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A Methodology to Replicate Cutting-Edge Surveying Equipment Using Cost-Sensitive Devices to Promote Innovative Mapping Solutions in Undergraduate Engineering

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Abstract

Engineering applications typically use mapping products as input for developing solutions. Several levels of data acquisition can support engineering projects, such as orbital, aerial, and terrestrial data gathering. Considering the terrestrial level, the way to acquire data can be static, where the equipment is at a fixed position during the measurements, or kinematic (mobile), in which a platform carries the equipment during data acquisition - in movement. Terrestrial mobile mapping systems (TMMS) usually have sensors assembled in a vehicle that collect data while moving, and nowadays, these systems can cost around one million dollars. That said, it is notorious that only a few commercial applications rely on this mapping strategy.

Regarding educational purposes, these commercial TMMS are introduced to students with point cloud data provided by mapping companies. However, these commercial TMMS are cost-prohibitive for most universities, preventing students from fully exploring this technology in terms of configuration, data collection, data processing, and product generation. Based on this, this project presents a service-oriented project-based learning approach to bring the sense of using TMMS to the university with low-cost devices.

The proposed strategy contemplates developing a cost-sensitive terrestrial mobile mapping system (CS-TMMS) to support a PBL (project-based learning) service-oriented project. The instructor integrated the CS-TMMS development into undergraduate research and courses to explore the potential of a CS-TMMS for cadastral applications related to power distribution and vegetation management, parcel-based solutions, and transportation.

Students were involved in software development, data acquisition, and data manipulation. Students defined possible applications based on features extracted from images collected by the CS-TMMS. After image acquisition, vehicle trajectories were established using Global Navigation Satellite Systems (GNSS) and used as input for the mapping stage, followed by cartographic product generation using Geographic Information Systems (GIS).

Based on the results, it was possible to create geodatabases with information regarding the location of different features and their characteristics, such as poles, traffic signs, residency, trees, and others. The products generated highlight the approach's feasibility for educational and technical purposes.

Introduction

In contemporary times, the importance of spatial data for effective management, both in public and private sectors, is widely recognized. Enhancing problem-solving efficiency through spatial representation is a commonly employed technique by managers. This technique, that is based on geoinformation, is sourced from various platforms/techniques, including orbital imagery, aerial surveys, and terrestrial data collection methods such as Mobile Mapping Systems (MMS) [1]

With the recent update on world urbanization prospects [2] indicating that 55% of the global population resides in urban areas - a figure projected to reach 68% by 2050 - detailed spatial information becomes imperative for managing urban development. This necessity aligns with the concept of smart cities, encompassing diverse definitions but ultimately referring to cities equipped with intelligent services, extensive structural knowledge, and sustainability [3].

MMS emerges as a valuable tool for acquiring spatial data within urban landscapes. Comprising a set of sensors, these systems can collect data that represents 3D information from various urban features such as road signs, buildings, and facilities, as presented in subsequent sections. MMS is deployed worldwide for mapping purposes, typically equipped with high-precision sensors capable of generating accurate feature extractions when properly integrated and synchronized [4].

According to [5], mobile mapping is a methodology that integrates different sensors aiming at the direct georeferencing of digital images. Therefore, the data collected by these systems serve as a basis for executing photogrammetric procedures for extracting attributes of interest. As described by several authors [6-9], the mobile mapping system is basically composed of positioning systems (GNSS receivers - Global Navigation Satellite System), inertial navigation systems (INS - Inertial Navigation System), and high-resolution cameras (video or photographic). These sensors can be found with different characteristics, which influence their performance and also their acquisition and maintenance costs. It is known from the literature on this subject that to obtain geoinformation with a high level of positional accuracy, it is fundamental to use high-performance sensors (dual-frequency GNSS receivers, high-sensitivity INS, and digital cameras with high resolution and geometric stability). Consequently, to develop a TMMS and ensure good performance, there is a high cost for the project.

Considering the cutting-edge devices assembled in an TMMS, the cost can reach a million dollars. Even being widely used for engineering projects, the TMMS is still not affordable for some companies and mainly for universities, which usually provide students a superficial content related to it.

Based on this, the main aim of this project is to replicate cutting-edge surveying equipment using cost-sensitive devices to promote innovative mapping solutions in undergraduate engineering (Surveying Program). To accomplish this aim, a service-oriented project-based learning approach was applied to bring the sense of using Terrestrial MMS to the university with low-cost devices - Cost-Sensitive TMMS (CS-TMMS).

CS-TMMS as a tool for improving the surveying engineering learning process

Surveying Engineering programs have a similar curriculum worldwide. The main sciences/areas covered by these programs are Plane Surveying, Geodesy, Photogrammetry, Remote Sensing, Legislation, Cadastre, and Geographic Information Systems (GIS). Professionals with surveying engineering backgrounds are usually involved in projects that must handle several types of data collection and processing. MMS and its products are a good example of a system that integrates different areas, such as Geodesy, Remote Sensing, Photogrammetry, and GIS.

To use a CS-TMMS as a tool for improving the learning process, it was chosen as a course related to cadastre and GIS called "Parcel-based GIS" in the Surveying Engineering Program at Penn State University - Wilkes-Barre campus. The reason for applying it to this course is because the images acquired by any TMMS provide valuable data about parcels that are not visible in aerial images (usually provided by the government, as the National Agriculture Imagery Program – NAIP[1] that covers the entire USA). The data from TMMS is complementary to aerial data bringing a new point of view related to the parcels and some facilities around them.

The Parcel-based GIS course is taught for junior and senior students who already have the necessary knowledge related to the components of a TMMS. These components include the Global Navigation Satellite Systems (GNSS) for trajectory determination, Photogrammetry for 3D information extraction, and GIS for data representation and analysis.

During the previous semesters, when the same course was taught, it was noticed that the students could easily handle data analysis in GIS related to applications involving parcels. However, all necessary data was available in geospatial repositories, such as PASDA[2] (Pennsylvania Spatial Data Access), which did not provide a practice of planning and collecting data for such applications. Due to the fact that orbital imagery and aerial missions are labor and expensive for educational purposes, the authors proposed the development and usage of an CS-TMMS for applications related to parcels.

Figure 1 provides an explanation of the steps carried out during the process of implementing this teaching/learning strategy.

[1] https://naip-usdaonline.hub.arcgis.com/
[2] https://www.pasda.psu.edu/

Step 1: The development of the system (sensor integration and software development) was established by undergraduate research with senior students who have knowledge in Geodesy, Photogrammetry, and coding. This was done in a 2-year period.

Step 2: Students were required to research possible applications that could benefit from data potentially collected by the CS-TMMS. After the research was done, discussions were carried out among the instructor, project proponent, and all course colleagues.

Step 3: All students were required to work in the same area (described below). The data collection was done with the presence of all students who were observing possible features to be mapped in the area - during the data collection.

Step 4: With the data collected, students processed the imagery and extracted the coordinates of all necessary information using the software developed in Step 1. The result was represented in a GIS platform where map layouts were created, and spatial analysis was carried out.

Step 5: The results obtained in Step 4 were used as a base for a business plan. The students presented to all colleagues their results, ideas, and possible costs for their specific project.

Figure 1. Workflow of the strategy applied to enhance the learning process using a CS-TMMS.

Another important aspect of focusing on junior and senior students is that it is a crucial time for preparing students with the critical skills and knowledge necessary for future academic pursuits and career success.

In the proposed approach, students engage in projects that not only address real-world problems or challenges but also contribute to serving the needs of a community or organization - when a deliverable is created and shared with the community. These projects typically involve identifying community needs (Step 2), designing and implementing solutions (Step 1), collecting and processing data (Steps 3 and 4), and reflecting on the impact of their work on both learning outcomes and community well-being (Step 5).

The set of sensors used in the proposed approach can be seen in Figure 2, where the cameras are shown in detail (Figure 2.a), and also the system assembled on top of a vehicle is presented (Figure 2.b). It used five GoPro cameras (three pointing forward - frontal and diagonals - and two pointing to the sides) and two Mapir cameras (cameras with infrared band for future research for vegetation identification).

Figure 2. (a) Set of seven cameras (five GoPro and two Mapir cameras). (b) Set of cameras assembled on top of a vehicle for data collection.

The area chosen for applying the proposed strategy was Harveys Lake in Pennsylvania (Figure 3.a), which is the largest natural lake in the state by total volume of water. It is situated in Luzerne County and covers approximately 621 acres. It is 7 mi from Penn State Wilkes-Barre campus, which facilitates data collection. The lake is a popular destination for recreational activities such as boating, fishing, swimming, and water sports during the warmer months. Surrounding the lake are residential areas as well as some commercial establishments catering to tourists and visitors. Considering the structure of Harveys Lake, it can simulate a normal neighborhood in terms of parcel types, utility features, and possible attributes for mapping.

To determine the geolocation of desired features, a photogrammetric intersection [1] was applied based on feature coordinates from all images where they appeared, exterior orientation parameters of the cameras (from their GNSS receivers), and calibration parameters of the system and cameras. Based on this approach, it was possible to extract the elements presented in Figures 3 and 4 from the dataset collected by the system in Figure 2.

Figure 3.b) presents a set of features mapped by the students. In this example, all the yellow/red dots represent power-line poles around the lake. Some groups of students choose this feature aiming to classify possible areas with risk in terms of vegetation (close to the pole and to transformers) and structure preservation (quality of the pole: material and verticality). A detailed

description of one feature (dot in the map) can be seen in Figure 4, where it is possible to see three images from the data collection, the coordinates of the feature (pole), and its attributes. All this information, including the images, is stored in a geodatabase in GIS.

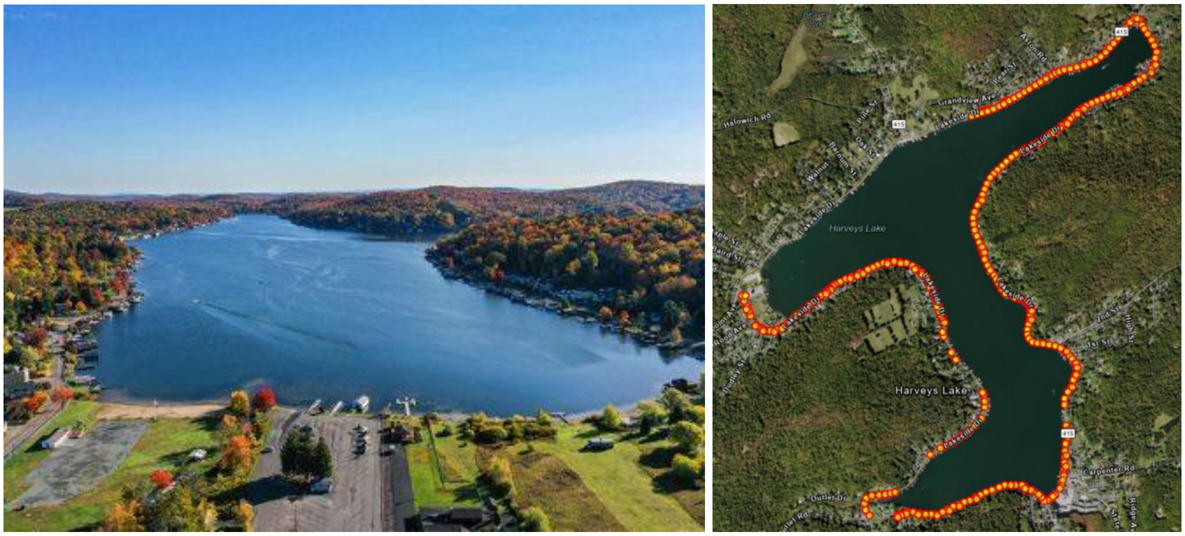

Figure 3. (a) Harveys Lake in Pennsylvania. (b) Data representation of poles around the lake.

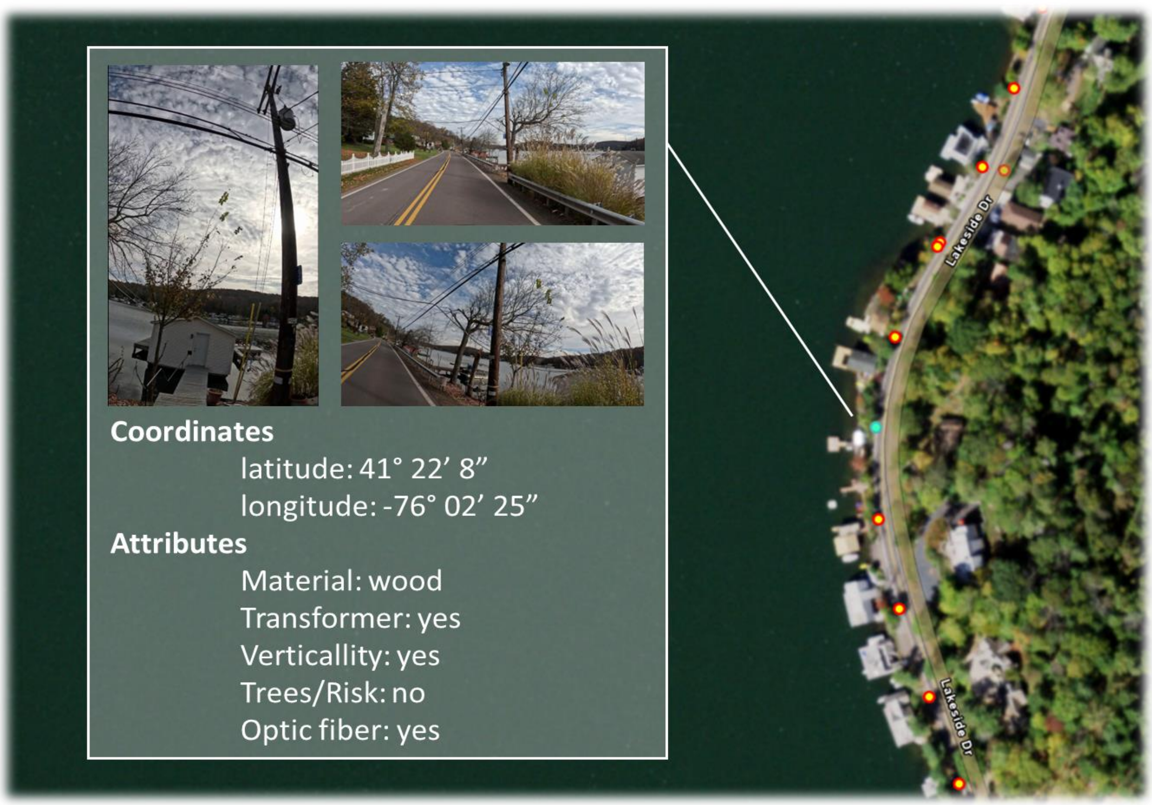

Figure 4. Representation of attributes extracted from the developed system together with respective images of the feature.

After the mapping process, students created map layouts and carried out spatial analysis to support their business plan, which considered several elements to estimate the cost of generating a product similar to what they created for the discipline. The focus of their presentations was to show how a manager could use their product to make strategic decisions for specific applications.

Conclusions

This paper described a strategy for implementing a service-oriented project-based approach for engineering programs. The developed system and software can be used for several courses that need geodatabases from street-level scale. Considering the current cost of a commercial mobile mapping system, the approach presented in this paper can be considered a good alternative to provide students with hands-on activity related to mobile mapping process. During the implementation, both undergraduate research and courses were used. The implementation was feasible for a three-credit discipline. Students had a great performance during the process and provided an excellent deliverable and business plan. Several applications that benefit from the CS-TMMS developed were found, such as: vegetation management, road system inventory, parcel tax update, traffic sign management, and others.

As a suggestion for similar implementation, the authors recommend bringing the community to be part of the project, mainly during the definition of the problem to be solved.

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