Software Pipeline for 3D Heritage Digitization - The Case of Faro Focus Scans

Kamil Żyła
Department of Computer Science
Lublin University of Technology
Nadbystrzycka 36B, 20-618 Lublin, Poland
e-mail: k.zyla@pollub.pl

Jacek Kęsik
Department of Computer Science
Lublin University of Technology
Nadbystrzycka 36B, 20-618 Lublin, Poland
e-mail: j.kesik@pollub.pl

Abstract: **Heritage 3D digitization is a research topic undertaken by a broad community of scientists and policy makers. One of the technological solutions chosen is Faro Focus laser scanners. 3D digitization is carried out according to a unified procedure using device-dedicated software. The sequential nature of this procedure and the features of the dedicated software prevent the full potential of the supported hardware from being used. Optimization is possible at the stage of process allocation for many digitization tasks. We propose a software pipeline and its simple optimization that allows at least some of these challenges to be overcome. Validation was performed on 3D scans of three Romanian wooden churches. The proposed approach allowed the production of high-quality 3D models. Optimization, despite simplicity, showed a noteworthy effect in the case of processing 3D scans of a number of objects.**

Keywords: software pipeline; 3D digitization; heritage; Faro Focus; 3D laser scanner; wooden church.

I. Introduction

Heritage 3D digitization is an emerging topic of current research [1]. We can observe efforts in terms of technology and heritage protection protocols in a variety of domains, including architecture [2], clothing [3][4], and small–medium sized objects [5], as well as intangible heritage [6]. Archiving [7], reconstruction [8], and dissemination [9][10] are considered as the typical goals of digitization.

Among technologies used, laser scanning emerged as the default technology used in the case of architecture [7][11]. One of the frequently used solutions is Faro Focus 3D laser scanner. As a result of the scanning, point clouds are produced. Then, they are transformed to a base 3D model, of reasonably high quality, that might undergo certain simplifications for the purpose of its dissemination.

We, based on our long-term experience and literature survey, see some important software challenges that occur during the transformation from point clouds from Faro Focus scanner to 3D models. The following can be mentioned [2][7]:

- Equipment performance – the time of data processing might be long (even days in the case of very large 3D models). Sometimes some of the data processing steps have to be repeated to obtain a result of proper quality.
- Software interoperability – in order to obtain a 3D model of a proper quality, many programs from different vendors have to be used. This causes the need for exporting/importing data in a compatible format, which also takes significant time.
- Workflow parallelization – in order to speed up data processing, some of the steps should be able to be executed in parallel. Usually the disk drive, processor and memory are not evenly and fully used during the sequential execution of the steps.
- Missing common software pipeline – due to the heavy and long computations, a proven and stable set of software tools is desired.
- Software pipeline dependent on requirements for the final 3D model – 3D models for the purpose of documentation focus on quality and precision, while dissemination 3D models focus on the presentation issues and performance of target devices.

This work presents a software pipeline that fits the specificity of a Faro Focus 3D scanner. Some basic optimizations are also discussed and preliminarily verified. The real-life case studies of wooden churches from Romania were chosen. We believe that this work might be valuable for readers in terms of identifying important challenges, describing the software gap that needs amelioration and automation, and providing a suggestion of what to do until better software appears. Persons involved in the hot topic of 3D heritage digitization can learn of a proven set of tools that could be applied during their activities.

In Section II, related works are investigated. In Section III, the proposed approach is introduced. In Section IV, materials and methods are described. In Section V, results regarding real-life examples, being three wooden churches, are discussed. Finally, in Section VI, conclusions are drawn.

II. Related Work

Faro Laser scanners have a broad range of applications: they are used to scan the interiors [11][12] and exteriors [13][14] of buildings, as well as sculpture-size objects [15][16], or even petroglyphs [17][18]. Authors of previous works highlight the specificity of the laser light, which makes it suitable for outdoor conditions as well as for dealing well with large-sized objects (even above one hundred meters).

It was also revealed that there is no common pipeline used. Authors employed a custom and differentiated set of software tools. Sometimes sets of tools were the same, although they were used to perform different data processing

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steps. Among others, the following pipelines are worth highlighting:

- Faro Scene for point clouds manipulation; then Autodesk Recap Pro for registration, denoising and decimation; finally MeshLab for 3D meshing [15].
- Faro Scene for point clouds manipulation; then Autodesk Recap Pro for denoising and remaining activities [11].
- Faro Scene for point clouds manipulation; then Geomagic Studio for remaining activities [17].
- Faro Scene for all the computation steps [18].

Finally, 3D data processing steps were usually not optimized. Execution was kept sequential. The topic of parallelization was omitted. Some authors have mentioned optimizations in terms of tuning-up 3D model characteristics, either in terms of the hardware acceleration of a single step, such as by utilizing graphical processing unit computing capabilities or running data computation on dedicated highly efficient machines. Works dealing with the topic of processing 3D scans of heritage objects made using Faro Focus 3D scanner in the same way as ours were not identified.

III. Proposed Approach

In order to properly present our idea for the software pipeline designed for Faro Focus scans, some introduction is needed first. The purpose of using the pipeline is to obtain a textured 3D model of high quality (so called base model), that is based on clouds of points from 3D scanning (so called scans). To achieve this goal the following software tasks (data processing steps) have to be performed: (1) opening and colorization of individual scans, (2) registration of scans in relation to each other, (3) scans cleaning, (4) generation of a 3D mesh based on scans, (5) mesh texturing, (6) export of the final model.

Software. We recommend using the following two proven software tools within the pipeline: first Faro Scene [19] and next Reality Capture [20]. Faro Scene is the dedicated software provided together with a Faro Focus 3D scanner. In our opinion, it is well suited for tasks one to three, i.e., operation on clouds of points. Reality Capture is third-party software well suited for tasks four to six, i.e., 3D model generation and texturing.

Faro Scene has some significant disadvantages, being: 3D model size limits, making Faro Scene useless in the case of large objects, like buildings; significant loss of 3D model quality due to the necessity of simplifications; unsatisfactory 3D model generation capabilities. Thus, it is supplemented with Reality Capture, which provides very rich functionality and interface, as well as capabilities for computing extremely large 3D models (even exceeding the largest ones that could be displayed by contemporary computers).

Unfortunately, the presence of two software tools within the pipeline, although necessary, introduces some overhead related to passing scans in a proper format from one tool to the other. Thus, two additional steps occur between steps three and four, i.e., data export from Faro Scene to the so-called “ordered format” and data import to Reality Capture.

Finally, software tools proposed by us might be perceived as comparable in terms of functionality with some tools identified during the literature review. Nevertheless, the proposal’s superiority lies mainly in the use of tools offering the highest level of functionality and usability (independently of the 3D digitized objects’ size), and being a very affordable choice at the same time. Reality Capture licensing promotes in its way academic and non-profit usage.

Optimization. Usually, the software tasks within the pipeline are executed sequentially, which causes computer resources to be partially and unevenly utilized. For example, some of the tasks heavily utilize a processor for a longer time, while disk and memory is idling.

The above-mentioned mechanism creates room for performing some specific types of tasks in parallel, e.g., data export and data import or mesh model generation. Thus, we propose to perform in parallel the types of tasks that do not heavily utilize the same computer resources. This should noticeably speed up the time of processing, which is usually the scarcest resource. Three basic types of computer resources might be distinguished: processor, graphics, and storage.

Software tools within the pipelines (not only within the one proposed by us) are basically not adjusted to the parallelization of software tasks done for one object. It is rather possible while executing many pipelines for many objects. The real-life example will be discussed in Section V, Results.

IV. Materials and Methods

The proposed approach was tested by us among others during the 3D digitization of wooden churches in Romania. Such choice was made to promote our recent activities. The scans of facades of the following churches were used for the purpose of this work:

- (C1) The orthodox church of Creaca: 13 scans – 10,338 x 4,267 pt.
- (C2) The orthodox church of Târgușor: 10 scans – 10,342 x 4,267 pt.
- (C3) The orthodox church of Petrindu in the open-air museum of Cluj-Napoca: 15 scans – 10,172 x 4,267 pt.

They all represent a similar class of heritage object, in terms of size, building materials, and shape complexity. Due to space constraints, their further description is omitted. To see short notes describing the churches, as well as models and panoramas, please refer to [21], which is a web page reporting works on the digitization of the wooden heritage of the Carpathians. This, along with the works themselves, is run as an internal initiative by the Department of Computer Science at the Faculty of Electrical Engineering and Computer Science of the Lublin University of Technology.

All computations were performed on a laptop computer equipped with: Intel i9 processor (8 cores), 64 GB RAM, nVidia RTX 2080m graphics, SSD M2 data storage drive, and Windows 11 operating system. We took care of equal conditions for each measured computation unit.

The procedure was as follows: the eight software tasks defined in Section III were executed sequentially for scans of the three chosen wooden churches. During the execution the following was measured: operator engagement; processor, graphics and storage load; task execution times. Based on the measured computer resources loads, optimization by parallelization was planned. Then, the software tasks were run again, but utilizing the planned optimization. The same measurements were performed. All computations were assisted by the same 3D digitization expert. The execution of each task for each church was repeated three times and measurements' average values were counted.

The operator engagement can be defined as a percentage of a total task time that involved manual actions of a human. It was described in the following scale: L (low – only up to 30% of task time), M (medium – from 31% to 70% of task time), H (high – more than 71% of task time). Computer resources loads were described using a similar scale, where L means an average load of up to 30%, M means an average load of between 31% and 70%, and H means an average load of above 71%. Task execution times were measured with a precision of 6 minutes (0.1 h), which was sufficient due to the many manual human activities involved, long overall time of computations, and general character of the evaluation.

V. RESULTS

Table I presents the validation results of our approach according to the procedure described in Section IV. In Table I, the column "Task name" contains the software tasks, in a proper order, leading from clouds of points to a 3D model. The column heading "Op. eng." stands for operator engagement. "Comp. type" stands for computation type, while the "seq" row holds values for the sequential execution of the task, and "par" holds values for the parallelized (optimized) execution of the task. "CPU" stands for the processor, "GPU" for the graphics, and "SDD" for the disk drive (storage). "C1", "C2", and "C3" stand for the models of churches 1, 2, and 3 respectively. Finally, "Exec. time" means execution time.

Thus, for example, regarding software task 1: The task, when executed sequentially ("seq" row), caused low ("L") operator engagement, medium ("M") load of CPU, low ("L") load of GPU, and medium ("M") load of disk drive. Execution of the task 1, when sequential, took 1 h 30 min in the case of church 1 ("C1"), 1 h 18 min – church 2 ("C2"), and 2 h 0 min – church 3 ("C3"). The "par" row holds values for the same single software task, but executed in the parallelized setting. It means, the measured values also refer to that single task. The times (similarly other values) might be almost the same or slightly different, because parallelization causes heavier usage of the computer resources, which might slightly slow down the execution of particular tasks, despite a shorter overall computation time being needed to obtain all 3D models of the churches.

After analyzing the measurements taken during the sequential execution of the tasks, the possible parallelized setting was developed. It took into account the preservation of the order of the tasks necessary when obtaining a 3D model from scans for a single heritage object. The optimized pipeline looked as follows: (1) Tasks 1–3 for the model of "C1". (2) In parallel, task 4 for the model of "C1" and tasks 1–3 for the models of "C2" and "C3". (3) In parallel, task 4 for the model of "C2" and tasks 5–6 for the model of "C1". (4) In parallel, task 4 for the model of "C3" and tasks 5–6 for the model of "C2", followed by task 7 for the model of "C1". Subsequent tasks for the models were carried out sequentially.

"*" denotes low operator engagement, because such scans were chosen that could be registered automatically by a software tool. "**" denotes a surprising property of Faro Scene, that export takes a lot of time yet does not heavily utilize the computer resources.

TABLE I. WORKLOAD WHILE PERFORMING 3D DATA PROCESSING TASKS

No.	Task name	Comp. type	Op. eng. [%]	Load of CPU/GPU /SDD [%]	Exec. time for C1/C2/C3 [h]
1	Opening and colorization of individual scans	seq	L	M/L/M	1.5/ 1.3/ 2.0
		par	L	M/L/M	1.5/ 1.5 /2.0
2	Registration of scans in relation to each other	seq	L *	H/L/M	1.0/ 0.5/ 1.0
		par	L *	H/L/M	1.0/ 1.0/ 1.0
3	Scans cleaning	seq	H	L/M/L	0.3/ 0.1/ 1.0
		par	H	L/M/L	0.3/ 0.1/ 1.0
4	Data export from Faro Scene	seq	L	L/L/L**	8.0/ 5.5/ 9.0
		par	L	L/L/L**	8.0/ 5.5/ 9.0
5	Data import to Reality Capture	seq	L	H/L/H	0.5/ 0.3/ 0.5
		par	L	H/L/H	0.8/ 0.5/ 0.5
6	Generation of a 3D mesh based on scans	seq	L	H/L/M	3.3/ 3.0/ 3.5
		par	L	H/L/M	4.0/ 3.5/ 3.5
7	Mesh texturing	seq	L	M/H/M	4.0/ 4.0/ 4.0
		par	L	M/H/M	4.0/ 4.3/ 4.0
8	Export of the final model	seq	L	H/L/H	0.3/ 0.3/ 0.3
		par	L	H/L/H	0.3/ 0.3/ 0.3

It can be seen in Table 1 that when execution is sequential, the computer is fully focused on one task only, thus times are shorter. When another task is executed in parallel, the computer resources are already occupied by the first task, thus performance drop (longer times) cannot be avoided. The key result is that, when tasks are running in parallel, a longer time for the execution of a single task is in many instances observed, although the total time needed to process the data of all the 3D scanned objects is shorter.

Finally, the sequential execution of the tasks, in order to get final 3D models of all three churches exported to OBJ file format, took 54 h 45 min. After the parallelization, achieving the same goal took 42 h 15 min. The resulting models can be found at a dedicated web page [21].

VI. CONCLUSION AND FUTURE WORK

In order to overcome challenges of postprocessing Faro Focus 3D scans, we proposed our own software pipeline (utilizing Faro Scene and Reality Capture tools), together with a simple optimization by parallelization of performed tasks. It was then verified on the example of three Romanian wooden churches. What is more, we have used it for a longer time during our digitization works involving Faro Focus scanners.

In our opinion, the pipeline proved itself useful. Among the main advantages is its being affordable, while offering functionality and quality at the highest level. Moreover, it does not heavily engage the operator. The proposed optimization allowed us to decrease noticeably the total time of acquiring all 3D models of many objects from scans. In the case of the scans here used, it was reduced by ~1/5, despite a slightly longer execution time being seen for particular tasks due to the heavier (better, fuller) usage of the computer resources. It was also revealed that optimization did not heavily affect the computer resources loads when they were observed separately for each particular single task done for a particular single model.

As a disadvantage, the use of two software tools might be mentioned. It requires an operator to learn how to use two different tools. Moreover, the list of tasks has to be extended by the resource-consuming export and import of data. Unfortunately, there is no other way, when it comes to obtaining high-quality models of large objects, due to Faro Scene's limitations. Finally, it is possible in rare cases that very heavy tasks may cause full usage of a particular computer resource, making parallelization barely possible.

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