown in [33], the technological improvement in GNSS positioning techniques has allowed significant advancements in methodology applied to monitor in real time the dynamics of building structures. These systems allow us to achieve a high level of safety and effective risk management.

Students of the Bachelor's degree in Geomatics and Surveying Engineering in collaboration with RNM282 research group applied a combination of GNSS precise positioning techniques with high precision leveling, making possible an accurate deformation monitoring of the Science and Technology building at the Campus.

3.1.2 Main Results

The main goal of this research has been to get precise deformation rates of the building from high quality continuous GPS (cGPS) and leveling measurements from July 2017. The GNSS equipment applied is composed by Leica Geosystems AR10 receivers with LEIAR10 antennas. GNSS data were processed by using Precise Point Positioning (PPP) methodology with the GIPSY software developed by the NASA Jet Propulsion Laboratory (JPL). Position time series of the geodetic sites (North and East components of P1 to P6 – Fig. 1) were analyzed in the timespan 2017–2019. The model applied to the time series, using weighted least squares, consists of an intercept, a site rate and the coefficients of several periodic signals. The error term was composed of white noise and temporally correlated random error. In addition, a high precision leveling profile were measured every month over two-year span along the upper deck of the building. A Leica DNA03 digital level, two 3-meter Invar bar-coded staffs, two sturdy steel-spiked base plates and a tripod with fixed-length legs were used. The quantification of vertical changes through the comparison of high precision leveling data is a widely used technique to monitor civil engineering structures. Comparison of leveling data provides information about the amount of vertical deformation accumulated along the time. Longer time series will improve the rates estimations and will allow to confirm these results. The combination of cGPS and leveling methods in repeated surveys enhances our understanding of the building security and prevents collapses.

Several competencies and skills are acquired with this approach, especially specific competencies related to the knowledge, use and application of topographical methods and instruments suitable for the realization of non-cartographic surveys and the knowledge and application of the methods and techniques of Satellite Geodesy.

3.2 CASE STUDY 2: Proposed Research for Bachelor's Degree Students that will perform the Bachelor's Thesis.

3.2.1 Framework and proposed research methodology

Today, dual-frequency GNSS receivers are widely used; however, low-cost single-frequency receivers have been relegated to navigation applications. Their main advantages (small size, ease of use, low-cost, and high precision positioning even in real-time) make them optimum candidates for positioning applications in many scientific areas. In order to determine their precision, the evaluation of the uncertainty of measurement applying standard operating procedures is required. The International Organization for Standardization (ISO) developed the standard ISO 17123-8 aimed at specifying field procedures to be adopted when determining and evaluating the precision (repeatability) of GNSS field measuring systems in real-time kinematic positioning (RTK). Using this standard, the positioning performance of two GNSS receivers, the geodetic dual-frequency considering a network RTK solution and the low-cost single-frequency using a single-base RTK solution, can be evaluated. GNSS receivers using RTK positioning are widely applied in geomatics applications. However, the main limitation of traditional RTK positioning based on a single reference station is caused by distance-dependent errors (orbital errors and atmospheric refraction), being limited to a few kilometers. Nevertheless, these errors can be modeled using GNSS observations from a network around the rover position, extending the single-base RTK positioning to a Network-based Real-Time Kinematic (NRTK). Today, a RTK network is an indispensable complement to GNSS positioning systems, allowing the determination of 3D positions in real-time with high precision and accuracy. Although the application of procedures for evaluating the uncertainty of the measurement results of surveying instruments is not new, the complexity of the measuring GNSS systems complicates the introduction of testing methods. Based on the standard ISO 17123-8, we have proposed this study in order to evaluate the RTK performance of two GNSS receivers, a geodetic dual-frequency one and a low-cost single-frequency one. Two different field procedures, namely simplified and full test procedure, are available. The last test, designed for determining the experimental standard deviation for a single position and height measurement, is adopted in order to determine the best achievable measure of precision. We propose applying it to two GNSS receivers under two different scenarios, considering RTK network corrections (case a) and using a single-base RTK solution (case b). The GNSS equipment in case a includes a dual-frequency receiver equipped with a GPRS module to receive NRTK corrections from the Andalusian positioning network (RAP) via Internet Protocol (NTRIP), a triple frequency (GPS/GLONASS/Galileo) antenna and a radio field controller. Case a considers the NRTK solution and the RAP reference frame. Case b considers two low-cost single-frequency RTK modules with patch antennas. The base station sends corrections to the rover module via radio-link. Case b considers the single-base RTK solution and includes a non-permanent base station (UJAC) located at an approximate distance of 300 m from rover points (Fig. 1).

According to the ISO standard procedure, a field test network must be designed considering two rover points. The rover points are located at the Science and Technology building on the Campus of the University of Jaén (Spain) and are materialized by leveling benchmarks (Fig. 4). For each configuration two independent RTK samples, A and B, must be measured. The calculation of the horizontal distance and height difference between two rover points from the RTK positions is required. In order to detect gross errors, these measurements are compared with nominal values (horizontal distance and the height difference) determined using a total station combined with a digital level and high precision leveling.

3.2.2 Main Results

RTK solutions have been determined corresponding to two samples (A and B) and two solutions (NRTK and single-base RTK) and no gross errors were detected. Considering the NRTK solution, the horizontal residuals are less than half a centimeter and slightly higher in the vertical component. For the single-base solution, the residuals double the values for the North and East components obtained with the NRTK solution and triple them for the vertical component. In this case, it is important to remark that the unmodelled antenna correction could include a bias in the altimetric precision. Considering the different sources of uncertainty, the results indicate that just as the geodetic receiver satisfies the sub-centimetric precision limits established for high precision applications, the low-cost receiver can achieve a competitive positioning performance on survey-grade dual-frequency GNSS receivers in real-time positioning for short baselines. The good results obtained with the low-cost receiver in this study may be due to the baseline length and further analysis is required with longer baselines and considering dual-frequency low-cost receivers.

The competencies acquired by undergraduate students with this approach include most of the basic, general, transversal and specific competencies shown in Universidad de Jaén (2014), high-

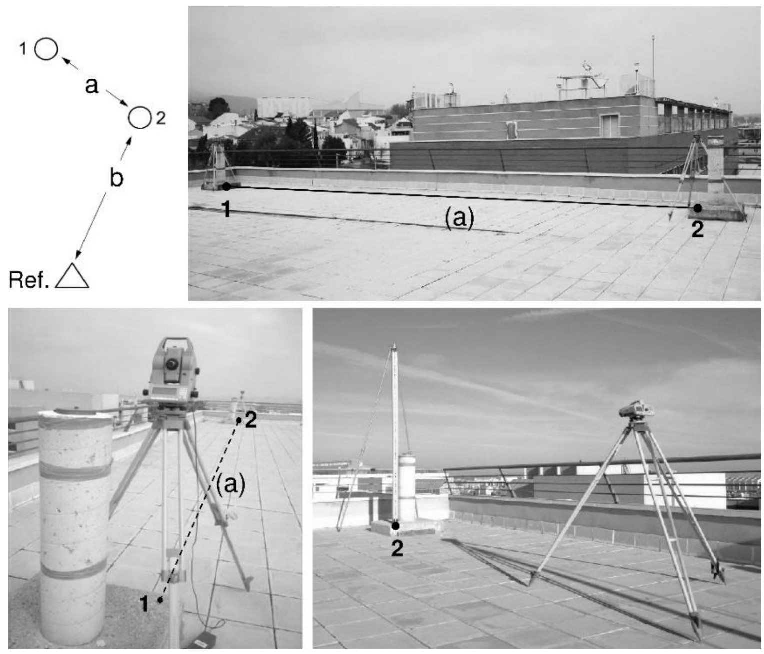

Fig. 4. Selection of two rover points according to the ISO 17123-8 standard procedure and determination of nominal values of distance and height difference using a total station and a digital level respectively.

lighting the ability to apply knowledge in a professional manner developing those learning skills necessary to undertake further studies with a high degree of autonomy, the ability to apply knowledge of statistics and optimization and computer programs with applications in engineering as well as knowledge of databases, the knowledge, use and application of instruments and topographical methods suitable for the realization of surveys and redefinitions, the knowledge and application of geometric geodesy, geomatics methods and techniques in the field of engineering and the ability to apply new technologies, including communication technologies. In addition, the publication of research results is a very important stage of the research process. It is important to note that the young researchers who have participated in this experience have collaborated in the preparation of manuscripts presented to scientific journals. Writing a scientific paper and experimenting the peer review and editing processes is difficult and time-consuming for the students. However, the preparation of a scientific manuscript presents several opportunities for students involved in the publication process such as:

- To experience the scholarly publication process. Writing, editing, and publishing the scientific results will provide very valuable feedback to student. Through these steps, the student will improve writing and research skills that will be useful in graduate studies or in future professional activities.
- To contact with other researchers. This process may help students to connect with other professionals and researchers, providing new opportunities for collaboration in research tasks.
- To display initiative and leadership. Being part of the team involved in the publication process is hard work. Employers and admissions committee members recognize this endeavor as an example of leadership.
- To publish a scientific paper will provide a level of experience that many undergraduates do not have. It will signal that serious steps were taken to achieve research goals.
- To start a career path. The publication process may help to define opportunities that otherwise have not been considered, for example, the student's interest in Master's degree.

As result of this research, an original Bachelor Degree's Thesis is developed, presented and defended before a University Court in the field of specific technologies of Geomatics Engineering and Surveying. A detailed description of this research

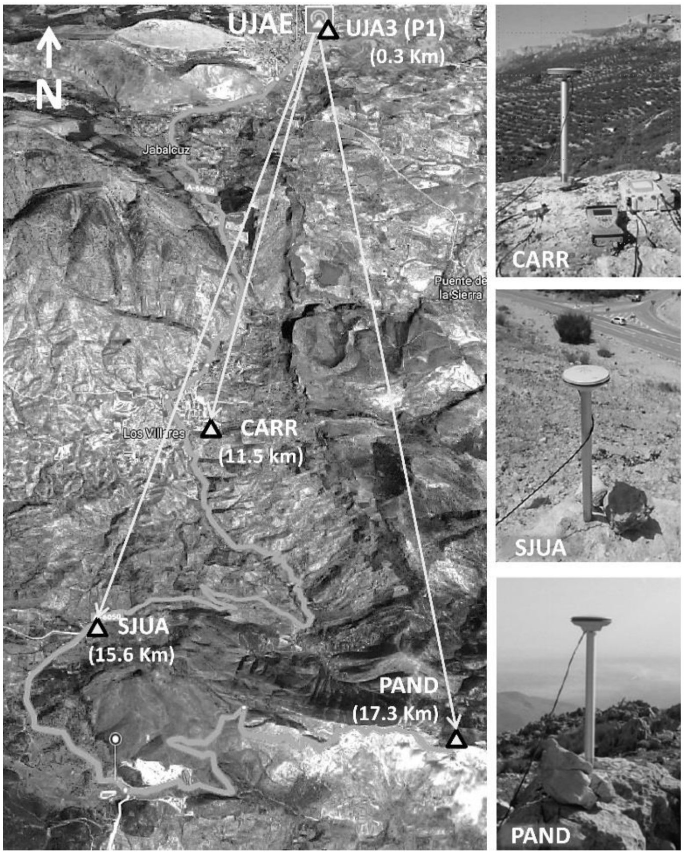

Fig. 5. Location of test sites relative to the CORS UJAE and details of test sites CARR, SJUA and PAND.

has been published in [34]. The contribution to this journal includes all aspects of the research: development and application of the technology of measurement and instrumentation, including results of research with practical developments related to the process, new developments in sensors and instrumentation and systems evaluation and modeling.

3.3 CASE STUDY 3: Proposed Research for Master's Degree Students that will perform the Master's Thesis.

3.3.1 Framework and Proposed Research Methodology

Regional and local scale active networks provide high accuracy real time positioning services and GNSS data files for post-processing precise positioning. However, in network based altimetric positioning it is important to model the error sources affecting the quality of GNSS positioning, especially in applications where large elevation differences between the user and reference stations are present. In order to analyze the altimetric positioning based on a local active network, four scenarios with different topographical, environmental and meteorological conditions in the southeast of the Iberian Peninsula were selected. The test area was located in the province of Jaén (SE Spain). The CORS "UJAE" and four test sites were used: "UJA3", located at geodetic pillar P1 at the University of Jaén and another three test sites (Fig. 5).

The baselines vary from a hundred meters to a dozen kilometers, with altitude differences between 20 and more than 1300 m, thus tropospheric conditions are different at each test site. The RAP reference stations, including UJAE, upload daily RINEX observation files (24 hour) with a sampling rate of 30 seconds. CORS UJAE, include a weather station Paroscientific MET3 providing a RINEX meteorological file with daily data at a 5-min rate.

At each test site, the survey must be performed under repeatability conditions: the same measurement procedure, observer and measuring instruments, used under the same conditions and repetition over a short period. All test sites are equipped with a triple frequency antenna (GPS/GLONASS/Galileo) and two real time dual-frequency GNSS receivers. Simultaneously to the GNSS data record, meteorological parameters were measured with a sensor datalogger. The aim is to check the quality and repeatability of network-based altimetric positioning (post-processed and in real time) considering short, medium and long baselines under favorable (rover located close to the reference station and at a similar altitude) and non-favorable conditions (with large distance and elevation difference from the nearest reference station).

This approach describes the methodology applied (test design, methodology, instrumentation, etc.) and discusses the results obtained in terms of precision, accuracy and repeatability that may be taken into consideration in order to improve the altimetric configuration of the local active network in the region.

3.3.2 Main Results

In precise RTK positioning it is important to model the error sources affecting the quality of positioning. It is known that the tropospheric delay is a function of the satellite elevation angle and the altitude of the GNSS receiver. If the residual tropospheric delay is not modelled carefully a bias error will occur in the vertical component. While ionospheric delays can be eliminated by using multi-frequency GNSS signals, an empirical tropospheric delay model is used to correct tropospheric errors in GNSS processing. This research reveals that, with short observation times, it is recommended to use an a priori model along with the standard atmosphere. Following this recommendation, the altitude estimated in post-processing has been used as reference value for the altimetric RTK solutions at test sites covering a wide range of altitudes.

Three specific skills have been acquired by the postgraduate student with this approach: gaining research experience in order to apply it in the field of R+D+I (Research+Development+Innovation), knowing the utility and applications of precision geodetic instrumentation and having the ability to assess the quality of GNSS positioning in an experimental field. The main results of this study have been published in [35]. This academic journal focuses on the theories, technologies and applications of Digital Earth and represents a platform for monitoring, measuring and forecasting natural and human activity on the planet. The research papers published by this journal are related to technologies and fields of research linked to Earth observation (remote sensing and in situ sensors), Global Navigation Systems, information and communication, Earth-system science, etc.

4. Discussion of Results

Three case studies, located at different academic levels, have been presented and show how the geodetic infrastructure is a valuable tool for introducing students to applied scientific research. Using local geodetic infrastructure, students can extrapolate their theoretical and practical knowledge to real cases of applied research at the same time that they begin their research careers. This research group recognizes not only the challenges, also the opportunities presented by this approach for contributing to develop students' research skills, as well as to promote their professionalism. This approach is a "scaffold" on which to build research options for the student. Relevant factors that evidence the strengths of this approach are:

- Through the participation of the students together with the research group in observation campaigns and surveys as well as in tasks of data processing and analysis of results, the students learn to recognize that teamwork is more important than individual effort in achieving common goals. This prepares them for working in multidisciplinary teams.
- The students provide their research material to academic tutors for discussion and reviewing as evidence of their practice and progression. Thanks to the continuous evaluation, they receive written feedback from their supervisors and tutors. Gradually increasing the level of complexity, the tasks presented by the tutors become more challenging and the students gain a greater depth of understanding.
- They develop their competencies in information and communication technologies (ICTs), statistics and GNSS data management as well as other basic competencies including teamwork, time and workload management and a wide range of communication skills such as the capacity for information management, analysis and synthesis and the capacity for oral and written transmission of information. These competencies and skills will be very useful in the presentation of the Bachelor's Thesis and the Master's Thesis.
- Through the participation in the publication process of the research results, the students see an opportunity to gain a scientific publication that can enhance their curriculum vitae. It is known that peer-reviewed journal articles or communications presented at national or international conferences arise from research projects.
- Finally, students bring enthusiasm and new and original ideas and as young researchers in this active-research-learning context of Geomatics Engineering, they contribute significantly to applied research carried out within this research group.

This approach also has some weaknesses. Until now, the number of students who agree to participate in this pilot experience is low. This is probably due to the insecurities generated by a novel situation for them as well as the difficulties in making research compatible with the other activities of the Bachelor's and Master's degree programs. We clearly recognize the importance of the integration of students into the research community. Ensuring the continuity and sustainability of this approach is vital. Research group members are engaged, and they recognize the benefits of researching with motivated students. Thus in the coming years the research group will propose more research projects, which may be new or a follow-up of previous studies. The assessment of research-based competencies represents a challenge. In this approach, the main competencies in Geomatics Engineering are developed through active experience and participation in research activities and they are assessed through the continuous evaluation. This has been feasible due to the low number of participating students. The research proposals, being necessarily short, have a significant risk of not producing short-term results due to the lack of time. This situation differs from Bachelor's degree and from Master's degree where eventual problems have more time to be adequately addressed and solved. The researchers, tutors and supervisors, work with the student, know the strengths and weaknesses of each student and offer detailed and valuable feedback over all period.

This approach requires students to take the initiative and to contact tutors. Taking the initiative to start a research project and to be part of a team is an important learning outcome in itself. Through individual interviews, with the head of the research group and with the participating professors and researchers, the specific research line or the research activity, that is more akin to the interests of the participating student, is chosen.

5. Conclusions

This pilot experience approaches the current challenges of applied research in Geodesy, using the geodetic infrastructure as a valuable tool for introducing students of Bachelor's degree in Geomatics and Surveying Engineering and Master's degree in Satellite Geodesy and Geophysics Applied to Engineering and Geology at the University of Jaén into the scientific research within the framework of a research group of Applied Geodesy. An active learning environment may be designed with all their components acting congruently to support research-based learning in Geomatics Engineering and this manuscript reveals that research-centered elements are effective in motivating and engaging students in research activities in geomatics engineering. This approach provides research opportunities to undergraduate and graduate students, it is sustainable in collaboration with a consolidated research group, and it promotes the dissemination of research results by peer-reviewed papers and scientific publications with students as co-authors.

Alignment of University, Higher Polytechnic School and Research Group aims will ensure the sustainability of this pilot experience. In addition, although several institutions (Institute of Statistics and Cartography of Andalusia, University of Jaén, etc.) have made valuable contributions to this local geodetic infrastructure over the past years, renewed investment is needed to maintain it as well as to enable the development of new applications with new scientific and academic results.

Acknowledgements – We thank two anonymous reviewers for their constructive comments that have improved the quality of this article. This research has been funded by the University of Jaén (Programa Operativo FEDER Andalucía 2014–2020 - Project 1263446 – call made by UJA 2018; POAIUJA 2021–2022 and CEACTEMA) and Junta de Andalucía (Research Group RNM282).

References

1. M. Healey, Linking research and teaching to benefit student learning, *Journal of Geography in Higher Education*, **29**(2), pp. 183–201, 2005.
2. C. D. Wilson, J. A. Taylor, S. M. Kowalski and J. Carlson, The relative effects and equity of inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation, *Journal of Research in Science Teaching*, **47**(3), pp. 276–301, 2010.
3. S. B. Ozay, The dimensions of research in undergraduate learning, *Teaching in Higher Education*, **17**(4), pp. 453–464, 2012.
4. A. Hajdarpasic, A. Brew and S. Popenici, The contribution of academics' engagement in research to undergraduate education, *Studies in Higher Education*, **40**(4), pp. 644–657, 2015.
5. UNESCO, *Engineering: Issues Challenges and Opportunities for Development*, Paris, France, 2010.
6. W. Sunthonkanokpong, Future Global Visions of Engineering Education, *Procedia Engineering*, **8**, pp. 160–164, 2011.
7. European Parliament – Council of the European Union, *Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE)*, 2007.
8. ESA, *ESA Convention and Council Rules of Procedure (ESA SP-1317*), 7th edition, 2010.
9. R. M. Lima, D. Mesquita and M. A. Flores, Project approaches in interaction with industry for the development of professional competencies, *Proceedings of the 2014 Industrial and Systems Engineering Research Conference*, pp. 1668–1677, 2014.
10. A. K. Ditcher, Effective teaching and learning in higher education, with particular reference to the undergraduate education of professional engineers, *International Journal of Engineering Education*, **1**, pp. 24–29, 2001.
11. F. J. García-Peñalvo, H. Alarcón and A. Domínguez, Active learning experiences in Engineering Education, *International Journal of Engineering Education*, **35**(1(B)), pp. 305–309, 2019.
12. S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt and M. P. Wenderoth, Active learning increases student performance in science, engineering, and mathematics, *Proceedings of the National Academy of Sciences*, **111**(23), pp. 8410–8415, 2014.
13. D. Angermann, T. Gruber, M. Gerstl, U. Hugentobler, R. Heinkelmann, L. Sanchez and P. Steigenberger, GGOS bureau of products and standards: Inventory of standards and conventions used for the generation of IAG products, *Journal of Geodesy*, **90**(10), pp. 1095–1156, 2016.
14. National Research Council, *Precise geodetic infrastructure: national requirements for a shared resource*, The National Academies Press, Washington, D.C. National Academies Press, 2010.
15. A. Martin and E. Mcgovern, An Evaluation of the Performance of Network RTK GNSS Services in Ireland, *FIG Working Week 2012. Knowing to manage the territory, protect the environment, evaluate the cultural heritage*, Rome, Italy, 2012.
16. E. Giménez, M. Crespi, M. S. Garrido and A. J. Gil, Multivariate outlier detection based on robust computation of Mahalanobis distances. Application to positioning assisted by RTK GNSS Networks, *International Journal of Applied Earth Observations and Geoinformation*, **16**, pp. 94–100, 2012.
17. M. S. Garrido, E. Giménez, M. C. de Lacy and A. J. Gil A, Surveying at the limits of local RTK networks: Test results from the perspective of high accuracy users, *International Journal of Applied Earth Observations and Geoinformation*, **13**, pp. 256–264, 2011.
18. J. Aponte, X. Meng, C. Till, T. Moore, M. Burbidge and A. Dodson, Quality assessment of a network-based RTK GPS service in the UK, *Journal of Applied Geode*sy, **3**, pp. 25–34, 2009.
19. C. Bruyninx, H. Habrich, W. Söhne, A. Kenyeres, G. Stangl and C. Völksen, Enhancement of the EUREF Permanent Network Services and Products, *Geodesy for Planet Earth*, IAG Symposia Series, **136**, pp. 27–35, 2012.
20. V. Wegener and L. Wanninger, Communication options for Network RTK / SAPOS® realization. *Joint 2nd Workshop on Positioning, Navigation and Communication 2005 (WPNC'05) & 1st Ultra- Wideband Expert Talk 2005 (UET'05*), Hannover, Germany, 2005.
21. A. Afonso, R. Teodoro and V. Mendes, SERVIR the Portuguese Army CORS Network for RTK, Integrating Generations, *FIG Working Week 2008*, Stockholm, Sweden, 2008.
22. D. Prochniewicz, R. Szpunar, J. Kozuchowska, V. Szabo, D. Staniszewska and J. Walo, Performance of Network-Based GNSS Positioning Services in Poland: A Case Study, *Journal of Surveying Engineering*, **146**(3), pp. 1–14, 2020.
23. M. Bakula, Study of reliable rapid and ultrarapid static GNSS surveying for determination of the coordinates of control points in obstructed conditions, *Journal of Surveying Engineering,* **139**, pp. 188–193, 2013.
24. Spanish National Geographic Institute, EUREF 2019 Symposium*,* National Report of Spain, Tallinn, Estonia, 2019.
25. R. Páez, C. Torrecillas, I. Barbero and M. Berrocoso, Regional positioning services as economic and construction activity indicators: the case study of Andalusian Positioning Network (Southern Spain), *Geocarto International*, **32**(1), pp. 44–58, 2017.
26. A. M. Herrera and M. C. de Lacy, Implementación de los efectos atmosféricos y de multipath en el desarrollo de un simulador de datos GNSS, *Física de la Tierra*, **26**, pp. 135–161, 2014.
27. M. S. Garrido, E. Giménez, M. I. Ramos and A. J. Gil, A high spatio-temporal methodology for monitoring dunes morphology based on precise GPS-NRTK profiles: Test-case of Dune of Mónsul on the south-east Spanish coastline, *Aeolian Research*, **8**, pp. 75–84, 2013.
28. J. A. Armenteros and A. J. Gil, A methodology for creating RTK positioning coverage maps via a radio modem link to CORS stations, *Survey Review*, **42**(318), pp. 406–411, 2010.

29. University of Jaén, Memory of Degree in Geomatics and Surveying Engineering, https://www.ujaen.es/gobierno/secgrados/memorias-grados/memorias-de-grados-verificadas, Accessed 20 April 2021.
30. University of Jaén, Memory of Master Degree in Satellite Geodesy and Geophysics Applied to Engineering, https://www.ujaen.es/estudios/oferta-academica/masteres, Accessed 20 April 2021.
31. A. M. Herrera, H. F. Suhandri, E. Realini, M. Reguzzoni and M. C. de Lacy, goGPS: open-source MATLAB software, *GPS Solutions*, **20**, pp. 595–603, 2016.
32. M. S. Garrido, E. Giménez, M. C. de Lacy and A. J. Gil, Quality Analysis of NRTK Positioning on Boundary Regions and Under Unfavorable Topographic Conditions in the Southern Iberian Peninsula, *IEEE Journal of selected topics in applied earth observations and remote sensing*, **6**, pp. 2364–2374, 2013.
33. N. Quesada-Olmo, M. J. Jimenez-Martinez and M. Farjas-Abadia, Real-time high-rise building monitoring system using global navigation satellite system technology, *Measurement*, **123**, pp. 115–124, 2018.
34. M. S. Garrido, M. C. de Lacy, M. J. Borque, A. M. Ruiz, R, Moreno and A. J. Gil, Low-cost GNSS receiver in RTK positioning under the standard ISO-17123-8: A feasible option in geomatics, *Measurement*, **137**, pp. 168–178, 2019.
35. M. S. Garrido, M. C. de Lacy and A. M. Rojas, Impact of tropospheric modelling on GNSS vertical precision: an empirical analysis based on a local active network, *International Journal of Digital Earth* **11**(9), pp. 880–896, 2018.

APPENDIX: Definition of abbreviations used

cGPS: continuous GPS
CORS: Continuously Operating Reference Stations
ECTS: European Credit Transfer and Accumulation System
EGNOS: European Geostationary Navigation Overlay Service
ERGNSS: Red Geodésica Nacional de Referencia de Estaciones Permanentes GNSS (in Spanish)
ESA: European Space Agency
EUREF: European Reference Permanent GNSS Network
GGOS: Global Geodetic Observing System
GLONASS: Global'naya Navigatsionnaya Sputnikovaya Sistema
GNSS: Global Navigation Satellite Systems
GPS: Global Positioning System
HEPS: Hochpräziser Echtzeit Positionierungs-Service (in Germany)
IAG: International Association of Geodesy
ICA: International Cartographic Association
ICT: Information and Communication Technologies
INSPIRE: Infrastructure for Spatial Information in Europe
ISO: International Organization for Standardization
ISPRS: International Society for Photogrammetry and Remote Sensing
JPL: Jet Propulsion Laboratory
NRTK: Network-based Real-Time Kinematic
NTRIP: Networked Transport of RTCM via Internet Protocol
PBL: project-based learning and problem-based learning
RAP: Red Andaluza de Posicionamiento (in Spanish)
RENEP: Rede Nacional de Estações Permanentes GNSS (in Portuguese)
RINEX: Receiver INdependent EXchange
RTK: Real-Time Kinematic
SEFI: European Society for Engineering Education
SERVIR: Sistema de Estações de Referência GNSS VIRtuais (in Portuguese)
STEM: Science, Technology, Engineering and Mathematics.

María S. Garrido-Carretero is an associate professor at the department of Cartographic, Geodetic and Photogrammetric Engineering (University of Jaén), member of the UJA Research Group "RNM282" and the Center for Advanced Studies in Earth Sciences, Energy and Environment (CEACTEMA), focusing its activities in the field of Applied Geodesy and GNSS positioning and navigation.

María J. Borque-Arancón is an associate professor at the department of Cartographic, Geodetic and Photogrammetric Engineering (University of Jaén), member of the UJA Research Group "RNM282" and CEACTEMA. Her current research includes geodetic deformation monitoring with GNSS techniques and classical methods.

María C. de Lacy-Pérez de los Cobos is a full professor of Geodesy at the department of Cartographic, Geodetic and Photogrammetric Engineering (University of Jaén) and member of the Research Group "RNM282" and the CEACTEMA. Her current research interest includes GNSS, crustal deformation monitoring and engineering geodesy.

Manuel Avilés-Moreno is engineer in Geodesy and Cartography. He has been working for several years at the RNM282 Geodesy Research Group. His current research interest includes deformation monitoring, engineering geodesy and GNSS.

Antonio J. Gil is a full professor of Geodesy at the department of Cartographic, Geodetic and Photogrammetric Engineering in the University of Jaén. He has been the Head of the RNM282 Research Group since 1997, focusing its activities in the field of Earth's crustal deformation monitoring, engineering geodesy and GNSS. He is author of more than two hundred works, articles and conference papers.