Report for 2017, Scientific Initiative

Title of project:

DEVELOPMENT OF THE EDUCATIONAL CONTENT “SMALL UAS IN CIVIL ENGINEERING APPLICATION SCENARIOS” (SUAS-CAS)

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REPORT OF THE SCIENTIFIC INITIATIVE

Introduction

In today's world, decision support for multiple application scenarios is widely deployed by geospatial information. All of us in one way or another use geospatial data and the accompanying technologies. Many of us ubiquitously use smartphones, tablets, and even ultralight radio-controlled aerial image acquisition systems on daily basis. These modern devices are equipped with digital cameras, antennas, global navigation satellite systems chip's, electronic compasses, height and distance sensors. These devices allow us to determine our position in space and at the same time to carry out the collection of geospatial data. We determine the directions to an object, the distance to the target, take the pictures and simultaneously we are coordinating structures, objects and phenomena. A special role in this process is played by photographic images with geospatial reference obtained by means of small unmanned aerial systems (UAS). For civil engineers and architects the existence of non-accurate, but the operational UAS geospatial data allows quickly to make the right decisions and assess their projects. In fact, non-professional users collect up to 60 percent of such data. With nowadays development and availability of free or low-cost software, end users are able to create and use three-dimensional models of objects without having special knowledge in the field of geographic informational systems and remote sensing technologies. Given the fact that non-professionals collect these data, the important question brings up. *How can we help ordinary users, in our case civil engineers and architects, to understand the role of modern geospatial technologies and at the same time to achieve the required geospatial data quality and accuracy without any special skills?*
As a result of our project the answer on this question and develop appropriate recommendations, educational programs and training courses for outreach modern geospatial data collecting technologies among civil engineers and architects was found.

Project outline

Specifically proposed project comprises: a) practical experience in small UAS (SUAS) imagery acquisition at in-room and outside environments; b) review and comparative analysis of the classical photogrammetry and computer vision based methods of the UAS data processing; c) commercial and open-source software review; d) accuracy considerations and compatibility with application requirements analysis. Educational outcomes of the proposed project encompass: 1) understanding of small UAV flight planning and limitations of the SUAS platforms and sensors; 2) knowledge of contemporary issues in sensor modeling and calibration deploying classical photogrammetric methods versus computer vision; 3) understanding of technological steps for 3D modeling and geospatial analytics of commercial-of-the-shelf and open-source software packages; 4) hands-on expertize of SUAS data acquisition and processing; 5) understanding of legal regulations of SUAS deployment in airspace of the different countries; 6) profound understanding of SUAS sensors platforms and methods matching to accuracy and procedural needs of the civil engineering application scenarios.

In order to achieve these aims, ISPRS WG V/7 proposed to develop educational content "Small UAS in Civil Engineering Application Scenarios" (SUAS-CAS). SUAS-CA is aimed in development of the unique computer based educational materials that will optimally integrate education in fundamental problems associated with geospatial data obtaining and processing in civil engineering applications with training in SUAS systems use in response to that kind of applications.

The following objectives are established for the proposed SUAS-CAS project:
Objective-1: Development of the multimedia training content covering topics associated with SUAS use in civil engineering and architecture application scenarios.
Objective-2: Creation of the practical lab content based on in-room and outside data acquisition.
Objective 3: Establishing the outreach and data dissemination strategy for SUAS-CAS use for ISPRS and integration to UN university programs.

Due to commonly accepted research and development projects methodology SUAS-CAS objectives were realized towards following project tasks:

Task-1: Analytical review and selection of rotary and fixed wing SUAS platforms suitable for the project.
Task-2: Analytical review and selection of commercial-off-the-shelf and open source software systems.
Task-3: Preparation of the SUAS-CAS syllabus.
Task-4: Preparation and multimedia recording of the SUAS-CAS lectures.
Task-5: Establishing of SUAS-CAS hands-on components.
Task-6: Develop SUAS-CAS web-portal.
Task-7: SUAS-CAS approbation at ISPRS Kyiv workshop.
Task-8: Create SUAS-CAS outreach and data dissemination strategy.

SUAS-CAS project will be culminated in establishing and approbation of the educational modules, which will include online training manual on the collection and processing of UAV geospatial data, educational website available for training and education of civil engineers and architects worldwide. Fig. 1 depicts schematically operational structure of the proposed SUAS-CAS project after successful completion.

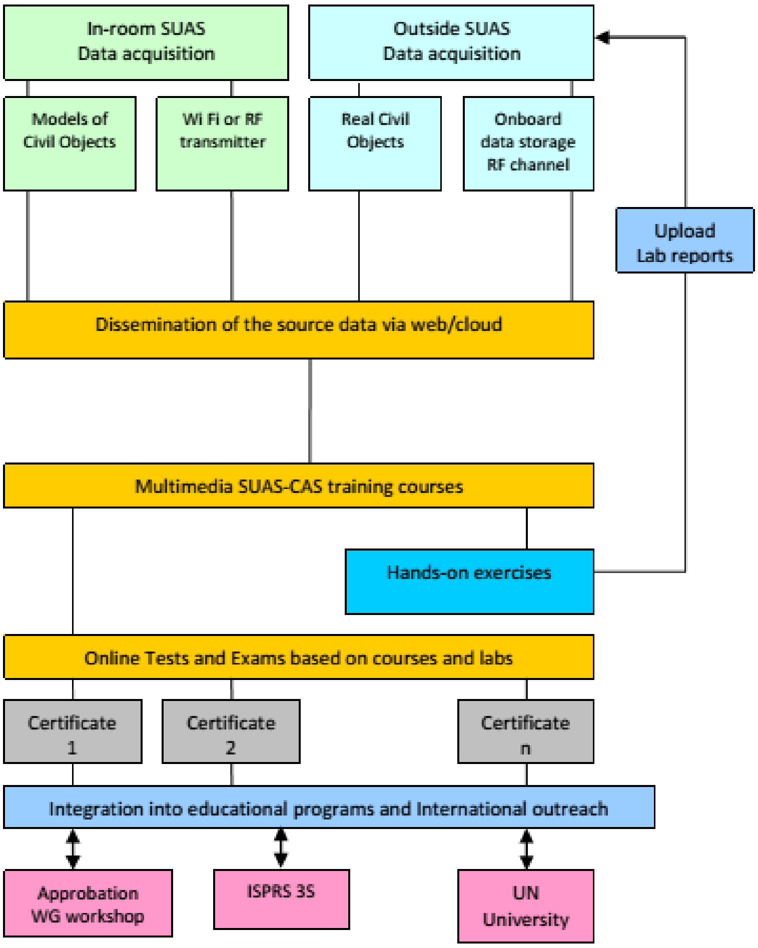

Figure 1. The SUAS-CAS educational content (operational structure)

Kyiv National University of Construction and Architecture is equipped with multiple in-room models to support in-room project approbation. Our decision to select that school for SUAS approbation was not spontaneous. Ukraine, as a young European state passed a difficult stage of its democracy development. The transition from outdated concepts and technologies of the XX century to modern technologies of XXI century is not always goes without errors. One of the reason for this situation is the low skills level in holding of the latest world achievements in the field of science and technology. This in turn is due to the absence or weak deployment of modern technology in the educational process and the promotion of new developments. Among these technologies is certainly true technology of collecting geospatial data using UAVs.

SUAS-CAS was implemented as a summary of the following project efforts: 1) identification and acquisition of the in-room and outside SUAV platforms (rotary or fixed wing); 2) analytical review of the commercial-of-the-shelf and open source software systems suitable for the SUAS data processing; 3) preparation of lectures and recording then in multimedia formats; 4) work on quizzes and SUAS-CAS final test; 5) development of in-room and outside practical labs. Use of in-room nano-UAVs may be helpful to resolve a problem of getting SUAS data when flying of the outside platforms will not be available due to weather or legal factors at specific locations.

Project realization

Task-1: Analytical review and selection of rotary and fixed wing SUAS platforms suitable for the project.

This task was realized using of methods of fuzzy logic and hierarchy analysis to carry out study of qualitative (competitiveness, ease of use etc.) characteristics of small UAS (the initial data for this study were got by literature review and surveys in social networks). As a result, for educational purposes two UAS were purchased.

Figure 2. Small UAS Kingco K88W

Figure 3. Small UAS Focus drone

Task-2**:** Analytical review and selection of commercial-off-the-shelf and open source software systems.

This task was divided on two parts. The first part included the detailed analysis and practical experimental researches of software tools for the calibration of non-metric digital cameras. The classification of software, which is based on value criteria, lens distortion model, the stability and accuracy of the computational algorithm, was offered. Since the non-metric digital cameras are mainly used for solving applied local problems the most effective utilization is inexpensive specialized software. We have studied conditionally expensive software: Australis, AgiSoft PhotoScan Pro, PhotoModeler and 3D Image Master. Each of these programs has certain advantages and disadvantages, but the average PhotoModeler was the most effective software. The most interesting results were obtained in studies of low-cost software: GML Camera Calibration, Camera Calibration Tools, CameraCalibrator (Photometrix), Image Master Calib (TOPCON), Agisoft Lens (Agisoft), Fauccal Matlab, Matlab Camera Calibration TOOLBOX. Common analysis of the results showed that the advantage should be given PhotoModeler type programs and under financial constraints Fauccal type program for Matlab.

The second part included the detailed analysis and practical experimental researches of software tools for data processing. We have studied conditionally expensive software: AgiSoft PhotoScan Pro, PhotoModeler, 3DSurvey, Pix4D and freeware software PhoX and PHOTOMOD Lite. As software for data processing, AgiSoft PhotoScan was chosen. Also we would like to pay your attention to Free Open Source Photogrammetry Foundation (FOSPHO).

Task-3: Preparation of the SUAS-CAS syllabus.

SUAS-CAS syllabus consists from one module and contains following learning outcomes:

→ understanding of small UAV flight planning and limitations of the SUAS platforms and sensors;

→ knowledge of contemporary issues in sensor modelling and calibration deploying classical photogrammetric methods versus computer vision;

→ understanding of technological steps for 3D modelling and geospatial analytics of commercial-of-the-shelf and open-source software packages;

→ hands-on expertize of SUAS data acquisition and processing;

→ understanding of legal regulations of SUAS deployment in airspace of the different countries;

→ profound understanding of SUAS sensors platforms and methods matching to accuracy and procedural needs of the civil engineering and architecture application scenarios.

Task-4: Preparation and multimedia recording of the SUAS-CAS lectures.

The task was carried out at Kyiv national university of construction and architecture. The main purpose at this stage was development of a small educational module for civil engineers and architects. The educational module presented below consists from the follow chapters:

1. Short review of state-of-the-art small UAS and free-ware or low-cost photogrammetric software.
2. Creation of small UASs surveying project with using specialised software, choosing of small UAS model and camera parameters.
3. Small UASs camera calibration.
4. Small UASs data post-processing.
5. Results export to specialised software for construction modelling.

Task-5: Establishing of SUAS-CAS hands-on components.

In order to reach the main aims of our project we developed the following components:

- application for surveying parameters calculation (VBA);
- application for UAS data quality assessment (VBA);
- application for UAS movement modelling Fig. 4 (Matlab application).

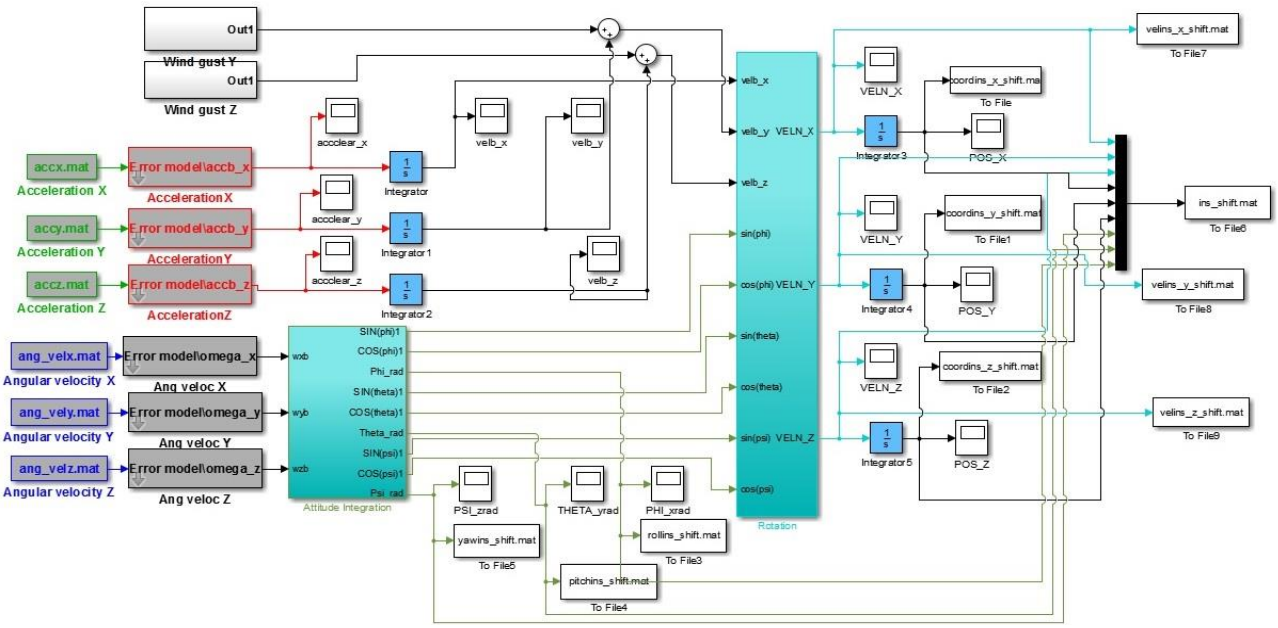

Figure 4. Matlab Simulink model of UAS movement

Task-6: Develop SUAS-CAS web-portal.

To be provided after upload of all data.

Task-7: SUAS-CAS approbation at ISPRS Kyiv workshop.

During joint ISPRS WG V/7, WG III/5, WG II/10 workshop “Geospatial solutions for structural design, construction and maintenance in training civil engineers and architects” in Kyiv, the project approbation was done. For students were held: practical school - DRONES USE FEATURES IN GEODESY (Organizer: Drone.UA LLC), Leading specialist: Tatiana Kondratyuk (Ukraine); master class - PHOX – PHOTOGRAMMETRIC CALCULATION SYSTEM FOR EDUCATION (Organizer: University of Applied Sciences, Oldenburg, Germany), Leading specialist: Thomas Luhmann (Germany); master class - RAPID MAPPING WITH LOW-COST CROWDSOURCING IMAGE ACQUISITION AND OPEN-SOURCE TOOLSETS (Organizer: Michigan Technological University, USA), Leading specialist: Eugene Levin (USA).

In 2017 at Kyiv national university of construction and architecture two student projects were carried out. The first project concerns to civil engineers. In order to achieve the aim of this project were used architectural in-room models. Some of examples of such models are presented in Fig. 4.

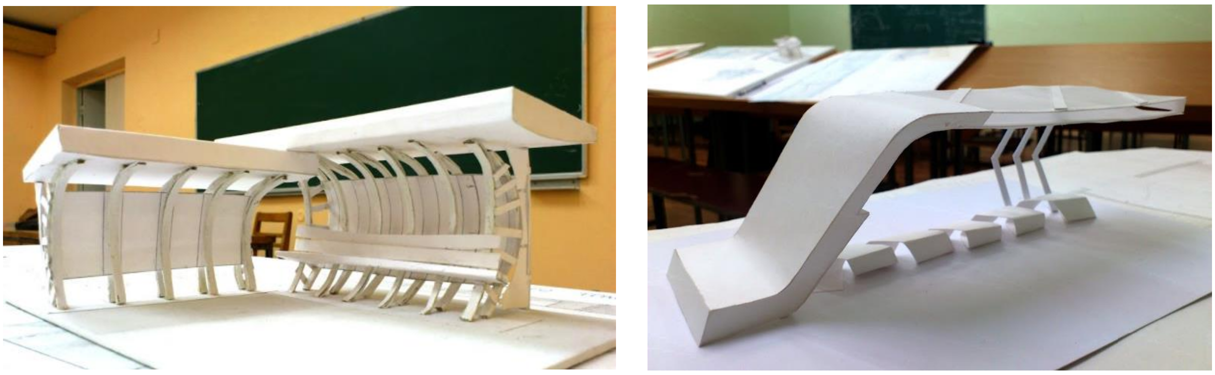

Figure 4. In-room models of architectural project of bus stop

Students created all of these models. It is a typical task for students. In such way they are trying to realise own ideas. However, during creation these in-room models students do not account the properties of construction materials and main laws of structural mechanic. That is why they need 3D models of their in-room models in order to check whether their projects will durable, stiff and reliable or not. This is the main reason why small UAS data suitable for 3D model creation in this particular case. In order to sort out this task, first of all we introduced a short overview about current state of UAS technologies and freeware photogrammetric software. It allowed students to chose correct UAS model, camera and software. The approximate size of models equals 30x15x15 cm and therefore the model scale equal 1:20. After lecture about main principles of the camera calibration, was done calibration for cameras. The camera calibration was done with using Agisoft Lens calibration software.

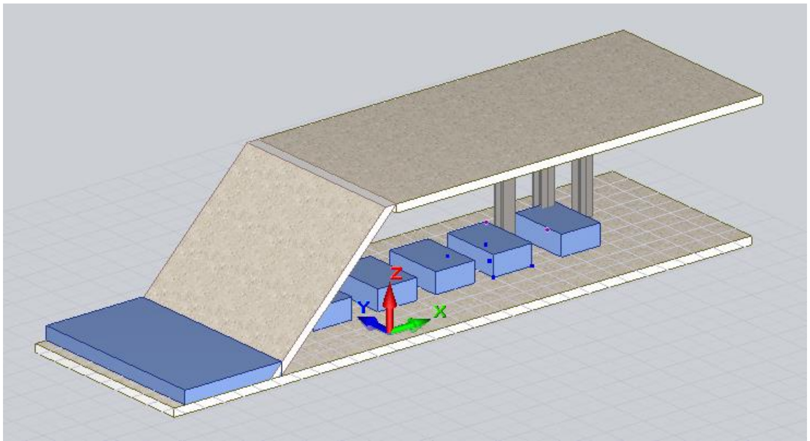

Figure 5. 3D model of architectural project of bus stop

This software was chosen according to results of our previous researches. The accuracy of calibration allows to carry out images post-processing and 3D modelling. Totally, for each in-room model more than 25 images were got. The surveying scheme in each case was similar. The surveying had been carrying out in plane for circular trajectory. In order to improve orientation process 12-bit coded targets were used. After images orientation and model scaling the 3D modelling of constructions was done. For instance in Fig. 5 presented the results of constructions 3D modeling.

On the following step, this 3D model was exported in one of well-known CAD file format. In our case it was *.dxf. This CAD model was uploaded in special software for structural engineering analysis and design LIRA-SAPR. This software allows to carry out constructions analysis by using finite element method. The finite element model of architectural project presented in Fig. 6.

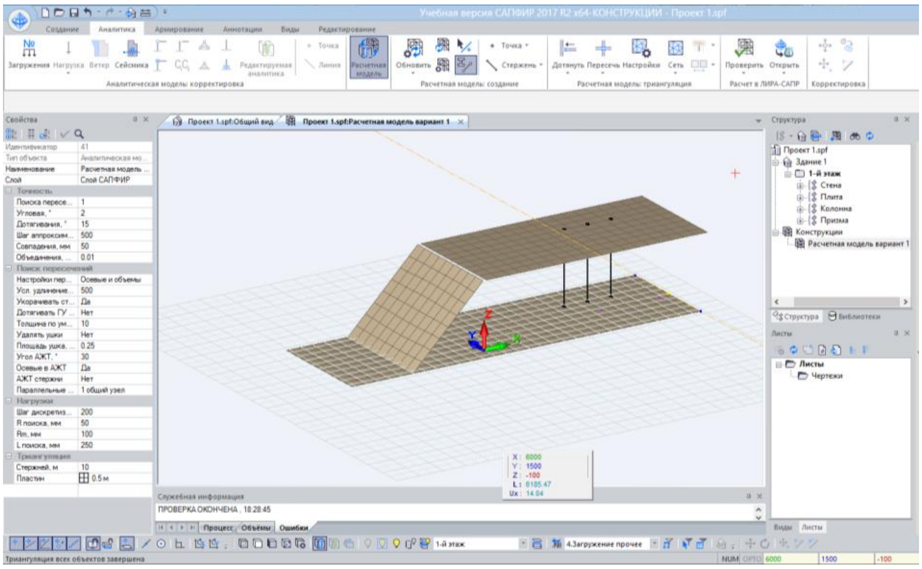

Figure 6. Finite element model of architectural project of bus stop

Using the results of structural engineering analysis students assessed their projects and make appropriate corrections in order to improve design results. At the same time, the analysis results brought them new ideas and emphasized necessity of combination of different design technologies.

The second project concerns to architects. The main purpose of this project is UAS for culture heritage preservation. In order to achieve the aim of this project low-cost photogrammetric technology for documentation of the fortifications II World War near the city Kyiv were used. One of the most dramatic stages of the II World War is considered the defence of Kiev, known as The First Battle of Kiev. The most important role in this operation played The Kiev Fortified Region (Russian abbreviation KiUR). Unique defense complex of defensive structures, consisting of permanent and field fortifications and engineering obstacles and long anti-tank ditches. The total length of the fortified region is about 85 km from the river Dnieper coast on the North from Kiev to the river Dnieper coast on the South from Kiev. The total amount of different fortifications is up to 600 without additional entrenchments and trenches around each object.

For digital cameras calibration we used Matlab camera calibration toolbox. To perform calibration students used the test pattern in the form of a chessboard. The calibration values were obtained with the assessment of the accuracy of the calibration. For a better perception and a clear understanding quantities and nature of the distortion caused by digital cameras imperfections, done graphical construction distortion models in the form of vector fields in Figure 7.

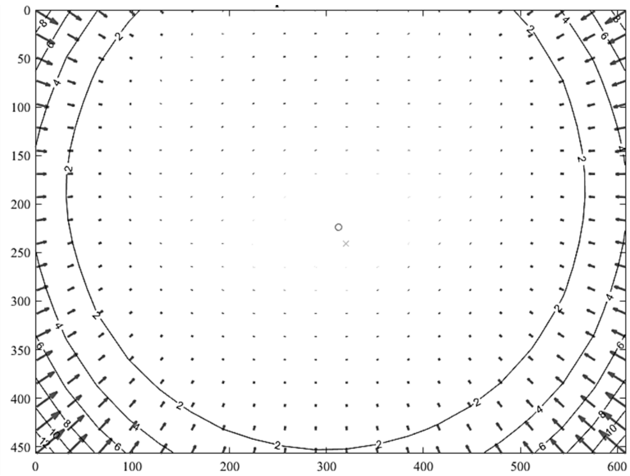

Figure 7. Complete distortion model for FocusDrone camera

We would like to note that the quality of the modern cameras in UAS is quite good. This is evidenced by the relatively small value of lens distortion (20 pix).

After a camera calibration was done a photographing was made. As a test object, we chose three pillboxes № 456, № 451, № 428 and artillery observation post № 453.

Figure 8. Pillbox № 456

Figure 9. Machine gun pillbox № 428

Figure 10. Image of artillery observation post № 453 with coded targets

The photographing of the pillbox № 456 was made without coded targets, as object has good texture and photographing conditions allow capturing images from any sides. Totally were got 48 images. To perform our modeling has been used relatively inexpensive software AgiSoft Photoscan, which is using high-quality images allowing to build three-dimensional model in the automatic mode. In order to scale models were made six control measurements of distances between the natural contours on the object. The result was a three-dimensional model of the object, a fragment of which is shown in Figure 11.

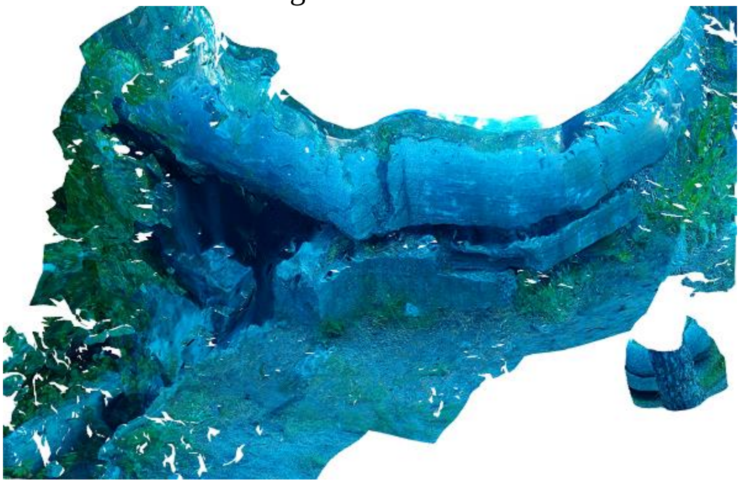

Fig. 11. A fragment of a pillbox three-dimensional model

***Task-8*:** Create SUAS-CAS outreach and data dissemination strategy.

We will actively promote the implementation of the results obtained in the performance of services and organizations in Ukraine who are interested in fast high-quality geospatial data. At the same time, it will set the goal in promoting affordable UAS technologies in everyday life, through the organization of seminars, conferences and web resources.

In the future, is planned the creation of educational resource based on STEM (science, technology, engineering math) with the necessary theoretical material, on-line lab works and the possibility of on-line testing. At this educational resource will take training students from Ukraine and other countries. Development of co-edited hard copy educational content, such as lab manuals, is also proposed. All data, algorithms and software prototypes will be disseminated via web sites and applications hosted by KNUCA and thus will be available for the global geospatial research community. This resource will form the basis for the organization of teachers and students exchange between universities. The evaluation and dissemination of results will be realized in publications in scientific and engineering journals. The research in the development of UAS geospatial techniques will attract for many scientific groups. Among them Global project Digital Earth, EU and UN projects, ISPRS (http://www.isprs.org), ASPRS (http://www.asprs.org), ICA (http://icaci.org), FIG (http://www.fig.net), SPIE (http://spie.org/x3636.xml) and many other scientific and professional associations. Educational journals and conferences such as ASEE (http://www.asee.org) is an ideal way to disseminate results.

Conclusions

Summarizing the work carried out would like to make the following conclusions. The considered technology of low-cost photogrammetry proved effective enough to meet the challenges for tasks of civil engineers and architects. In report the project description “Development of the new educational content “Small UAS in civil engineering application scenarios” was made. The core of this project is educational module for civil engineers and architects that was developed and described. This module was implemented as a part of course “Architectural photogrammetry” for the second year students at Kyiv National University of Construction and Architecture. During the lessons students carried out step-by-step all necessary operations in order to transform their own in-room models or historic structures in to 3D digital form. These 3D models were used for analysis in software for constructions modelling. For instance finite element model analysis for each 3D model was done. It allowed improving buildings reliability and durability. From the other hand, such approach allows students to understand better the whole process of buildings design. The final step of this project will be creation of educational on-line resource devoted to using small UAS in civil engineering and architecture applications.

Acknowledgements
We gratefully acknowledge for the promotion and financial support of the International Society for Photogrammetry and Remote Sensing (ISPRS). Thanks to ISPRS financial support, Kyiv National University of Construction and Architecture got an opportunity to implement modern photogrammetric technologies in educational process.

Justification of money spent in 2017
The grant for Scientific Initiative was equal CHF 4,000.
In 2017, we spent:
Travels CHF 400.
Equipment CHF 200.
Educational workshop organization CHF 700.
Educational on-line portal creation CHF 700.
The total costs for students assistants CHF 2,000.