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ADVANCED REAL-TIME SAFETY MANAGEMENT SYSTEM FOR CONSTRUCTION SITES

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ABSTRACT

This paper reports the results of preliminary experiments concerning position tracking of workers in construction sites. The experiments are part of an ongoing research concerning the development of a new generation of advanced construction management systems allowing real-time monitoring and coordination of tasks, automatic health and safety management, on-site delivery of technical information, capture of "as-built" documentation, etc. This paper focuses on the development of a reliable methodology for real-time monitoring of workers' and equipment's position in outdoor construction sites through the application of technologies based on Ultra Wide Band (UWB). Guidelines for the design of the receivers' topology will be addressed and the results of measurements done on a typical medium sized block of flats in different construction progress phases will be summed.

KEYWORDS

Automation in construction, construction management, health and safety, ultra wide band, position tracking systems

1. INTRODUCTION

Building construction facilities are nomadic and custom designed. Worker teams are assumed through local labor supply and workflow is frequently affected by local conditions (e.g. weather and local labor availability). Furthermore building projects are very complex, involving thousands of parts and components, and changes of design plans at construction time are not uncommon. Building parts and components are mostly made or assembled on-site, standardization is rather low, and adjustments are made on site, sometimes without any reports on the original building plans. Consequently the management of building construction sites is a rather complex task. Today a set of new technologies could provide the necessary background for developing a new generation of real-time construction management systems, which can be seamlessly integrated into the actual arrangement of the construction work [1, 2]. These systems would support the semi-automatic management of real-time health and safety monitoring and coordination of tasks, on-demand distribution of information (e.g. shop drawings), collection of "as built" documents. At the core of such functionalities there is the capability of precisely tracking the position of workers and equipment in real time. Despite this functionality has been developed and reliably applied to manufacturing [3, 4], it is almost completely missing in construction sites, due to its outdoor, heterogeneous and highly evolving nature. Some preliminary results have been obtained in construction sites through the application of standard outdoor position tracking technologies. In [1] a mechatronic helmet, equipped with a GPS antenna and a bidirectional communication system for workers' safety control is proposed; in [5] a policy for integrating "as-built" information into IFC devices used in PDM systems is developed; the authors in [6] developed a policy for collision detection among construction equipments, based on GPS.

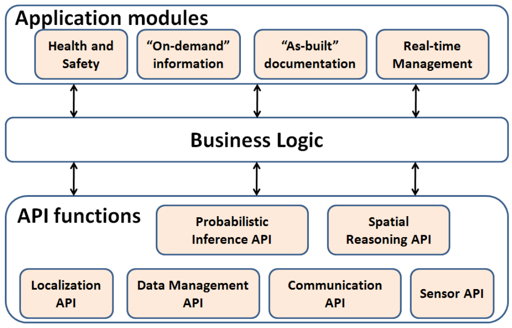

Figure 1. Software architecture for real-time construction management

The "FutureHome" EU funded project [7] has developed systems for product and process analysis suited to manufactured and prefabricated construction solutions. This paper addresses the problems related to the application of Ultra Wide Band (UWB) technologies to accurate and real-time position tracking of workers and assets in construction sites. This technology provides position accuracy of approximately 0.3 m and, if accurately designed, can overcome the indoor shadowing problems of GPS. Design guidelines for the receivers' topology and the results of measurements done on a typical medium sized block of flats in two construction stages will be reported.

2. THE SYSTEM

2.1. Software architecture

Figure 1 shows the scheme of a three tier software architecture for a real-time construction management system. The lower level implements the sensor, communication and data management logics. The middle level business logics implement high level task oriented functionalities (e.g. virtual fencing or collision e). The application layer (highest level) customizes general business logic functionalities to specific application domain, such as health and safety management. In this paper we will focus on development of the position tracking module, which is part of the localization API.

2.2. Ultra Wide Band position tracking

The UWB localization system tested in this paper consists of a set of active tags (one of which is usually used as a calibration or reference tag), UWB receivers and a central processing hub [8], manufactured by MultispectralTM Inc. The hub is connected to the receivers through standard CAT-5 cables, and interfaced with a PC via Ethernet. The UWB active tag operates at a centre frequency of 6.2 GHz and has an instantaneous -10dB bandwidth of 1.25 GHz. Short pulse, radio frequency emissions from the tags are subsequently received by some sensors and processed by the central hub's CPU. In the used configuration, the tag works at 1 Hz. Time differences of arrival (TDOA) of the tag burst at the various receiver sites are measured and sent back to the central processing hub for processing. Calibration is performed at system start-up by monitoring data from a reference tag which has been placed at a known location. The main problem occurring in asset tracking system installation is that, in order to accurately determine tag position, a minimum number of receivers (three for 2-D measures, as in this case) must have a direct or attenuated line-of-sight transmission path. Hence, as walls and machinery may create signal attenuation or even complete signal blockage, receivers' positioning must be previously and strategically designed.

That problem could be solved by using an "over-specified" or "over-determined" system, but trying to avoid ambiguities in position determination. That problem is particularly true for construction sites, hence our test are aimed at providing empirical guidelines for arranging UWB systems in typical sites at different construction progress stages.

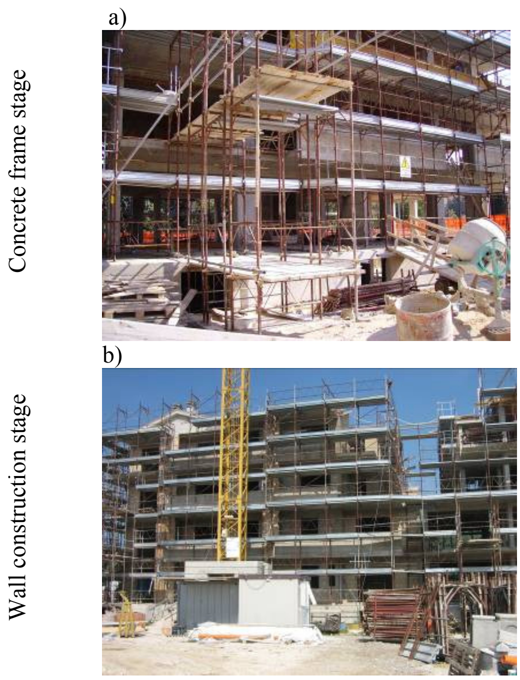

Figure 2. Two main stages of the construction site

3. THE EXPERIMENTAL CAMPAIGN

3.1. The construction site

The experimental tests were carried out in a site relative to a block of flats (Figure 2) built with a reinforced concrete frame structure and light masonry walls. External hollow walls including 0.05 m polystyrene insulation, made as in Figure 3-a, had the external wall layer of solid bricks and the internal one of cellular 0.08 m blocks. Partitioning walls between apartments were made of 0.12 m thick concrete cellular blocks (Figure 3-b) and walls among rooms of the same apartments made of 0.08 m thick cellular blocks (Figure 3-c). Test were performed in two stages: after the erection of the concrete frame structure and walls' completion.

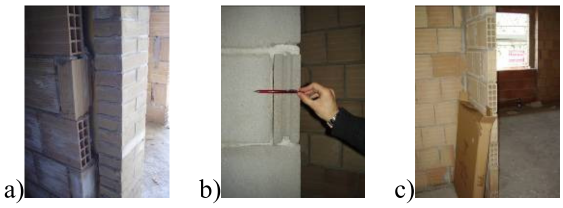

Figure 3. External walls (a), concrete blocks (b), internal partitions (c)

3.2. Description of the experimental campaign

The first test case concerns position tracking of workers and facilities (excavator, bulldozer etc.) moving within the excavation area. Hence that phase was simulated making measurements in the parking area showed in Figure 4-a, where the receivers have been placed at the four corners, according to the scheme in Figure 4-b, of the rhomboidal shaped area, whose maximum height and length are equal to (12.5x16.6) m.

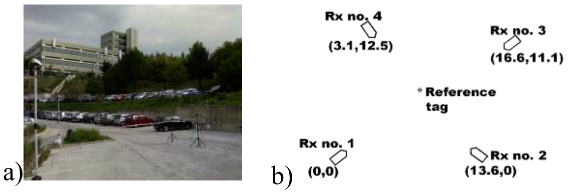

Figure 4. Simulation of the excavation stage

One reference node was placed at the coordinates (7.9, 6.3) m from the left bottom corner of the area. Workers' position was monitored with an accuracy of 0.3 m; the same held for facilities in case the tag was placed on the top of their ceilings. In case the tag is placed inside the cabin, then the accuracy decreases to about 1m, because the system gives alternatively localization measures which are within the ray of 1 m from the exact known location of the machine (due to the reflections that UWB rays undergo before getting out the facility). Both 0.3W and 1W powered tags worked well. The second phase of the experiments was performed in the construction site of Figure 3-a (soon after concrete frame structure's erection). Figure 5 shows the hub, PC and receivers' positioning, while Figure 67 depicts a scheme of the experimental setup used for these tests: four receivers have been placed at the corners of the site (4 m high) and one reference tag in the building's ground floor.

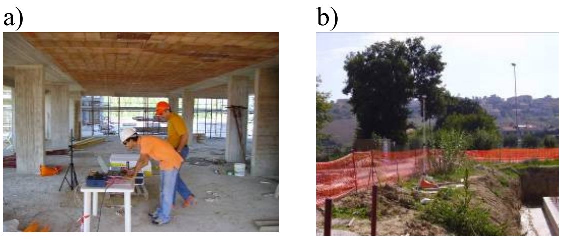

Figure 5. Positioning of the hub and reference tag (a) and of one of the 4 receivers (b)

To be noticed that along the building's perimeter a metallic scaffold had already been installed. The whole measurement area was approximately rectangular and (38x35) m large. Figure 8 shows some of the successful measures, obtained using the 1 W power tag (the 0.3W was subject to blinking). A worker moving in the area and a worker moving on the scaffold (Figure 8-a and 8-b) were tracked. By comparing the worker's actual routes with the ones tracked by the system, it was found that the UWB system was able to track the worker's position both in the ground floor of the building and when moving along the front scaffold. Other 2-D measures were made on the first floor and it resulted that the receivers were able to track the worker, as well. The same did not hold for the second floor.

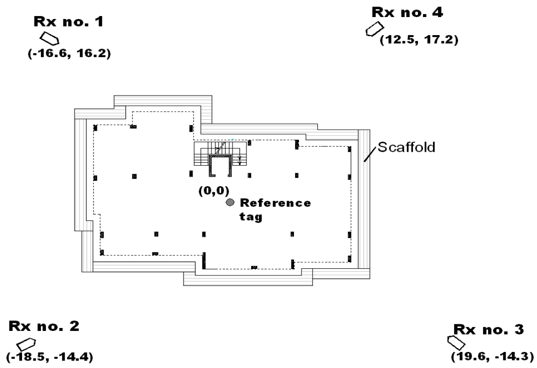

Figure 6. Testing setup at the€ "concrete frame" stage

The last set of experiments has been performed with the building in the third phase: after the wall completion and with the presence of the scaffold along its perimeter (Figure 3 b).

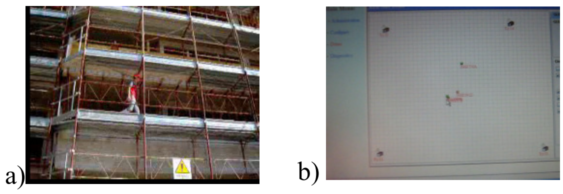

Figure 7. Worker route (a) and his tracking on the building's scaffold (b)

In this case, it was noticed that the system setup as in Fig. 8 did not allow to real-time monitor workers' positions, as one or more receivers did not receive the 1W tag's signals from some locations inside the building, hence indicating that walls act as obstacles. Some field tests have been performed, one for each of the 17 locations pictured in Figure 9. The results are listed in Table 1, where per each position (P) is indicated which receiver can be seen and if position was tracked or not.

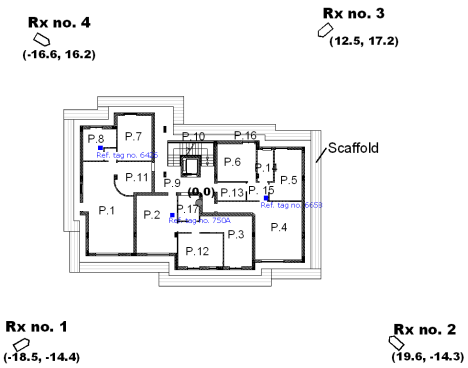

Figure 8. Site layout at the "wall completion" stage

Table 1. Position tracking table in the 3rd phase

Position	Receivers	Result	Errors
1	1,4	bad	M0
2	1	-	-
3	1,2	-	-
4	1,2,3	good	Ref750A (rare)
5	2,3,4	bad	M0
6	2,3,4	bad	M0, R0
7	1,3,4	blinking	M0
8	1,3,4	discrete	M0 (rare)
9	1,3,4	discrete	M0 (rare)
10	1,3,4	good	No
11	1,3,4	good	No
12	1,2	bad	M0
13	2,3	bad	M0
14	3,4	bad	M0
15	2,3	bad	M0
16	1,3,4	bad	M0
17	1,3,4	bad	M0

3.3. Discussion on experimental results

Different results have been obtained in the three stages of the construction sites. In excavation case, tests have confirmed what already stated in [8], obtaining an accuracy of about 0.3 m. When tags are left inside a facility, then they decrease their accuracy, due to the reflection that the UWB signals undergo before getting out the facility's cabin. Both the 0.3 and the 1W powered are suitable for this kind of monitoring. As far as concerns the reinforced concrete frame structure case, four receivers resulted to be enough for monitoring the workers' movement all around the whole site at the ground floor and on the scaffold. However only the 1 W tag worked well, being the other signal (0.3W) not strong enough. Probably, it was due to the interference provided by the scaffold and reinforced concrete columns. We remark that some errors in the localization (signal blinking) were noticed only in the areas close to the staircase and lift block (Figure 7), made with reinforced concrete walls: in this case we think that it will be necessary to add further receivers covering that area to avoid blinking. By comparing Table 1 with Figure 9, relative to the walls' completion stage of the site, it is possible to infer general statements about the behavior of the UWB system. Single layer walls made up of 0.08 m cellular blocks are quite transparent to UWB. Both hollow walls with a double layer of blocks and internal insulation, and concrete cellular blocks weakened UWB signals. For example, signals travel from position no. 9 to receiver 1, but not from position no. 6 to receiver 1: it is blocked by the hollow wall between positions no. 9 and 6. A similar statement holds for the cellular concrete block wall between positions no. 11 and 2. When three receivers are in the line-of-sight, then localization works properly (e.g. in positions no. 4, 10, 11). Instead it could not work, even if three receivers are read, in case the quality of the signal received is low (such as in cases no. 5, 6, 16, 17). In this case, the number of receivers used in relation to the complexity of the environment is too low. UWB can pass through a maximum of two heavy walls. In our construction site we would have to enhance the system setup, by adding further receivers. In order to demonstrate this assumption, other tests have been made in a smaller area, using the system setup in Figure 9, whose results are listed in Table 2. It can be noticed that, with the exception of position no.1 (that is in contrast with Table 1, hence not considered), the tag's signal has always been received by 3 receivers.

It can be noticed that very frequently error M0 is had, meaning that the tag is not able to point 3 receivers at the same time. Given that three receivers are always visible, then we can infer that the frequency of the received signal is too low (low quality), due to obstacles. That problem could be tackled by adding another receiver in the centre of the ground floor.

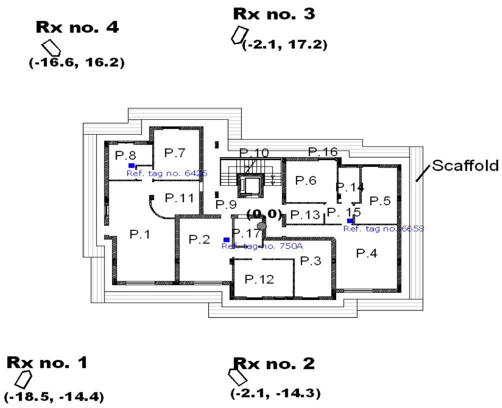

Figure 9. Site layout and experimental setup for the reduced area

Table 2. Position tracking for the 2nd system setup in the 3rd phase

Position	Receivers	Tracking	Tracking
1	1,2	bad	M0
2	1,2,3	Discrete	M0 (rare)
7	1,3,4	Discrete	M0 (frequent)
8	1,3,4	Discrete	M0 (frequent)
11	1,3,4	Discrete	M0 (frequent)

4. CONCLUSIONS

We can conclude that the UWB systems can be successfully applied in the real-time management of constructions sites, if the installation is properly designed. The possibility to reliable tracking depends in the quality of tag signal's reception at the receiver level, which showed to not be able to pass through more than two heavy walls.

5. ACKNOWLEDGMENTS

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