PERSONAL NAVIGATION SYSTEM FOR INDOOR APPLICATIONS

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1 Introduction

Navigation is usually associated with marine and aviation domains. Except for some lighthouses for orientation or landmarks near the coast, navigation instruments are essential because routes are virtual. Therefore, current position of ships and aircrafts must be drawn on the map.

Land navigation is generally bound to the road infrastructure. Car navigation systems have been introduced to replace the use of road maps in order to assist the driver in the choice of the correct way. Most of the developments for land navigation involve more interactions between navigation sensors and digital road maps.

Most of the navigation technologies are linked to the vehicles or to the infrastructure. After leaving the vehicle, the navigation process stops and the final destination is not always reached. The last mile has to be travelled by foot or by public transportation. In this case, a continuous navigation process could help to reach the proper destination.

1.1 Context of Indoor Navigation

Air and maritime navigation have followed rules and standards for a long time. Instruments and maps are certified and all users have to comply with specific procedures. International and national laws regulate most of the road traffic and transportation (e.g. the Transport Division of the United Nations Economic Commission). The development of car navigation has promoted new standards for digital road maps. The Geographical Data File (GDF) provides a general data model for the definition and exchange of geographic information for ITS (Intelligent Transportation Systems) applications.

Most road networks are digitised in geographical coordinates. The GDF standard provides a geometric model and a topological model with lots of features. This geographical format is used in many applications like car navigation and location based services (LBS). This dataset is limited to the road and its immediate surroundings.

For the pedestrian case, the use of GDF data could be useful for outdoor applications, mainly in the centre of cities. Most of the pedestrian routes follow the streets and the avenues, however, this is not the case for all applications, especially when entering buildings or when using underground paths.

The behaviour of people change when they move from a street into a building. The spatial perception of the environment is very different and has an influence on the way to move or to search for a desired area. Route guidance is a well-defined procedure for car navigation, which could not be transposed without adaptation to the pedestrian navigation. Before evaluating route guidance procedures for indoor applications, it is necessary to discuss the data model to be used.

The objective of this research is to define and to implement a dedicated data model for indoor applications. Based on this specific model, route guidance and navigation algorithms can be integrated in order to develop indoor applications. Therefore, we orient this project in the field of applications with particular requirements. Navigation of blind people is one example where the database must fit with specific algorithms in order to deliver reliable navigation information to the user.

1.2 Requirements for Specific Applications

The pedestrian navigation covers a large field of applications where the requirements are very different. From entertainment to safety critical applications, the users' needs must be specified. This project focuses on very demanding applications, where the performance of the system must be optimised to cover the users' needs.

The requirements for the application of indoor navigation should be expressed in terms of accuracy, integrity, availability and continuity of the system. These concepts have been defined by the civil aviation authorities to describe the required navigation performance. At any time, these parameters inform the user about the status of the navigation service over the coverage area [Tiemeyer, 2002].

The **accuracy** is the position error that will be experienced by a user with a certain probability at any instant in time and any location in the coverage area. The **integrity** risk is defined as the probability that a user will experience a position error larger than a specified limit without an alarm being raised within a specific Time-to-Alarm, at any instant in time and for any location in the coverage area. [Breeuwer et al., 1998].

The **availability** of the navigation service for the user is established by fulfilling simultaneously the accuracy and integrity requirements. The **continuity** of service requires that the navigation service is available for the user over a minimum time interval.

This concept of performance could be transposed for safety critical land and indoor applications (e.g., police, fire brigades, etc). The quality of the positioning system and the ability to inform the user in case of a failure of the system should be evaluated and stated explicitly.

2 Context of indoor map databases

2.1 Database for buildings

Current indoor map databases have been designed and developed for CAD systems (Computer Aided Design). The graphic standards used to draw 2D or 3D models are based on the description of objects using polylines and shapes. Map views are used for the construction and maintenance of buildings and utilities (e.g., water and gas networks). Buildings are composed of rooms, corridors, doors and lifts (Fig. 2.1). However to propose a smart itinerary to a pedestrian, a deeper knowledge of the map objects is required, along with more information about their topological relationships.

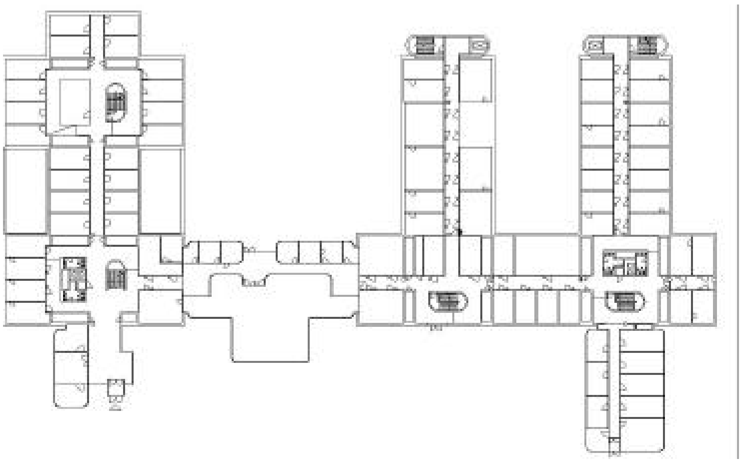

Figure 2.1: An example of the design of building

All the elements of the database may have a label with a list of attributes (for example, a room number). Such a database is useful to find the position of a specific point of interests. Then, the location of this point may be used to generate a simple view of the area from a digital map.

Most of this graphical information is not georeferenced. CAD systems are based on local 2D or 3D coordinates linked to the building. This geo-information could be useful for a local orientation (e.g. to find a room from the entrance of the building), however, these data are not compatible with geo-information of the surroundings or of other buildings.

2.2 Database of the campus EPFL

The development of indoor navigation applications is growing, and one must use existing digital map databases for localisation and guidance procedures. Due to the specific design of indoor maps, special algorithms must be developed to combine different sources of data.

The campus of the Swiss Federal Institute of Technology in Lausanne (EPFL) has developed a geo-information system based on a web-mapping server (http://plan.epfl.ch). The database of "plan.epfl" is mainly constituted of the geographic information inherited from the digital maps created for the construction and the maintenance of EPFL. The mapped objects are composed of buildings, rooms, corridors, doors and points of interest. Additional attributes about these objects have been imported from other databases (e.g. staff management).

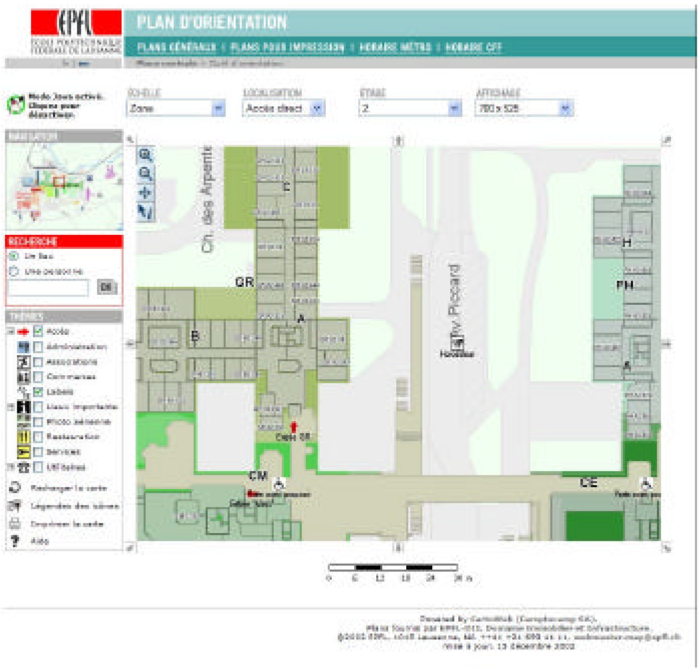

Figure 2.2: View of the web-mapping service of EPFL

The staff and students of EPFL use this database «plan.epfl» to find a specific room or point of interest. Visitors can access the web-mapping server on the Internet in order to find the correct location of their destination [Philipona, 2002].

The current version of the web service shows results on a raster map (Fig. 2.2). The information given to the user is static and there is no possibility to manipulate the data. Because, the data are derived from CAD files, the implementation of navigation functions is very limited. The structure of the design files is composed of points, arcs and polylines, which represent objects like buildings, rooms, doors, corridors and stairs. Moving from this primitive data model to a new topological model requires specific algorithms in order to handle the data.

All these shape-files have been georeferenced in the Swiss national grid for the purpose of this project.

2.3 From CAD to Topological Model

The content of the current database must be upgraded to be compatible with a data model designed for navigation. An improved connectivity, and thus a more elaborate topological model, is essential for the implementation of route guidance and map matching algorithms.

The spatial entities are defined by the localisation and the shape of objects, and by their topological relations. This vision of the space, the relations between objects, are more important than their own forms. It is rather a question of knowing a neighbourhood and the relative positions between objects. This vision is essential to build the spatial relationship (connectivity, proximity, intersection, and membership) between the objects and the features of a network.

The content of CAD files includes many features which are useless in a topological model of a network. A step of data conversion is necessary to identify specific objects required for indoor applications. After detection, the objects are clearly identified as door, room, corridor, building, etc. and all unused elements of the CAD files are removed. Figure 2.3 shows an example of such a detection, where the door composed of lines and arcs in a CAD form, is replaced by a single point in the topological model.

All these procedures for the extraction of CAD features have been implemented in the program "GEOEXTRACT" developed at the EPFL [Zweiacker, 2003].

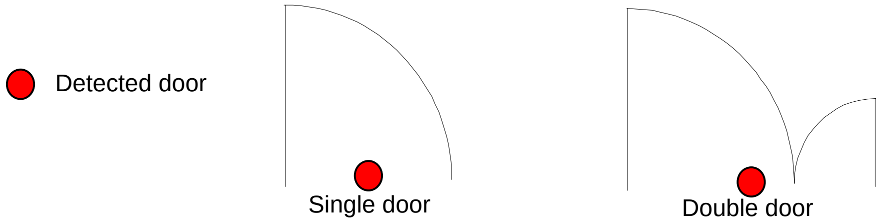

Figure 2.3: design of doors.

The next step consists of linking the different objects of the network, but the elaboration of an abstract model is required before creating these links. The development of this model and its related attributes are described in detail in section 4.

3 Concept of indoor navigation aid

Challenging applications require a high level of integration between the navigation system and the database. Geo-information plays a strategic role in a very demanding application. However, the navigation system itself must fit the requirements of the application. The next section describes a navigation module developed for pedestrians.

3.1 Personal Navigation System

For dead reckoning (DR) with vehicles, the traditional approach consists in using a triad of accelerometers and gyroscopes generating signals, which are integrated to obtain the relative displacement. However, the classic GPS/IMU approach used for vehicle navigation does not adapt well to pedestrian navigation. This concept is difficult to implement with a low-cost system. The principal reason is that the sensors' noise blurs the signals that correspond to the displacement of a person. An approach by occurrences was developed, whereby the steps are detected, their type identified and their length estimated based upon a subset of sensors as well as physiological and biomechanical parameters of the walk.

The Geodetic Engineering Laboratory of EPFL has been involved the development of a Pedestrian Navigation Module (PNM) fulfilling these requirements (Fig. 3.1). This project results from a close collaboration between the EPFL and Leica Vectronix AG. [Ladetto, 2002]

The PNM consists of a GPS receiver, a digital magnetic compass, a gyroscope, a barometer and embedded DR algorithms. All the sensors are placed in a small box. The weight of the device is about 150 grams and it works generally if clipped at the belt. Hence, it can be worn without discomfort.

The first area of interest consists in the determination of the physiological parameters necessary to quantify the speed of walk and the step length. While the variations in the signals of the accelerometers are good speedometers, the frequency of the steps improves the robustness of such models. The influence of the gender added to the great human diversity implies the normalisation of the various relations deduced. Many tests carried out under everyday life conditions reveal that the variation of the stride length, especially with the slope, strongly depends on the physical training of the person as well as on the duration of the ascend or descent. Characteristic patterns were identified to differentiate between the forward, backward and lateral movements. Various models were suggested and then favourably tested with some blind people, whose walking rhythm varies strongly according to the degree of confidence they have in the path that they follow.

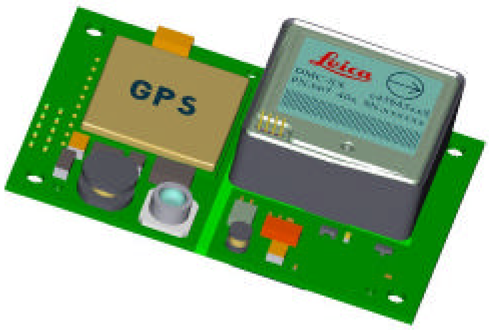

Figure 3.1: The Pedestrian Navigation Module (PNM)

The various technologies have been integrated to build an autonomous pedestrian navigation system. During periods with a fair reception of the satellite signals, the embedded GPS receiver allows to calibrate the different sensor parameters and physiological models. An initialisation phase has been developed to individualise the parameters of the walk and to adapt them from the general model. The consideration of several phenomena, specific to the displacement of humans, brings artificial intelligence into pedestrian navigation. The coupling of various sources of measurements, the influence of their precision on the computed position as well as their implication on the PNM reliability are described and illustrated in various publications[1] [Ladetto, 2002].

[1] http://topo.epfl.ch/presentation/publications/publications.php

3.2 Implementation of Algorithms

In this paper, we present the development and the implementation of algorithms to access map databases by a user equipped with a pedestrian navigation module. We have seen that the data from the original map must be extracted and adapted for the purpose of navigation.

The first step results in the building of a topological model especially designed for the localisation process. The different objects of the building must be assembled in order to provide a model for route guidance.

The second step consists in the development of map matching routines. The pedestrian navigation module provides the user's position, which is combined with mapping data. A dedicated map matching algorithm processes the combination of the position data with the map content.

The final objective of the navigation system is the computation of the best route from the present location to a specified target. Such procedures are well implemented in car navigation systems based on road databases. For indoor navigation, the concept of "route" guidance must be reconsidered for several reasons:

- The content of diverse databases is difficult to mix because of the various sources of data.
- The environment requires other means for localisation, in particular, sensors mounted on the wheels or on the steering shaft are out of place and the availability of GPS is limited.
- Specific needs arise for different kinds of users, typically for disabled people who are unable to use stairs, or blind people who require a special interface other than a graphical display.

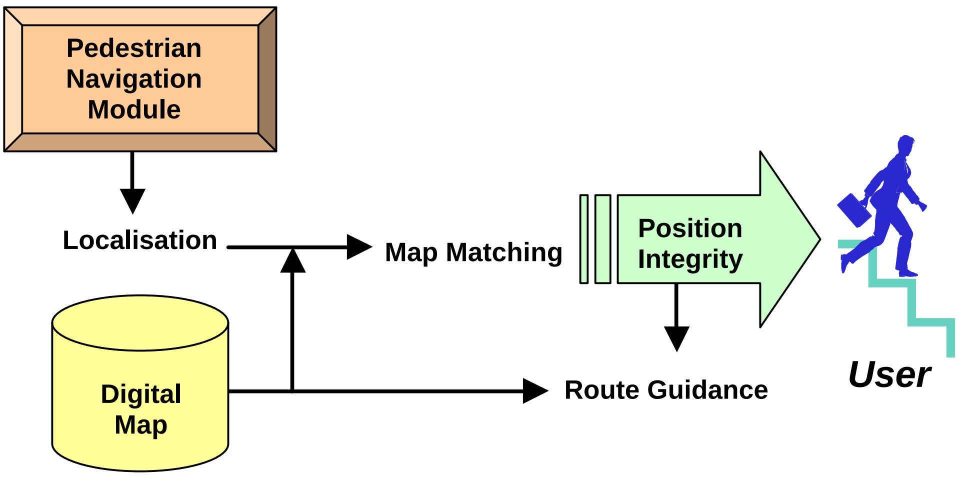

Figure 3.2: Concept of navigation

Figure 3.2 shows the general concept for pedestrian navigation. The navigation system outputs a 3D position in all conditions and at any time, which is useless if not combined with mapping data. Thus, a procedure of map matching should be implemented in order to extract the specific points and arcs from the database. The measure of spatial positions by the system is compared to the geo-elements extracted from the database. This procedure is designed to improve the navigation solution. Figure 3.3 shows an example of indoor navigation with the raw measurement of the trajectory (in blue) and an enhanced solution (in red) based on an appropriate processing of the height component.

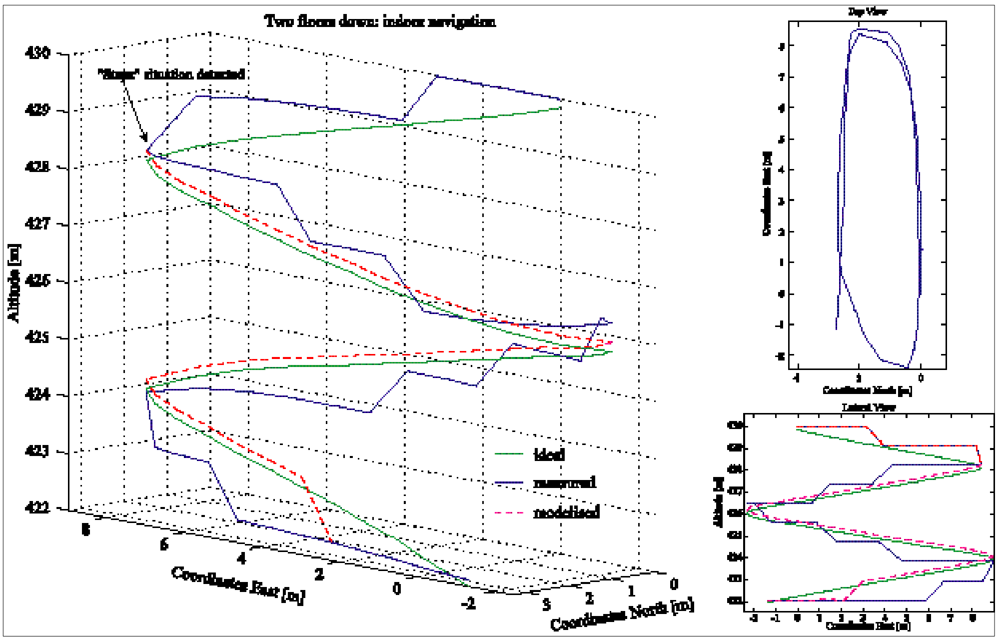

Figure 3.3: Example of a 3D downward walking of stairs inside a building

4 Topological Model for Navigation Applications

4.1 Abstract Model

The link/node view of a street network has a significant advantage in supporting navigation, since a path through a network is readily expressed as a series of decision at nodes. The algorithms developed to find optima paths through networks, such as the shortest path, are based on link/node structures [Goodchild, 2000]. The transformation of CAD data into single elements like nodes and links is a first step for building the network necessary for navigation. Therefore, we have built an abstract model with elements and relationships with objects of the network. Such a node/link model requires certain classes of attributes, especially for routing problems. This new structure is needed to support information about condition of access and connection between links. Figure 4.1 shows the process of data modelling for a part of a building.

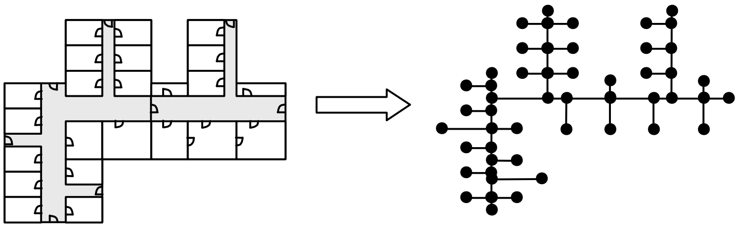

Figure 4.1: Transformation of a CAD model into a node/link model

A node/link model is composed of the following elements:

- corridor, way, road, path between buildings, room, hall
- stairs, lift, door, point of interest

Many other objects could be added to this list. However, these elements are essential for the procedure of route guidance and map matching. For the needs of navigation, all objects are represented as points or links, which are connected. This kind of data structure is well adapted for the computation of routes.

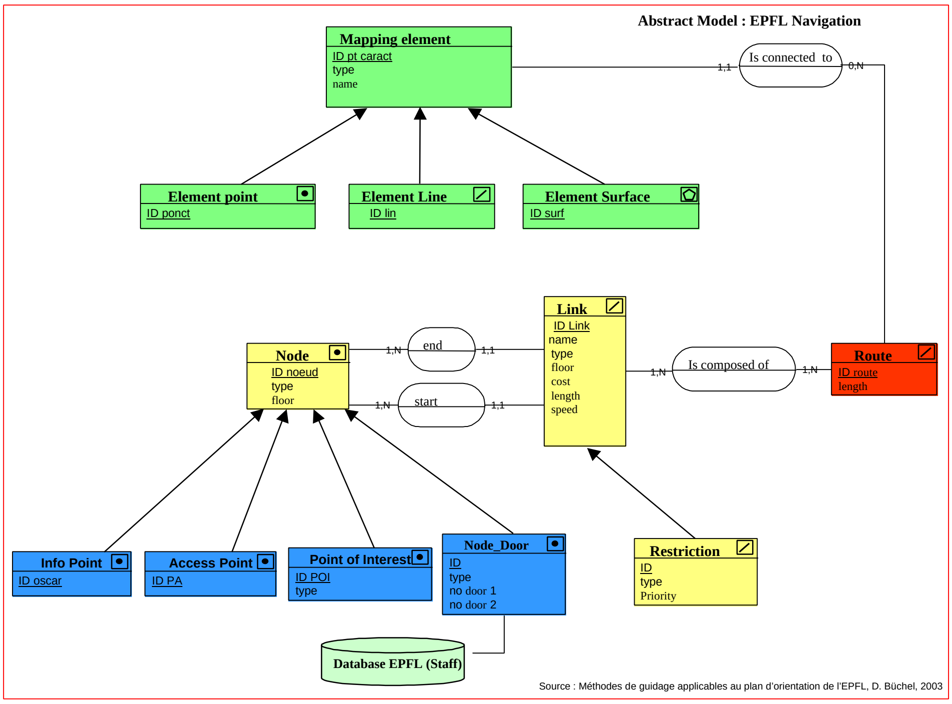

Figure 4.2: An abstract Model for route guidance at EPFL

The node is the basic element of this abstract model. A node can be connected to a door, a point of interest, an access point or a link. Each link is composed of a starting node and an ending node. All elements of the network have attributes necessary for the computation of routes:

- type of link (straight, stairs, lift), length of link
- restricted access (staff EPFL only), access for disabled people
- type of node (crossing, connector)

This model has been developed in a project for the implementation of route guidance algorithms [Büchel, 2003].

4.2 Indoor Route Guidance

The data model presented in section 4.1 is designed for the implementation of guidance algorithms. The main advantage of the model is the basic link/node structure, which allows for a simple use of cost functions. Each link has an attribute called "cost", mainly based on the time to travel a link from start-node to end-node. We use a mean speed of travel time to compute the cost for each link. The cost to go upstairs or downstairs is given by a mean time of travel. Other attributes (access, restriction) can be included in the cost function.

The implementation of a shortest path algorithm (e.g. Dijkstra's algorithm) is simple when the cost function is defined for all links (edges) of the database. The length of a path is the sum of the costs of the links. As more than one solution exists, the algorithm has to propose the solution with the minimal cost. Depending on the number of parameters, the cost function could be more complex.

5 Implementation of Map Matching Algorithms

The pedestrian navigation module (PNM) has the capability to provide a position even during bad reception of GPS signals. A dead reckoning (DR) process based on relative measurements of azimuth and distances gives the continuity of positioning. Without any update of the position, the errors are growing because of the biases and drifts of the sensors. However, geo-information can be used to update and to verify the position given by the PNM. This process is well known in car navigation, is called map matching [Shan Hung et al. 1998].

Car navigation is a relatively even process, which follows the road geometry. The behaviour of people walking on the street is less predictable. Pedestrians can walk forward, backward and can change the direction of walk at any time, or they can move upstairs or downstairs, therefore, vertical displacements must be take into account. The PNM with its multi-sensor system, is already able to detect those particular movements.

Systems to support pedestrian navigation must somehow deal with this complication. Developing a set of map matching functions for pedestrian navigation is a challenge because the trajectory of people is not always similar to the geometry of the mapping data. The development of algorithms is based on the comparison of topological elements from the trajectory and the database. This approach will limit mismatching, e.g. to match the current position with a wrong link.

Topological approach

The navigation system provides an initial position, which allows selecting all surrounding links from the database. The initial position is then projected on all selected links. Each solution has a probability function depends on the projected distance. The link with the best probability is selected. Then the exploitation of the topology of the network is envisaged. This process is based on the estimation of the best path compared to the DR given by the navigation system. Both azimuth and distance must be considered in the process of map matching.

Travelled distance

In order to determine the travelled distance along a link, it is necessary to evaluate the real trajectory. The topological model is imposed to rectify the position given by the navigation system. Figures 5.1 shows an example where the real trajectory is not following the straight geometry of the road (example b). Therefore, it is necessary to detect the displacements perpendicular to the selected link. The angle (θ) between the origin of the travelled link and the current position is computed, thus allowing to deduce the travelled distance.

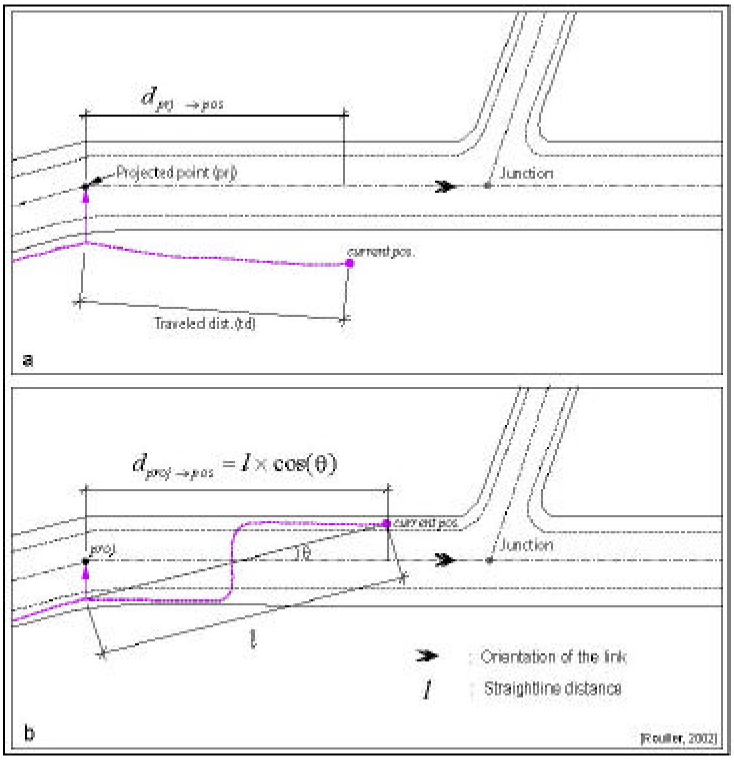

Fig. 5.1: Estimation of the travelled distance

The movement (change) from one link to another is possible when reporting the travelled distance along the link.

Change in direction

The change in direction involves a crossing or a junction. The navigation system detects that the direction is changing. This information has to be checked with the content of the database. If the turning point is correctly estimated, it shows that the point is corresponding to a junction node of the database. The following figure shows a set of steps with the indication of the difference of azimuth between steps. The turning point can be clearly determined by the computation of the variation in the azimuth.

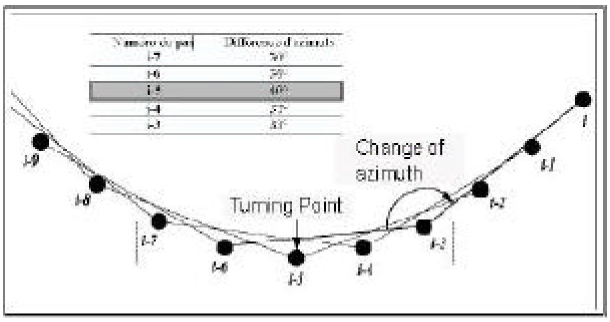

Figure 5.2: Variation of the azimuth

In car navigation a significant change of direction is easily detected by the signal of the gyroscope. The trajectory of a pedestrian is subject to major variations, which do not always fit with the mapping data. Therefore, map matching algorithms have to be robust for pedestrian navigation to filter misleading information [Rouiller, 2002].

6 Conclusion

Indoor navigation is based on diverse technologies, thus involving a high level of integration to combine navigation system and databases. Comparing to car navigation, indoor applications are built on hybrid systems and various structures of data. The challenge results in the implementation of data models, which are designed to integrate specific navigation algorithms. At the end, the integrated system has to provide reliable information to the user, especially for very demanding applications (e.g. safety, rescue).

The next step of this project will focus on the evaluation of the performance of indoor applications. Concepts for the evaluation of the navigation performance must be applied in the context of pedestrian navigation. Integrity, continuity and availability are certainly useful parameters in order to improve the confidence in the system, thus broadening the field of applications.

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