

Knowledge Base Assisted Mapping for an Impulse Radio Indoor Location-sensing Technique

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Abstract

An impulse radio indoor wireless location-sensing technique providing mapping and positioning information without deploying fixed references has been proposed. The environment surrounding an impulse radio network can be reconstructed using times of arrival (TOAs) of dominant impulses from different radio channels measured in individual radios. 2D Mapping and positioning algorithms based on various geometry-related assumptions have been developed for this technique. In order to find the correct assumption and its corresponding algorithm efficiently, a knowledge base, which comprises samples of each typical indoor environment either successfully reconstructed or which appears as a common substructure in most floor plans, is introduced for querying purposes. In this paper, an efficient and representative data format for the knowledge base is investigated, in order to achieve an optimised querying performance. A case study is used to demonstrate how this knowledge base can assist in mapping the surrounding environment and even predicting the upcoming ones.

Keywords

Location-sensing, Radiolocation, Indoor positioning, Mapping, Navigation, Impulse radio, UWB, Knowledge base

INTRODUCTION

Global Positioning System (GPS), the dominant system offering location information outdoors, suffers a poor indoor performance due to low signal availability, as GPS signals are not designed to penetrate most construction materials. This makes indoor localisation a hot research topic recently. Many indoor positioning techniques have been developed [1-8], most of which rely on fixed references to determine the location of tagged devices. This architecture implies that location information is only available in environments where references with known positions have been deployed. However, in many scenarios where location information is very useful, a reference system is not likely to have been previously deployed. For example, when a fire brigade is rescuing people from a burning building, a fireman needs to know his location in order to find the nearest exit or corridor. Also, a fireman needs to know the position of his colleagues in order to help or get help from them. In this case, there is no time for

the fire brigade to deploy a reference system before entering the building. Therefore, an indoor wireless system providing location information without fixed references would be useful.

It has been found in indoor multipath measurements at a range of frequencies [9,10] that the channel impulse response (CIR) consists of a small number of dominant echoes from large flat surfaces like walls, interspersed with noise-like scattering from smaller objects across the entire range of delays. These dominant pulses could be selected out in receivers by suitable thresholding.

Based on this, an impulse radio indoor wireless location-sensing technique providing mapping and positioning information without deploying fixed references has been proposed [11,12]. When an impulse radio ad-hoc network is operating in an unknown environment, it could use times of arrival (TOAs) of dominant pulses including direct line-of-sights (LOSs), single reflections and most double reflections detected in individual radios to map the major features of the environment.

Assuming pulses from different users could be discriminated in individual receivers [11,13], various 2D mapping and positioning algorithms have been developed for the proposed technique [12,14-16]. TOAs of echoes in the self-to-self channel of individual users are used to estimate the distance from surrounding walls to the users. TOAs of pulses in inter-radio channels are used to estimate the position of transmitters in relation to receivers and surrounding walls. Reconstructed maps are verified by checking whether it explains all measured TOAs.

The algorithms are designed based on various assumptions related to the geometry of the surrounding environment, which affects the types of individual pulses. For example, in an environment where the LOS between two radios is not blocked, e.g. the rectangular room shown in Figure 1, the first TOA in the channel between the two radios represents the LOS, while in an environment where the LOS is blocked, e.g. the turning of a corridor as shown in Figure 2, the first TOA in the channel between the two radios represents a single reflection, instead of the LOS.

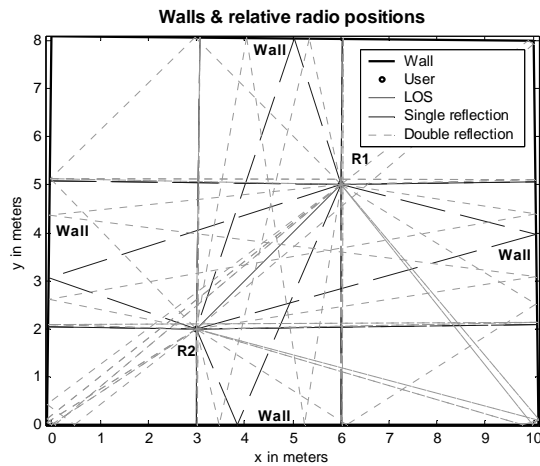


Figure 1. Two radios communicating in a rectangular room

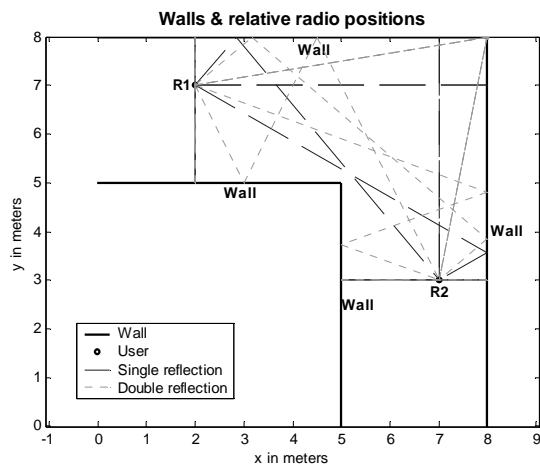


Figure 2. Two radios communicating around the turning of a corridor

However, individual radios have no knowledge about whether a measured TOA represents a single reflection, a double reflection, or the LOS. Therefore, the network needs to test several assumptions, until it finds the correct one, which leads to a geometry that successfully explains all received pulses. This test was originally a routine going through all assumptions representing a list of most typical indoor geometries, from the most likely ones, e.g. rectangular rooms, to the least likely ones. Each assumption will be applied to the measured TOAs. Then, geometries reconstructed using the algorithms corresponding to the assumptions will be checked by whether they explain the measured TOAs. The test stops whenever it finds a geometry that explains the measurements. The total computation time is therefore heavily ‘likelihood dependent’, as less likely geometries take a longer time to reconstruct.

This suggests the mapping process can be made more efficient by identifying the correct assumption before moving onto the reconstruction algorithms where most of the computation is spent.

A knowledge base, which comprises samples of each typical indoor environment either successfully reconstructed or which appears as a common substructure in most floor plans, is therefore proposed. Having this knowledge base, the network can query for similar cases given a set of newly measured TOAs and save time on finding the correct assumption.

THE PROBLEM

Originally, a data item in the knowledge base consists of measured TOAs, reconstructed scenario and corresponding assumptions. Given a set of newly measured TOAs, the TOA set from a data item in the knowledge base is identified to be similar by satisfying certain predefined conditions, e.g. time differences between corresponding TOAs from both sets are within a certain range. By finding the similar TOA set from the knowledge base, the network can use the corresponding assumption of the set to aid in reconstructing the scenario. However, TOA sets corresponding to similar environments can be considerably different, if the dimensions of the environments are different. As a result, sometimes there is no similar case found in the knowledge base, though actually there is. This suggests an alternative method to find the similarity between two sets of TOAs, instead of comparing arbitrary TOAs, is necessary.

PROPOSED SOLUTION

Dimension independence

By enlarging and reducing the dimension of scenarios, while keeping the relative position between radios and environment unchanged, it has been found that, corresponding to individual pulses, though the TOA values could be considerably different, pulse types (i.e. the LOS, a single reflection, or a double reflection) and the walls reflecting them remain the same. Based on this, it is proposed that, when saving a successfully reconstructed environment into the knowledge base, instead of saving a set of arbitrary TOAs corresponding to the environment into the data item, a pattern showing the type of each pulse, i.e. the LOS, a single reflection or a double reflection, and the correspondence among these pulses are saved. For example, the TOA set in Table 1, which corresponds to the scenario shown in Figure 1, can be converted into the pattern in Table 2. In Table 2, ‘S’ is used to represent a single reflection; ‘D’ is used to represent a double reflection and ‘L’ is used to represent the line of sight signal. Lower case letters from ‘a’ onwards are used to represent different walls. This pattern is called ‘SD pattern’, where ‘S’ represents single reflections and ‘D’ represents double reflections. For channels between radios, two single reflections may correspond to two double reflections instead of a single one. For example, ‘Sc’ and ‘Sd’ from Channel(R1→R2) in Table 2 correspond to both ‘Dcd’ and ‘Ddc’. This is explained in Figure 3, where the double reflection reflected by Wall(a) before Wall(b) (Dab)

takes a different path from the double reflection reflected by Wall(b) before Wall(a) (Dba).

Table 1. TOA set corresponding to the scenario in Figure 1 (Unit: nanosecond)

Channel(R1→R1)	20.266	26.915	33.333	40.252
	43.104	52.578	53.598	67.162
Channel(R1→R2)	0.000	11.244	17.796	17.876
	24.190	24.366	28.791	29.707
	30.634	33.254	44.148	50.371
	63.898			
Channel(R2→R1)	0.000	11.244	17.796	17.876
	24.190	24.366	28.791	29.707
	30.634	33.254	44.148	50.371
	63.898			
Channel(R2→R2)	13.333	20.500	24.593	40.465
	47.163	49.172	53.797	67.659

Table 2. SD pattern corresponding to the scenario in Figure 1

Channel(R1→R1)	Sa	Sb	Sc	Sd
	Dbc	Dcd	Dac	Dbd
Channel(R1→R2)	L	Sc	Sd	Sa
	Sb	Dcd	Dad	Dbc
	Dac	Dab	Dbd	Dca
	Ddb			
Channel(R2→R1)	L	Sc	Sd	Sa
	Sb	Ddc	Dda	Dcb
	Dca	Dba	Ddb	Dac
	Dbd			
Channel(R2→R2)	Sc	Sd	Dcd	Sa
	Sb	Dbc	Dac	Dbd

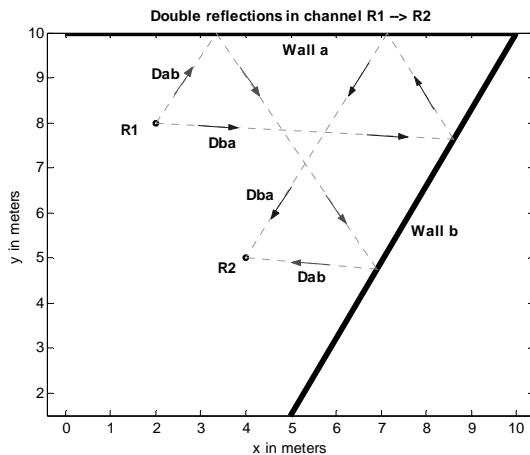


Figure 3. Dab and Dba take different paths

Adopting this change, given a newly measured TOA set, instead of comparing it with another set of arbitrary numbers, whether the SD pattern from a data item can explain the measured set will be checked by applying the constraints suggested by the pattern into the set. Introducing SD patterns solved the problem that TOA sets are sensitive to the dimension of the environment.

Relative position independence

Though SD patterns are ‘dimension insensitive’, they are found to be ‘position sensitive’. This means SD patterns can be considerably different, if the relative position

between the radios and the environment has changed, even inside the same environment. For example: as the radio user moves from the position shown in Figure 4 to the position shown in Figure 5 within the same environment, the corresponding SD pattern changes from the one shown in Table 3 into the one shown in Table 4.

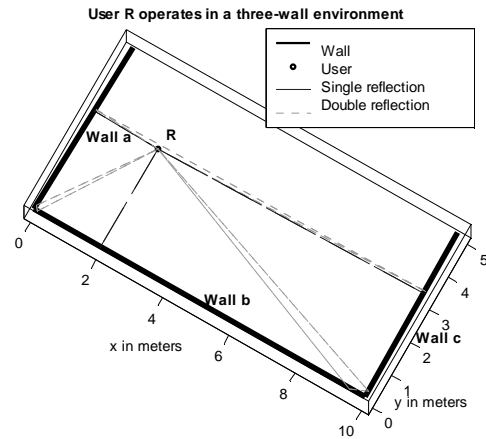


Figure 4. Radio R operates in a three-wall environment

Table 3. SD pattern corresponding to the scenario in Figure 4

Channel(R->R)	Sa	Sb	Dab	Sc	Dbc	Dac
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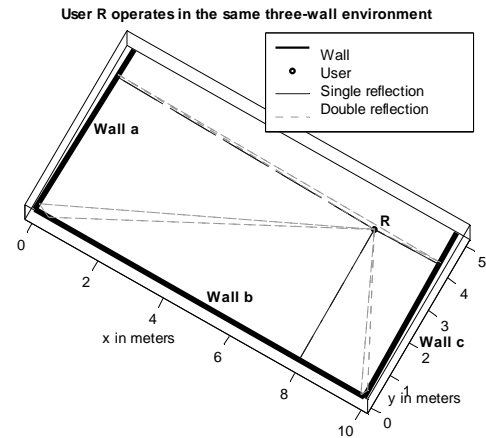


Figure 5. Radio R operates in the same three-wall environment

Table 4. SD pattern corresponding to the scenario in Figure 5

Channel(R->R)	Sc	Sb	Dbc	Sa	Dab	Dac
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It has been found that in self-to-self channels, there is a constraint between the TOA of any double reflection and the TOAs of the two single reflections reflected by each of two walls contributing the double reflection [16]. This relationship exists wherever the radio user is inside the environment and is directly related with the relative position between the two walls. This constraint shows less dependency on the relative positions of radio users inside

the environment. Based on this, SD patterns are reformatted into what we call ‘grouped SD patterns’, where single reflections and their corresponding double reflections compose individual groups. For example, the SD patterns in Table 3 and 4 can be converted into the grouped SD patterns in Table 5 and Table 6 respectively. Both patterns in Table 5 and 6 comprise 3 groups of the same contents and therefore they are suggesting a similar environment.

Table 5. Grouped SD pattern corresponding to the scenario in Figure 4

Channel(R->R)	Sa	Sb	Dab
	Sb	Sc	Dbc
	Sa	Sc	Dac

Table 6. Grouped SD pattern corresponding to the scenario in Figure 5

Channel(R->R)	Sc	Sb	Dbc
	Sb	Sa	Dab
	Sc	Sa	Dac

By investigating grouped SD patterns derived from other open 3-wall environments similar to the one shown in Figure 4, it is found that they are mostly similar. Further investigations on other typical indoor geometries suggest that grouped SD patterns represent a class of environment sharing similar geometry features and similar assumptions. Therefore, using grouped SD patterns, for each class of environment, only one typical case needs to be stored in the knowledge base for further reference. This reduces the amount of data immensely comparing with using SD patterns where various radio positions inside the same environment would need to be stored and using TOA sets where even various dimensions of similar environments would need to be stored. By storing grouped SD patterns instead of SD patterns or arbitrary TOAs, the knowledge base becomes more data efficient and geometry representative. In order to match with a newly measured TOA set, a grouped SD pattern from the knowledge base must be converted into possible SD patterns beforehand. This can be done by calculating possible permutations of all pulses from the same channel in the grouped SD pattern, knowing that no double reflection appears prior to any single reflection from the same group.

KNOWLEDGE BASE ASSISTED MAPPING

Having grouped SD patterns stored in the knowledge base, this section uses a sample case where a radio user moves from one part of a corridor into another through the door in between to show how this information can assist the mapping. In this case, the corners in the environment are not exactly square in order to represent a typical room with more reality. As only walls forming an acute angle contribute a double reflection, those corners greater than 90 degrees do not have double reflections around them.

Initially, the radios have no knowledge of the surrounding environment.

At pedestrian speeds in indoor environments (~1.5m/s), the position of a radio user cannot change by more than 15cm in 0.1 second. During this period, the radio can transmit up to two million pulses at a typical rate of 20 million pulses per second (Mpps). These two million pulses offer plenty of scope to improve the accuracy of TOAs by averaging, and then update this TOA information at a rate that gives Nyquist sampling according to the speed of movement. For example, if the radio can resolve 1 nanosecond (15cm one-way / 30cm round-trip distance) on a single pulse, as it takes the user at least 0.1 second to move 15cm which results in a detectable TOA variance, a transmission rate of one pulse per 0.1 second (10pps) is needed; averaging 100 pulses to get 0.1 nanosecond (1.5cm one-way / 3cm round-trip distance) resolution, a transmission rate of 100 pulses per 0.01 second is needed; averaging 10,000 pulses to get 0.01 nanosecond (0.15cm one-way/ 0.3cm round-trip distance) resolution, a transmission rate of 10,000 pulses per 0.001s (10Mpps) is needed. By choosing a suitable sampling rate, radios are allowed to map transition scenarios when moving from one environment into another. Based on this, when the radio moves from one part of the corridor (corridor part I shown in Figure 6) into another (corridor part II shown in Figure 7), separated by e.g. sliding doors, it will be able to capture the transition scenario in between while the door between the two parts is opened (shown in Figure 8).

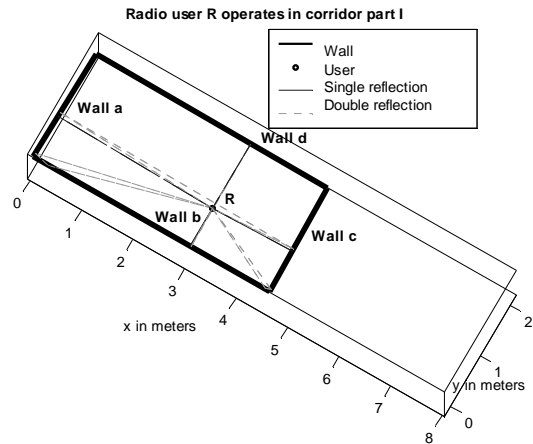


Figure 6. A single radio operates in the corridor

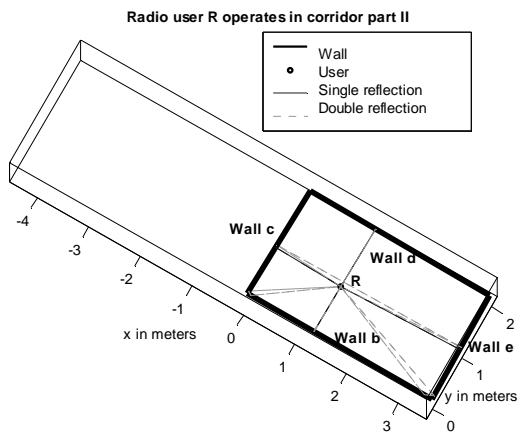


Figure 7. The radio operates in another part of the corridor

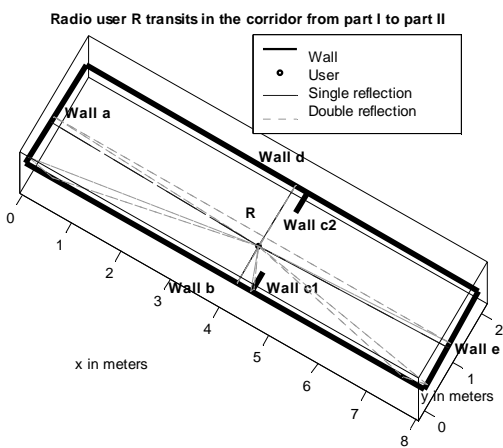


Figure 8. The user is moving from one part of the corridor to another

When moving in corridor part I, the radio can reconstruct the surrounding environment using developed algorithms [16]. Mapping information including the grouped SD pattern is then stored into the knowledge base as a data item.

While moving from corridor part I to part II with the door on Wall(c) opened as shown in Figure 8, the algorithm recognised that the environment has changed, as an extra pulse belonging to no group appears in the measurement, though all other pulses can still be explained using the grouped SD pattern representing corridor part I. It is expected that the geometry of the current environment, apart from the bit contributing the extra pulse, should be similar to corridor part I. Excluding the TOA of the unexplainable pulse, a reconstruction of the current environment, using the same algorithm used for reconstructing corridor part I, results in the scenario shown in Figure 9. Comparing with the geometry of corridor part I in Figure 6, the reconstructed geometry suggests a greater distance from Wall(a) to the wall opposite to it. This implies Wall(c) in Figure 6 has ‘disappeared’. As the environment normally does not change, the algorithm

expects there is a door on Wall(c), which is opened. If this is the case, some part of Wall(c), which is not a part of the door, should remain. This explains the origin of the extra pulse. As the algorithm knows exactly where Wall(c) is according to the map of corridor part I, an estimated map based on Figure 9 showing an opening on the original Wall(c) can be derived as shown in Figure 8, where Wall(c1) and Wall(c2) represent the remainder of wall(c). This estimated map explains all measured pulses by identifying the extra pulse as the double reflection around the corner formed by Wall(b) and Wall(c1).

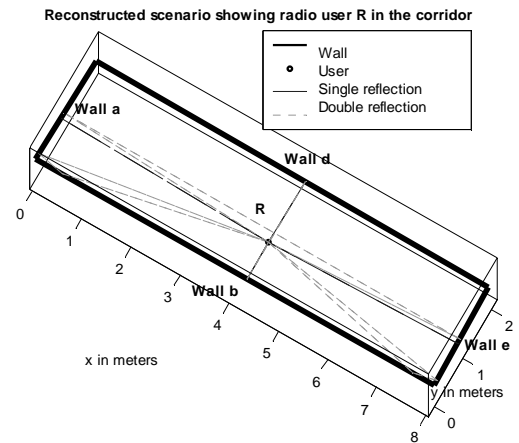


Figure 9. Scenario reconstructed based on the information excluding the extra pulse

Having this information, the algorithm can predict the upcoming environment after it passes through the opening door as the environment shown in Figure 7. This is derived by ‘closing the door’ in Figure 8 and cutting off corridor part I.

The radio will store the map showing both corridor part I and part II, so that it can easily predict the upcoming environment when visiting this corridor again. This regional map will expand by including each newly reconstructed substructure as the radio user moves on. When there are other radio users in range, regional maps carried by individual radios can be exchanged [13] and combined into more complete ones.

CONCLUSION

This paper has addressed the problem that it is inefficient to search for similar cases in a knowledge base by comparing arbitrary TOA values. A solution, which uses patterns showing type of pulses and relation among them to represent the geometry features of the corresponding environment, has been reached. A case study has been used to demonstrate the knowledge base can assist on mapping the current surrounding environment and even predicting upcoming ones.

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