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BUILDING GEOMETRY SURVEY BY USING ULTRA-WIDEBAND (UWB) WIRELESS TECHNOLOGY AND ALGORITHM-BASED BIM MODELLING

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Abstract

The efficiency and degree of maturity of the architectural survey determine the construction process in many ways. From the economic and technical point of view, it is significant. It can be found in almost all activities and, depending on the technology used, it provides different qualities and quantities of initial data and information to prepare and support, among other things, the design, demolition, and construction work processes. The objective of the research and development project and this article is to investigate and demonstrate the application of a novel solution that differs from the conventional building survey tools, methods, and procedures of the information. It breaks with traditional methods by implementing wireless (using Ultra-Wideband (UWB) technology) spatial positioning and algorithm-based post-processing methods, as well as Building Information Modelling (BIM).

Keywords: *building survey, building information modeling, ultra-wideband technology.*

1. Introduction

Several survey tools are available today, which can be grouped according to their operational technology.

There are conventional solutions, such as tape measures and standard laser rangefinders, whose effectiveness is subject to compromise. The main factor affecting the quality of the results is the operator themselves.

Meanwhile, another group of tools, already specifically designed for digital work, is growing in popularity. These are devices that are already equipped in many cases with all the technical solutions currently available. They include, among others, various augmented reality (AR), and virtual reality (VR) based solutions. However, the technology comes at a price, as in addition to the high cost of the equipment and tools, the operating staff must have at least higher skills than those required for traditional equipment. In terms of efficiency, the human factor is less important (mostly limited to the handling of the device) and the quality and accuracy of the devices depend on the hardware and software solutions. However, even in this case, the processing of survey information and its transformation into agreed technical design or model files requires human, and engineering resources.

We believe that in addition, it is appropriate to create a third category. This category could include those solutions in which the target-specific hardware components are combined (even in a customized design) and complemented by targeted programs and algorithms. The latter can help establish a specific link with design software that extends the possibilities of general solutions and program functions that already exist in various forms. [1]

1.1. Ultra-Wideband (UWB) technology

UWB is a wireless communication technology most used for high-accuracy spatial positioning. [2] The technology uses broadband signals (typically in the high GHz range) for data transmission, generally with very short pulses and power consumption. [2, 3] The systems used consist of fixed anchor points and one or more moving units. [2] The position of the moving units in relation to the anchor points is determined by mathematical relationships. [4] The growth in popularity of the technology dates back to recent years. Hardware has become affordable and is increasingly available in consumer products (e.g. Apple Iphone 11). [5] The fundamental difficulty is that the best way to determine the relative position of the anchor points is to take manual measurements. Of course, technical solutions for self-calibration and collaborative localization are being developed to overcome this. [6, 7] In terms of accuracy, and depending on the environmental conditions, much of the literature considers it to be in the range of 20 cm or less [8],], which is already enough to be a possible future state-of-the-art alternative for building surveys. The current research is based on this statement and aims to explore the opportunities or barriers to its use.

2. Concept, design, and structure

Considering the basic objectives, which were to investigate the creation of a tool to capture building structural positions and to perform automated post-processing supported by algorithms using an unconventional technology (UWB), the basic objectives already included several difficulties. A literature review on the topic has shown that the complexity of the initial ideas was only a fragment of what is involved in applying the technology in reality.

Regardless of this, the ambition to implement a use case remains a priority. The long-term goal is to build a novel tool and software environment in which a simple building survey can be easily performed with minimal human resources and 3D or BIM modelling can be automated.

2.1. Design and structure

To carry out the most comprehensive research and development, it was necessary to expand the range of useful tools at the beginning of the process (Fig. 1).

It became clear that the Decawave DW1000 type UWB module alone was not enough, but also required the integration of several sensors and additional hardware.

The control electronics are based on a single ESP32 programmable microcontroller for each module, which allows the hardware to work together to wirelessly control the architectural survey process via Wi-Fi.

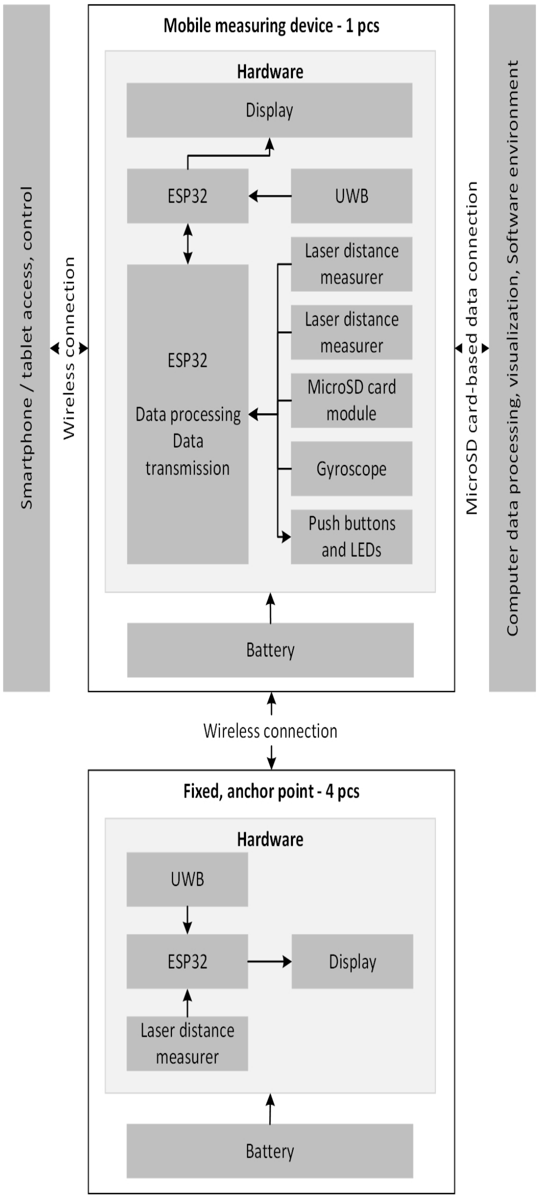

Fig. 1. *Logic diagram of hardware architecture.*

The ESP32 modules are also equipped with VL53L0X [9] and VL53L1X [10] laser range finders, which measure the distance from the floor and ceiling to the device for the mobile survey unit and the height from the placement of the anchor point.

In addition, the survey unit is equipped with an acceleration and rotation sensor, which provides information about the position of the device during the survey (e.g. whether it is vertical, inclined, or horizontal).

Additional hardware includes a MicroSD card module for continuous data recording during the measurement, a function button, and an LED indicator.

Of course, each unit is equipped with a battery and a 1.3" OLED display with 128*64 resolution for displaying the relevant data of the measurement process (e.g. distance to anchor points, bottom, top distance). The display ensures that anchor points can be verified to be ready and their unique network identifier is visible. For the meter, it allows the most important information to be read.

As the mobile display is planned to contain all the data in detail, the information displayed on the unit will focus only on the most relevant ones..

3. Operational mechanism

The planned survey and data recording process starts with the placement of anchor points inside the building (Fig. 2).

At the current research stage, the anchor points (Fig. 2 – 1, 2, 3, 4) and their distances (Fig. 2 – b12, b23, b34, b14) still need to be measured and recorded in the mathematical trigonometric equations used for the calculation during each positioning. In this case, a standard laser rangefinder and tape measure are used to record the distance.

In addition, the distance of the anchor point from the floor planes is also recorded to calculate the position of the building structures not only in the horizontal plane but also to calculate real 3-dimensional spatial survey points (Fig. 3 – y1).

Once the anchor points have been placed, the survey unit must be calibrated. This should also only be completed at the start of the measurement process. For this purpose, a 3D printer was used to create a levelling table on which the horizontal axis position can be adjusted by placing the device (Fig. 4).

Without this, less reliable information about the orientation of the device is generated. Misleading data should be avoided as they affect the accuracy of the resulting BIM model.

As a preparation, we also need to connect the mobile phone or tablet to the network created by the device via Wi-fi protocol and display a web page available on the IP address I have defined

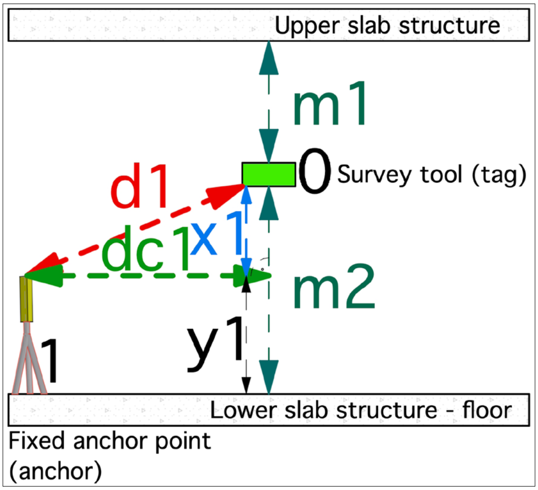

Fig. 3. *Determination of vertical position.*

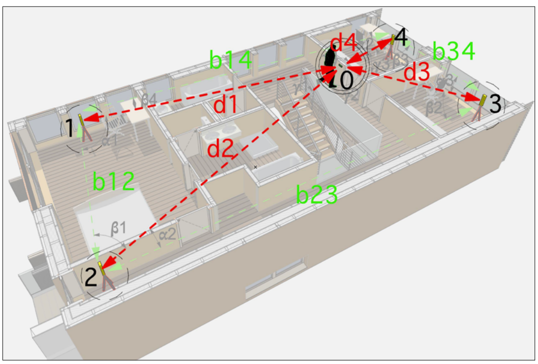

Fig. 2. *Operational logic.*

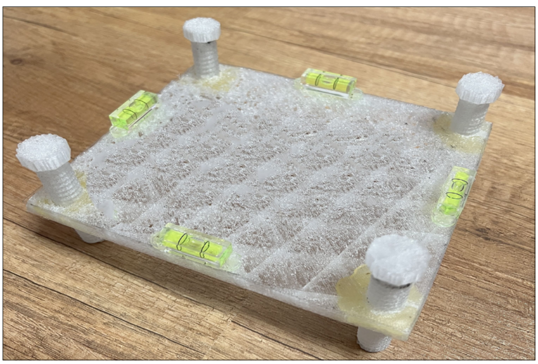

Fig. 4. *Leveling table*

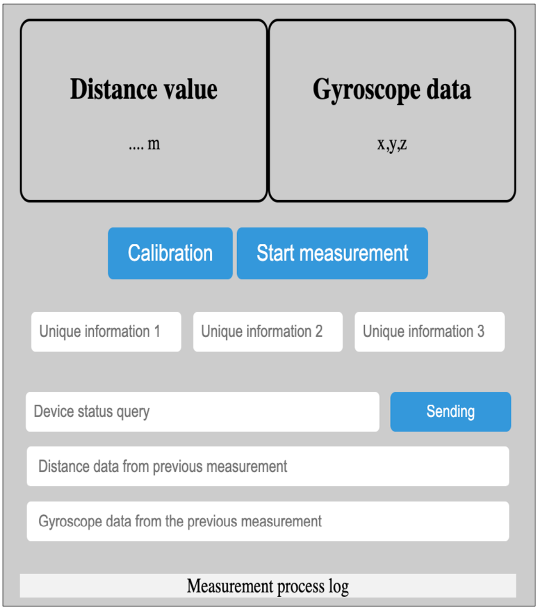

Fig. 5. *Preliminary structure of the HTML website.*

Fig. 6. *UWB modules*

192.168.6.66. It is planned to control the survey tool and monitor the measurement through this (Fig. 5).

The final version will be designed with a modern look with a responsive function.

The survey workflow can then begin (Fig. 6).

By walking through the building and placing the survey unit on the plane of the building structures to be surveyed it records (at the touch of a button or using the functionality of the web-based interface) the distance of the structures from the anchor points (Fig. 2 – d1, d2, d3, d4), and consequently their spatial position. After correct calibration, their position is calculated automatically.

The orientation and surface plane of building structures are determined by using rotation sensor data.

In addition, the floor and ceiling distances are recorded at the same time (Fig. 3 – m1, m2).

The measured data is stored on a microSD card attached to the survey unit, which allows easy transfer to any computer. The structured data stored on the card allows the post-processing algorithm to work correctly and to build automated models from the information (Fig. 7).

The output of the workflow is a simplified building model that can be displayed in architectural design software and used, among other things, to support future design processes.

```
25 || Distance1: 1683   Distance2: 22 || X : -0.03    Y : 0.00     Z : -0.19
26 || Distance1: 2004   Distance2: 22 || X : -0.02    Y : 0.00     Z : -0.18
27 || Distance1: 1686   Distance2: 21 || X : -0.01    Y : 0.00     Z : -0.17
28 || Distance1: 1827   Distance2: 23 || X : -0.01    Y : 0.01     Z : -0.16
29 || Distance1: 1985   Distance2: 21 || X : -0.01    Y : 0.00     Z : -0.16
30 || Distance1: 1767   Distance2: 22 || X : -0.01    Y : 0.01     Z : -0.15
31 || Distance1: 1886   Distance2: 22 || X : -0.01    Y : 0.01     Z : -0.14
32 || Distance1: 1947   Distance2: 23 || X : -0.02    Y : 0.01     Z : -0.13
33 || Distance1: 1857   Distance2: 22 || X : -0.02    Y : 0.01     Z : -0.13
34 || Distance1: 1770   Distance2: 21 || X : -0.01    Y : 0.01     Z : -0.13
35 || Distance1: 1644   Distance2: 23 || X : -0.01    Y : 0.01     Z : -0.12
36 || Distance1: 1973   Distance2: 22 || X : -0.02    Y : 0.01     Z : -0.11
37 || Distance1: 1979   Distance2: 23 || X : -0.01    Y : 0.02     Z : -0.11
38 || Distance1: 1805   Distance2: 23 || X : -0.02    Y : 0.02     Z : -0.09
39 || Distance1: 1633   Distance2: 21 || X : -0.01    Y : 0.02     Z : -0.09
40 || Distance1: 1854   Distance2: 21 || X : -0.02    Y : 0.02     Z : -0.08
41 || Distance1: 1867   Distance2: 21 || X : -0.01    Y : 0.03     Z : -0.07
42 || Distance1: 1601   Distance2: 23 || X : -0.00    Y : 0.04     Z : -0.05
43 || Distance1: 1845   Distance2: 21 || X : 0.00     Y : 0.04     Z : -0.05
44 || Distance1: 1777   Distance2: 21 || X : -0.00    Y : 0.04     Z : -0.05
45 || Distance1: 1820   Distance2: 22 || X : 0.00     Y : 0.05     Z : -0.05
46 || Distance1: 1755   Distance2: 22 || X : 0.01     Y : 0.05     Z : -0.03
47 || Distance1: 1879   Distance2: 23 || X : -0.00    Y : 0.06     Z : -0.02
48 || Distance1: 1622   Distance2: 23 || X : 0.01     Y : 0.06     Z : -0.02
49 || Distance1: 1967   Distance2: 23 || X : 0.02     Y : 0.06     Z : -0.01
50 || Distance1: 1667   Distance2: 22 || X : 0.00     Y : 0.05     Z : -0.00
51 || Distance1: 1896   Distance2: 23 || X : -0.00    Y : 0.06     Z : 0.01
52 || Distance1: 1877   Distance2: 21 || X : -0.01    Y : 0.06     Z : 0.02
53 || Distance1: 1938   Distance2: 21 || X : -0.01    Y : 0.05     Z : 0.03
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Fig. 7. *Data generated during measurement*

The basic principle of the algorithm is to use the surface planes and their relations recorded from building structures to create spatial models. This is further supported by the distance of the measuring instrument from the anchor points and the ceiling or floor per measurement. Together, this information contributes to the arrangement of the planes into the appropriate spatial positions. The planes aligned in this way are then joined together. The resulting intersections separate the redundant planes from the planes that create the survey space. The algorithm uses these planes to generate the model elements (e.g. walls, slabs).

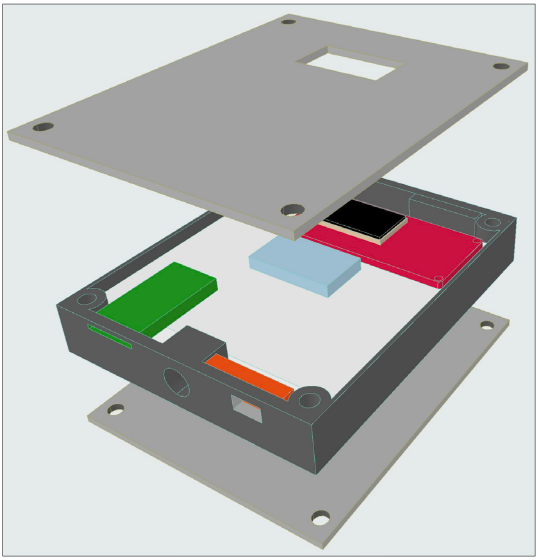

Fig. 8. *3D model of the designed frame.*

The programs and algorithms needed for the processes described are partially but not yet complete.

4. Device skeleton

Basic protection of hardware components must be ensured for both the anchor points and the survey unit involved in the project. To this end, we designed a dedicated frame and enclosure for both the anchor points and the survey unit.

The test versions (Fig. 8) are being designed and 3D printed. The final device skeleton is still under development.

To protect against possible drops and falls, a black-colored 1.75 mm diameter Extruder GreenTEC PRO Carbon filament was used in the project, which is much more resistant to various environmental impacts than conventional Polylactic Acid (PLA). The type we use is characterized by high-temperature resistance and low weight, in addition to its resistance to mechanical impacts. The latter is particularly important for a device that is held in the hand for a long time.

5. Conclusions

Although the research and development project is still in its early stages, the results are encouraging. The UWB technology and the software environment and methodology under development are capable of capturing and processing data on the positions and characteristics of building structures as they move through spaces, and of representing them in design software. The 3D or BIM datasets to be produced can provide initial information for more important project processes based on the survey. The measurement inaccuracy observed during the research project (variable, but averaging between 5-10 cm after several calibrations) is still significant and should be addressed as a priority for future activities. In addition, it is necessary to understand and study precisely the interference caused by objects in space, which can also affect the measurement and the possibilities of automatically determining the relative positions of the anchor points.

Accordingly, the process will continue to be developed further, to extend its functionality and address the problems that arise.

Acknowledgements

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