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An alternative view of positioning observations from low cost sensors

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ABSTRACT

The measurement uncertainty of low-cost, low-quality positioning sensors in consumer electronics, such as smart phones, is well-known and prevents reliable location awareness in mobile applications, for example. In this paper we argue that location awareness arises from qualitative spatial descriptions which are only partially reliant on the absolute accuracy of the positioning system used. Qualitative descriptions would relate the actual position qualitatively to a location. To facilitate qualitative spatial descriptions we suggest an integration of different positioning sensors by searching for event patterns within the sensor readings. It is hypothesized here that integrating qualitative information derived from traditional measurement sensors into the position computation process will improve the overall reliability of the location awareness information generated.

1. Introduction

Measurements are intrinsically uncertain. While the traditional approach to reducing measurement uncertainty is investing in more accurate and expensive sensors and processing techniques, the emergence and ubiquitous availability of cheap sensors is changing this approach. One way of utilizing cheap sensors and dealing with their larger positioning uncertainty is applied in professional measurement instruments: collecting large numbers of highly redundant observations allows averaging out their noise. This often involves complex computations or even post-processing of data which incur high computational overheads. Thus, cheap sensors integrated on consumer electronics such as smart phones require alternative approaches. These platforms are general-purpose, serving typically real-time information needs with no high accuracy requirements but perhaps ubiquitous availability requirements. Accordingly they are limited in their computational power, limited by their form factor (for example, with no space for redundant sensors), and limited in costs by a price-sensitive competitive market. These platforms usually come with applications that use single sensors or positioning technologies, such as car navigation applications on mobile phones using the in-built Global Positioning System (GPS) sensor for positioning. This design does not only limit the applications to certain environments, it also neglects the potential of integrating the multitude of available sensors on these platforms, which could facilitate ubiquitous positioning of higher accuracy. It also limits the communication, since such a sensor only detects a position, i.e., a point in a coordinate reference system.

In this paper we suggest to go a step further. We will investigate the on-board integration of various cheap sensors of such consumer-level mobile sensor platforms with a particular focus on detecting qualitative changes of positions. These qualitative changes, such as moving from outdoor to indoor, should be detectable from events in some sensor readings, and could be supported by existing map data. In contrast to traditional map-matching that constrains an observed position to a linear network, this approach on event modelling is more flexible in two ways. First, not all movements are along networks, thus, map-matching may be too limiting. Secondly, users of these platforms and services typically do not care for accurate position descriptions, but they do care for being aware of where they are, i.e., a qualitative description of their location. For example, users may want to know that they are *on Federation Square* rather than their exact position on Federation Square. This qualitative information can be derived from observable events, such as entering the local WiFi network of Federation Square, and map knowledge. Thus, location is a relative description, a local qualitative distinction of a place from other places.

As in traditional sensor integration and map-matching, the goal here is reducing the uncertainty of positioning. In this sense, we use concepts of location-awareness to improve positioning accuracy. The underlying research question is how positioning observations collected by consumer-level mobile sensor platforms can be translated to reliable position information, i.e., to position information that is qualitatively correct.

Thus the task here is to combine the various sensors on a consumer-level mobile sensor platform for the provision of qualitative spatial descriptions. To demonstrate the principle of such a combination we will integrate the readings of commercially available low-cost Global Navigation Satellite System (GNSS) receivers and

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micro-electro mechanical (MEMS) inertial navigation sensors (INS), and compare with the positions derived from high performing positioning sensors. The comparison can be made for geometric accuracy only, but would rather form a demonstration of current state of knowledge (for example, Kealy, Roberts, & Retscher, 2010). Thus the research question requires a stronger hypothesis: *Combining the various sensors on a consumer-level mobile sensor platform provides accurate qualitative descriptions of the position of the platform.*

For human users qualitative descriptions are of higher fitness for purpose in many decision making contexts than any further improvements of positioning accuracy. This means qualitative correct positioning is of relevance for people (Sperber & Wilson, 1986). Qualitative descriptions are also interesting from a theoretical perspective, with respect to spatial reasoning and spatial communication: While geometric descriptions (positions) are inaccurate by nature, qualitative descriptions are at least unambiguous. Qualitative descriptions can only be false or true, and this form of uncertainty can be dealt with by spatial granularity as we will lay out below.

The paper is structured as follows. Section 2 develops the conceptual model and includes the background of our contribution and references to related work. In Section 3 this model is implemented and tested for illustration purposes. The paper ends with a discussion and conclusions (Section 4).

2. Sensor observations and events

Mobile positioning is concerned with locating a mobile sensor platform in a spatial reference frame. In this section we will develop a conceptual model demonstrating that positioning can greatly be enhanced by studying movements, and especially events during movements. The section first studies properties of location, in particular from mobile positioning. Uncertainty of positioning is introduced here, and the dealing with uncertainty in qualitative descriptions via granularity. Then the section focuses on mobility, especially events in the readings of sensors during movement. These events are classified as either state changes or outliers. Events allow us to form hypotheses about transitions between environments, and thus the third part deals with deciding on these hypotheses by combining events in space and time with knowledge of the environment from spatial databases.

2.1. Location

Location will be defined as the outcome of a mobile positioning process. Observations of mobile positioning are uncertain, and so must be the location determined by positioning. One way to deal with uncertainty is choosing an appropriate level of spatial granularity to describe location in a qualitative manner.

2.1.1. Mobile positioning

Mobile positioning, in contrast to positioning stationary objects, is the process to locate and optionally orient a mobile agent in an environment, who is equipped with a mobile sensor platform. For this purpose the mobile agent is conceptualized as a (orientable) point object. Its locations can be determined in two ways, *absolute* or *relative* to the environment.

Positioning leads to an *absolute* location if the sensor readings are processed to time-stamped coordinates describing the relationship to the datum of a spatial reference system. These coordinates can be stored in computers, for example in spatiotemporal databases (Güting & Schneider, 2005; Sellis et al., 2003). If not observed directly by appropriate sensors the orientation of the agent can be derived (approximately) from the last two locations.

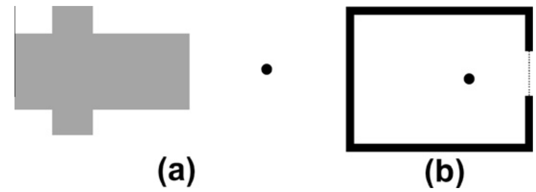

Fig. 1. Relative positioning ends up in a relationship to an environment populated with objects.

Table 1
Qualitative spatial relationships of a sensor platform, abstracted to a point, with another object.

Topological	Contained in, not contained in (out)
Distance	There, near, far
Directional	Cardinal directions (absolute reference frame), Ahead/ left/ right (egocentric reference frame), In front of/ left of/ right of (allocentric reference frame)

For example, a robot could position itself in an indoor spatial reference system to (SRF1; 8844; 9317; 21; 9:44) such that its location at time 9:44 was recorded as (8844; 9317) in some spatial reference frame SRF1, and its heading was recorded as 21° from some reference direction. Time-stamped coordinates can be analyzed for patterns, for example in spatiotemporal data mining, or used for automated mapping and routing, for example in robotics.

Positioning leads to a *relative* location if the sensor readings are processed to a description of the relationship of the sensor platform to other objects around. Expressed in common language we say for example: "The agent is *in front of the church*"—a directional relation—, "I am *an hour from home*"—a distance relation—, or "I am *in Room 4.13*"—a topological relation (Fig. 1).

Relative location depends on spatial relationships. Spatial (qualitative) relationships are categorized into topological relations, distance relations and direction relations. Table 1 lists the types of relationships.

Absolute location typically comes in quantitative measures (coordinates), but relative location can be given both in quantitative measures ("I am an hour from home") as well as in qualitative measures ("I am in front of the church").

Relative location is long studied in robotics. The foundations were laid by Kuipers (1978), who recognized that becoming qualitative in spatial modeling and reasoning is more efficient than quantitative methods (see also Fogliaroni, Wallgrn, Clementini, Tarquini, & Wolter, 2009; Levitt & Lawton, 1990). In our context, however, the qualitative description is produced with a goal to overcoming some of the measurement uncertainty rather than some efficiency gains in modeling or automated reasoning. Also, the produced description is communicated to human users instead of being used in internal reasoning.

2.1.2. Uncertainty

All observations of physical reality are intrinsically uncertain (for example, Chrisman, 1991; Frank, 2007; Morrissey, 1990) Error theory captures physical aspects of uncertainty, but there are also aspects of abstraction of continuous reality to discrete objects, discretization of numbers, and projection of a curved Earth surface on a plane that add to uncertainty. Uncertain data leads to uncertain reasoning. For example, to decide whether "I am in Room 4.13", the uncertain location computed from mobile positioning has to be tested whether it is inside the polygon representing Room 4.13. Consider Fig. 2: The nearer the computed location is to a line segment of the polygon the more undecided is the relationship of