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# Mobile objects in indoor environment: Trajectories reconstruction.

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## ABSTRACT

GPS is the reference for outdoor positioning, implementing direct connection between satellite and receiver device. Indoor positioning raises challenges, locating target devices requiring wireless sensors networks and other technologies. Sensor networks deployed in buildings are commonly used for many applications based on location: surveillance, detection, navigation, etc. These indoor locating sensors generate data related to tracking information. Exploiting this information for investigation issues remains a relevant purpose. This paper context is related to indoor locations systems based on wireless cell, ICCARD sensors and video surveillance cameras. In this context, as no global reference system similar to GPS is available, the location information issued from various devices have neither standards nor common formats, and remain heterogeneous. This paper presents a contribution to extend our framework [24] to information generated by location sensor networks deployed in an indoor environment. The use case is illustrated in a forensic application [1].

## Keywords

Tracking, hybrid queries, forensic, indoor location.

## 1. INTRODUCTION

Providing users, via spatio-temporal queries, with geo-located data based on sensor networks captures aims at locating, identifying, extracting metadata, from connected devices or objects in a given area, at a distance from other objects or sensors, at crossing paths, etc. Such applications are based on object positioning that can be expressed according to two ways, depending on different reference systems: geometric (coordinates relative to a reference system as geodesic datum, map of a building, etc.) and symbolic (more semantic description related to points of interest, address, transport networks, parts of a building, etc.). Coping with these positions, processing predicates related to a common reference highlight how the gap between the two ways of expressing positions is accurate, a geometric position being expressed by a point while a symbolic one is usually represented by geometry (a room, a building or an RFID cell).

In outdoor environments, applications use in most cases location models based on GPS sensors that are widely embedded (cars, smartphones, etc.). The indoor environments are becoming more complex and there is no single reference system to which any measure can refer to: company buildings, subways infrastructure,

airports, etc., generate a significant need to manage indoor location in terms of applications.

Facing the lack of satisfactory and generic answer, various applications have been developed in our team about outdoor location problems, in particular in forensic-oriented projects [1], [2]. These applications led us to the need for extending it to indoor environments with sensors such as Wi-Fi hotspots, ICCARD readers and video surveillance cameras. The main problem in the indoor environment is the heterogeneity of location information given by the various sensors. This heterogeneity concerns the following cases:

- positions are either geometric or symbolic: while the location based on the wireless gives geometric positions relative to the 2-dimensional coordinate system, the location based on the cells in the case of the cellular network gives symbolic positions, that is also the case with technologies such as infrared (IR) and RFID (Radio Frequency Identification),
- positions are expressed according to different coordinate systems.

Our work focuses on these two points and consists in checking that the generic modeling we propose can be extended and that our trajectory query framework can integrate indoor environment.

This paper is organized as follows: after a review of related work on indoor location models, trajectories and types of spatial queries in section 2, section 3 presents the definition of a model of hybrid trajectory based query. Section 4 presents indoor coordinates system. The different algorithms are developed in section 5 and finally, Section 6 concludes and discusses future researches.

## 2. STATE OF THE ART

### 2.1 Indoor location models

Indoor location aims at defining a user's/object position in an indoor environment. An indoor environment is generally made of a three-dimensional space (2D + floor for example): building in which people live, work, transit, and usually spend their time (houses, shopping centers, companies, stations, etc.) [3]. To represent this space, spatial models based on the definition of a topology model have been proposed that translate space, defining the location of objects and trajectories. This representation is called location model. [4] defines a location model as an expressive, flexible and efficient representation of location information.

The indoor space is partitioned either using geometrical methods that generate a space division in uniform or non-uniform cells [5], [6] or using symbolic elements, most of the time related to the topological elements of the building (rooms, hallways, doors, floors, entrances, etc.). In our case, to be consistent with the use cases our applications state, we only consider approaches relying on building structure elements for space partitioning, since human trajectories are mainly guided by these structures. Based on this

space partitioning, geometric and symbolic location models are defined.

### 2.1.1 Geometric location models

Within geometric location models, the space (or partitions of the space) is seen as an Euclidean space so entities locations as a 2D (X, Y) or 3D (X, Y, Z) set of coordinates with regards to global or local reference systems [7]. The main advantages of these kinds of models are the location high accuracy (ignoring the sensor measurements errors) and the straight forward computation of distances. Their main drawbacks are related to the non-representation of topological relation (e.g., connections between different rooms) and the fact that this representation is non-intuitive for users.

### 2.1.2 Symbolic location models

In symbolic location models, positions are identified by names or abstract symbols (e.g. "Room C1", "Scale S9") [9]. Many research works addressed the problems of lack of topological relations and of semantics of the geometrical location representations. These drawbacks are addressed by symbolic location modeling based on much more semantic descriptions about moving objects based on structural entities and/or points of interest (e.g., room/floor identifier, building name, etc.). The drawbacks of this type of models are that: (i) the accuracy depends on the level of abstraction of the space model, (ii) the model is less suitable for distance computation, (iii) the choice of named locations depends on the application (lack of interoperability), (iv) the modeling effort is sometimes valuable (symbols for locations often needing to be "manually" created and managed).

Some works also combine advantages from both geometrical and symbolic models and propose hybrid location models [10], [4].

Hybrid models are combinations of geometric and symbolic models [11]. We are also interested in how positions vary in time; taking into account that dynamicity leads us to present in the following a review of the literature on the trajectories.

## 2.2 Trajectory definition

A trajectory (or path) is defined as the change of the position of a moving object in time. A trajectory can be segmented according to several criteria. The segment of a trajectory is defined as a maximum subsequence of the trajectory such that all space-time positions match a given predicate (e.g. constant direction) [12].

[2] gives a formal and generic definition of a trajectory and segment of trajectory. Trajectory (see equation 1) is defined as a tuple composed of a trajectory identifier, an object identifier, a set of trajectory segments and a time interval giving the "start" and "end" time of the trajectory.

$$Tr = (tr_{id}, obj_{id}, \{u_k\}, [t_{start}, t_{end}]) \quad (1)$$

$$u_k = (u_{id}, \{position_i\}/1 \leq i, [t_{ks1tart}, t_{kend}]) \quad (2)$$

A trajectory segment (see equation 2) is a tuple that contains a segment identifier, a uniform set of positions and a time interval which is optional.

The objects movement can be performed freely (e.g. air moving) [8] or forced by the architecture of a building, for example [9] (e.g. moving inside a subway station is constrained by the arrangement of the different spaces and their connections).

In the following, we present the types of potential spatial queries in an indoor environment.

## 2.3 Spatial queries

A spatial query is any user's query including at least one geo- or spatial location element (expressed as geometric coordinates or symbolic names) and/or a time reference (date, time, and interval) [13]. The usefulness of spatial queries on the past trajectory of objects and the predicted queries has been proved many research and commercial works. There are several works about spatial queries like (i) position queries [14], returning the position of a moving or static object (geometric or symbolic position), (ii) region queries [15], [16], [17], [18], e.g. "what are the pharmacies located in the area?" (iii) nearest neighbors' queries [19], e.g. "what are the nearest houses of the intersection?", (iv) navigation or trajectory queries [20], e.g. "what is the shortest path to reach home?".

[27] present a prototype (AQMISS) that return adapted documents that meet the user profile (interest, location, etc.). To realize it, they allow the user to request several types of queries that concern his interests and/or the desired location.

Most of the works on objects trajectories aim to use the old trajectories to detect regular travel and thus to predict the future position of objects. There are less trajectories-oriented works that consider reconstitution queries and, as far as we can know, no framework of query that manages heterogeneous trajectories (containing both symbolic and geometric segments) in indoor environment. In the following, we will present two use cases that demonstrate the utility of such queries.

Let's suppose an "intelligent" working building. Each employee has a smartphone that is legally tracked by positioning systems based on different location sensors. Other types of sensors are monitoring the energy consumption and the temperature everywhere in the building.

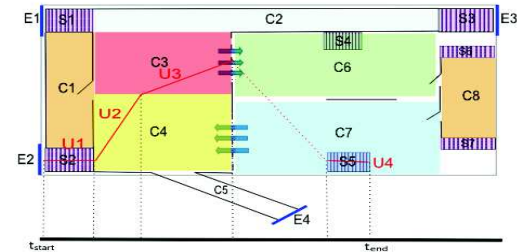


Figure 1. Example of trajectory one

Figure 1 illustrates the trajectory of a person inside the building. The trajectory is composed of four segments (U1, U2, U3 and U4). There might be a lack of position information for a given period of time (a person turned off his smartphone, so no more information comes about his position). The dotted line represents a gap in the definition of the trajectory (called "hole") that can be "filled" using interpolation functions [21]. Based on this trajectory, we want to compute different operators like aggregation of the energy consumption, identifying the sensors situated on the path or at a given distance of the path.

Let's consider the next case, surveillance in a working space; [26] explains the notion of managing the surveillance coverage zone using sensor networks. The classical scenario is triggered when a problem occurs in a given area of the building: someone is moving inside a restricted area. His/her movement track is generated based on the detection of his/her smartphone by the surrounding Wi-Fi cells. This generates coordinates (x, y) with regards to the building map. At a given place, the signal gets lost

and the only available information is that he/she entered a secured room (his badge was validated at the entrance of the room). In this case the person's trajectory would look like the one in figure 2. The first two segments of the trajectory are U1 and U2, there is a period where the object gets lost and the last part of the trajectory is U3 which takes place in room C1. In that case we want to identify the video cameras on the given path in order to visualize the recordings.

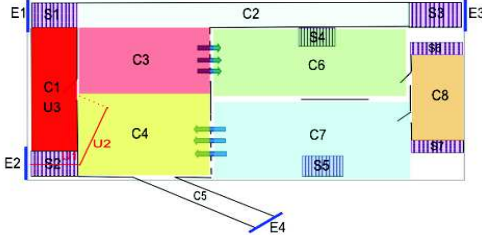


Figure 2. Example of trajectory two

### 3. TEMPLATE OF HYBRID TRAJECTORY BASED QUERY

According to the steps of our strategy, we will start by defining a query template that the system will be able to support based on the two examples of use cases presented in Section 2.3. The innovation that we introduce into the trajectory definition is the fact that each position is expressed relatively to a reference system (e.g., building plan, ICCARD reader's network). Positions are homogeneous within the segment (expressed according to a single reference system) but the individual segments may contain heterogeneous positions as in the examples in Section 2.3.

Hybrid trajectory query is defined as a tuple shown below:

$$T_r = (tr_{id}, \{u_k\}, [t_{start}, t_{end}]) \quad (3)$$

where  $tr_{id}$  is the trajectory identifier,  $\{u_k\}$  is the set of spatial segments constituting the trajectory and  $[t_{start}, t_{end}]$  represents the time interval of the trajectory query.

The definition of a path segment is as follows:

$$u_k = (u_{id}, refS_{id}, \{position_i\}) \quad (4)$$

where  $u_{id}$  is the segment identifier,  $refS_{id}$  is the identifier of the reference system about which the positions are defined and  $position_i$  is the set of positions that make up the trajectory segment.

To manage the heterogeneity of path segments, we define the position of an object as being composed of two parts, one identifying the reference system, another one referring to the location relative to the reference system.

The idea goes in the same sense as that proposed by [22] which defines the syntax of a hybrid indoor location based on the syntax of a URI (Universal Resource Identifier).

A hybrid trajectory is composed of two parts, a spatial one and a temporal one. The spatial part consists of a sequence of segments, each segment consisting of a reference system identifier and a sequence of positions (geometric or symbolic) expressed relatively to the corresponding reference system. The temporal part is an interval of time. This hybrid trajectory will constitute the entry point of our query framework. Figure 3 shows an example of hybrid trajectory that contains two segments, one composed of geometrical positions expressed with regards to the floor map and one composed of one symbolic position which

represents the ID of the sensor (ICCARD reader) which is expressed with regards to the ICCARD reader's network deployed in the building.

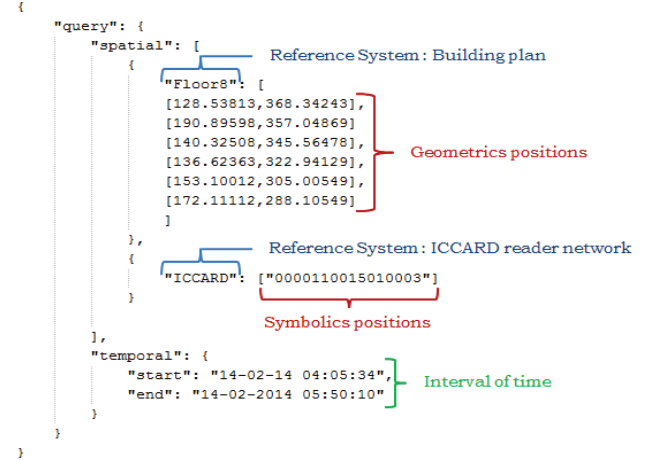


Figure 3. Example of a hybrid trajectory query

This query gives the trajectory possibly followed by the person to identify. The spatio-temporal information generated by the various sensors and saved will be queried by this trajectory to determine the relevant objects (people, devices, etc.), as well as surveillance cameras that could have filmed this path during the time interval of the query.

### 4. INDOOR COORDINATE SYSTEM

Expressing localization information with regards to different local reference systems is one of the main sources of heterogeneity and lack of interoperability among location models. In outdoor environment, GPS reference system makes things much easier. In general, spatial models have a multi-layer structure with associated mapping functions that can be used to project any local coordinates with regards to the GPS reference system.

In indoor environments, as there is no global reference system, local coordinate systems might be associated to the whole building (for 3D positions), to one floor or to each room. Given the map of the building we are going to consider one coordinate system per floor. Positions are expressed using 2D coordinates with regards to each plan of the floor. A third coordinate is associated to each position to indicate the floor number.

### 5. ALGORITHMS

The entry point of our system is a hybrid trajectory query that mixes geometric and symbolic positions which are expressed according to different reference systems and a time interval. Once this query is interpreted by a query interpreter module, it is expressed as a set of points ( $p_1, p_2, \dots, p_n$ ) and a time interval  $[t_1, t_2]$ . These points form a sequence of spatial segments ( $u_1, u_2, \dots, u_n$ ) for the geometrical positions and circles center ( $c_1, c_2, \dots, c_n$ ) for the symbolic positions. This sequence of points and the time stamps are the inputs of the search algorithms. The aim is:

- to propose a set of objects (person, device, etc.) whose positions have "intersected" the trajectory given by the query in the time interval  $[t_1, t_2]$ ,
- to propose a set of objects within the coverage area (range) of each ICCARD reader of the query trajectory in the time interval  $[t_1, t_2]$ ,
- to propose a list of cameras whose field of view (which may be variable) has "intersected" the trajectory of the query in the time interval.



## 5.1 Searching for the objects positions related to wireless terminals

Drawing a (poly-line) trajectory from the query given positions enables to define points. Then it is necessary to expand these points in geometries in order to cope with uncertainty and imprecision or approximation and human subjectivity (e.g. 168 instead of 168.142154). It implies to perform translations for the poly-lines from one end to the other of this trajectory in order to define a geometry that includes it enhancing a larger surface.

Based on this trajectory, we have to find the objects/persons that are "on" (or within) it. To succeed, we will "intersect" the poly-line with Wi-Fi data set (positions of objects/persons) stored in the Oracle database (Wi-Fi data set whose time stamp is in the interval  $[t_1, t_2]$  given by the query); the objects/persons which are on the path constitute our results.

### Operators:

The result is the set of pairs:  $R = \{r = (obj_i, pos_i)\}$ ; function  $draw\_geometry(u_k)$  helps to draw a geometry using the poly-line formed by segments  $u_k$ ; function  $get\_object([t_1, t_2])$  returns a list of objects whose time (date time) is in the interval  $[t_1, t_2]$  and the corresponding positions.

### Algorithm:

**Algorithm 1:** algorithm for identifying objects whose positions intersected the query path

**Inputs:** a sequence of path segments:  $u_k$  and an interval of time:  $[t_1, t_2]$ .

**Output:** A list of objects that have intersected the path and the corresponding positions.

```

1:  $geometry \leftarrow draw\_geometry(u_k)$ 
2:  $list\_object(obj_i, pos_i) \leftarrow get\_object([t_1, t_2])$ 
3: for each  $obj_i$  of  $list\_object(obj_i, pos_i)$  do
4:   if  $pos_i$  intersects  $geometry$  then
5:      $add\_result(obj_i, pos_i)$ 
6:   end if
7: end for

```

## 5.2 Searching for objects positions related to ICCARD readers

In this case, we are dealing with symbolic positions which are specific surfaces in the building. Each ICCARD reader has a field of action or a scope. When the trajectory query passed in the query interpreter module, the reader names are represented on the plan of the building by points (algorithm inputs) which are the positions assigned to readers; these points help to draw geometries that are circles, whose diameter is scope of each reader. The rays of the circles are customizable. Search objects are in the surface area of the circles. So we search here objects within the constructed geometries.

### Operators:

The result for ICCARD readers is all pairs:  $R = \{r(obj_i, pos_i)\}$ ; function  $draw\_circle(p_n, rayon_i)$  allows to draw circles whose centers are the points  $p_n$  and the rays are  $rayon_i$ ; function  $get\_object([t_1, t_2])$  returns a list of objects within circles and whose time (date time) is in the interval  $[t_1, t_2]$  along with the corresponding positions.

### Algorithm:

**Algorithm 2:** algorithm for identifying objects within geometry

**Inputs:** a sequence of points:  $p_n$  and an interval of time:  $[t_1, t_2]$ .

**Outputs:** list of objects within geometry and the corresponding positions.

```

1:  $list\_object(obj_i, pos_i) \leftarrow get\_object([t_1, t_2])$ 
2: for each  $p_n$  of query do
3:    $geometry_i \leftarrow draw\_circle(p_n, rayon_i)$ 
4:   for each  $obj_i$  of  $list\_object(obj_i, pos_i)$  do
5:     if  $obj_i$  within  $geometry_i$  then
6:        $add\_result(obj_i, pos_i)$ 
7:     end if
8:   end for
9: end for

```

## 5.3 Camera selection Algorithm

[2] propose an algorithm for selection of fixed cameras. As our work is an extension to indoor environment, we will adapt this algorithm to this context.

The aim is to propose to the operator a list of cameras that may have filmed segments of the trajectory given as query. For each camera we must give the interval of time in which she filmed the trajectory.

The algorithm proceeds in two steps, the filtering step and the refining of results:

- filtering: selecting cameras that are at a distance less than the distance of maximum visibility of the trajectories segments;
- refining: for the selected cameras in the filtering step, we calculate the geometry of the field of view, and select those whose geometries touch the trajectories segments.

The result is the set of triples  $R = \{r = (c_i, u_k, [t_a, t_b])\}$  where  $c_i$  is the selected camera,  $u_k$  is the filmed segment and  $[t_a, t_b]$  the interval of time in which the camera filmed the segment of the trajectory.

These algorithms are implemented in the Searching engine module of the framework developed architecture.

## 6. CONCLUSION

Our contribution in the field of indoor location is an extension of previous works on the construction of trajectories. We define an indoor coordinate system which can be associated to the building plan, a floor or to each space. Positions are expressed using 2D coordinates in relation with floor plan; a third coordinate is associated to each position in order to indicate the number of the floor for example. We have proposed a model of hybrid trajectory query which comprised geometric and symbolic positions expressed in relation to different reference systems. The developed algorithms used to find objects (people, devices, etc.) which are on a trajectory given as a query during a specified interval of time, and to look for cameras that could have filmed this trajectory.

Our approach has been tested within the context of the French national projects on video surveillance and forensic METHODEO, funded by the National French research Agency. It has also been implemented in the context of OVALIE platform<sup>1</sup>. This platform implements a modular space (family room, restaurant room, airplane cabin, etc.) equipped with data collection devices (different types of cameras, microphones, static or moving, directional or not, etc.) in order to analyze social interaction from facial recognition, posture, congruence, etc.

Our work can be instantiated in the context of forensic, for example during an investigation [24]. We plan to extend this context in order to be able to deal with real-time queries or predict the trajectories based on statistics realized on stored data. For indoor location systems based on surveillance with cameras, the result of the proposed operator is a list of cameras whose intervals

<sup>1</sup> <http://www.certop.cnrs.fr/OVALIE-une-plateforme-pour-l-etude>

of time may overlap. A perspective therefore relates to the scheduling of results depending on the distance from the cameras relative to the segments of the request for example. In our algorithms, we search topological relations between objects and geometries. The issue of research topological relations between regions of space is topical, especially between the regions of space with uncertainties. In the processing of a request, it will take into account the uncertainty (temporal fuzzy and spatial fuzzy) [25]. The research issue of topological relations between regions of space is topical, especially between the regions of space with uncertainties. In the processing of a request, it will take into account the uncertainty (temporal fuzzy and spatial fuzzy) [25]. During the query processing, the inclusion of the uncertainty is capital (temporal fuzzy and spatial fuzzy) [25]. These contributions gave the basis for designing a framework whose architecture has been developed w.r.t. different contexts, as a tool to support hybrid querying.

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