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On human-centric and robot-centric perspective of a building model☆

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ABSTRACT

The effectiveness of mobile robots operating in buildings depends strongly on their ability to cooperate with people. The cooperation requires a common language for communication. In this paper, the problem of modelling buildings in the context of communication between humans and robots is considered. Significant differences between the perception of building elements by humans and robots are discussed at the onset. This analysis allows us to propose a human-oriented building model, which represents elements, features and relations used by people in communication. This model warrants the unambiguous identification of building elements, which forms a good basis for the communication between humans and robots. Further, the model is implemented by means of a flexible, document-based database. Finally, a mapping between the proposed model and the existing robot-oriented models of buildings is proposed, followed by case studies that demonstrate the usage of the proposed methodology.

1. Introduction

While HRI[3] is a well established domain in Robotics, Computer Science and Psychology, as can be seen from the report [1], several issues related to the narrower domain of Mobile Autonomous Robots seem still to remain open. Rapid progress observable during the last decade in Mobile Robotics leads this discipline towards practical applications. The first area, where results of research in mobile robotics clearly find practical outcome, is the automotive industry. Navigation aids, sonar bumpers, parking assistants, vision-based lane trackers are available today even for middle class vehicles. All leading car companies work intensively on autonomously driven vehicles[4]. They compete with some players from the IT-sector, like Google, who announced the will to develop an autonomous car several years ago[5].

We believe that, besides the obvious interest of the defence sector, the second domain, where mobile robots will come into everyday reality, is the AEC[6] –industry. A concept of Intelligent Building (IB) is already well established in this domain[7]. Until now IB was understood as a building allowing us to reduce the amount of energy needed to keep inhabitants comfortable and to assist them in such aspects like remote control or security. In the future, IB will probably incorporate mobile robots delivering various services inside the building.

The forerunners are already on the market. In 2014, the iRobot company producing a tiny vacuum-cleaner Roomba[8] generated $557 million in revenue and employed more than 500 of the robotic industry's top professionals. A self-propelled tug Aethon[9]distributes bedclothes and drugs over many hospitals in the United States. The Minerva robot[10] brought many inspiring solutions into Mobile Robotics. It was never commercialised but it serves up today as a guide in the Smithsonian's National Museum of American History.

Several approaches towards the development of in-door mobile robots are present in the literature. The most ambitious, perhaps, is an

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[4] http://next.mercedes-benz.com/en/autonomous-driving-in-the-tracks-of-bertha-benz/.
[5] http://spectrum.ieee.org/automaton/robotics/artificial-intelligence/how-google-self-driving-car-works.
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[8] http://www.irobot.com/For-the-Home/Vacuum-Cleaning/Roomba.aspx.
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attempt to produce a robot that will be capable to act in any building, as people do. Such a robot should be able to recognise a function of a room by its appearance [2], or to distinguish particular pieces of furniture or other objects in its surrounding [3]. Among several EU-founded projects that were devoted to the cognition-based approach, the KnowRob [4] seems to be worth mentioning. A recent survey on this approach, called *semantic mapping*, can be found in [5]. In Poland the topic of semantic mapping is on the research agenda as well, as can be seen from the paper [6].

At the other extreme, one could think how the building itself could facilitate the service provided by mobile robots. Artificial landmarks[11] that simplify navigation, RFID[12] labels placed on objects and QR-codes[13] bearing information about specific elements of the building come here into play.

When writing this paper we were inspired by the results of the EU FP6 IST project "CoSy" reported in [7]. The authors of this article point out that, in order to perform in-door service efficiently, robots must use the same concepts as people would do. They also observe rightly that the knowledge about building should be partitioned into two parts: an *innate knowledge* and an *acquired knowledge*. The first one is given the robot in advance, whereas the second one should be learned by the robot in the course of its work.

For obvious reasons, human beings and robots perceive the environment in different way. The aim of the present paper is to show how a bridge linking those two perceptions can be established in a well-defined domain of in-door service robotics. When building such a bridge, we pay more attention to the innate part of the building model, since learning the acquired knowledge is present in the literature to a greater extent.

The rest of the paper is organised as follows. In Sections 2 and 3 we discuss differences between the human-centric and robot-centric attitudes toward a building. In Section 4 a formalized model of a building is proposed. Section 5 shows the implementation of this model performed with the aid of a document-oriented database. In Section 6 two examples of mapping between the proposed model and existing representations are presented, whereas Section 8 presents case studies. The paper ends up with conclusions recapitulating the proposed methodology.

2. Human-centric view of a building

Humans living in developed countries consider buildings as their main and natural environment. A person living in a town spends most of her or his life inside various buildings. This situation creates a need of describing features of buildings, learning and processing their structure and reasoning with the help of common knowledge. These activities can be summarized as an abstract human way of modelling buildings.

Obviously, the modelling method cannot be precisely formalized, as every person may use slightly different ways of acquiring, representing and processing building's features. However, some general rules in this area can be pointed out and can be further used for better understanding of the needs concerning building modelling methods suitable for mobile robots. Note, that at this point we enter the domain of psychology. A thorough study of the human behaviour in a building has been conducted at Wrocław University of Technology under FP-7 project LIREC[14]. One of the outcomes of this project was the social robot FLASH[15].

The most important conclusion of informal analysis of the human building modelling method presented in the sequel is that it is possible to define common notions, entities, relations and algorithms used by majority of people. At least several reasons for this fact can be pointed out:

- Humans are similar between each other, equipped with the same types of sensing and actuating abilities.
- The development of a new person is directed by other, older people. The knowledge (including perception methods) is knowingly or unknowingly passed to new generations.
- The set of activities performed by people inside buildings is common and rather narrow.
- People need to communicate between each other, therefore they need common notions describing the domain of communication.

These facts may seem obvious and unworthy of mentioning. However, they will become crucial in the context of in-door mobile robots, where only the last one remains true.

Planning and executing action in buildings require basic abilities related to the problem of building modelling. Regardless of the type of service action to be performed, the three basic goals can be identified:

- Mapping – creating the building model itself.
- Localization – determining own location in a building.
- Path planning – selecting actions required for changing own location.

2.1. Mapping

The process of model creation always requires a source of information. The main sources of information used by humans in this case are shown in Fig. 1:

- Exploration and observation.
- Inquiring other people.
- Reading documentation.
- Past experience and reasoning using possessed knowledge.

The observation includes looking at (and other ways of experiencing of) the building elements, but also reading dedicated signs, marks and inscriptions. This way a person collects up-to-date information on the layout of communication links, characteristic points and functions of particular rooms.

Asking other people is also a very common method of collecting general knowledge about the structure of building or about the location of particular elements. This method is often preferred to reading printed plans or exploring a building.

The reasoning based on possessed general knowledge about buildings is probably the most significant source of information. People know that a building has storeys, that there will be an elevator or a staircase, that a door leads to adjacent space and that there must be a rest room somewhere. Moreover, there are other facts, that people use without even realizing their importance. There is a horizontal floor used for walking, walls are generally vertical and there are lights, mounted on a ceiling. This knowledge is used subconsciously to fill the missing parts in the information collected using other methods.

The interesting remark in this context is that people almost never use the most accurate and complete sources of information about buildings available, which are formal plans created during design and exploitation. Various formal models used by architects and constructors, like BIM[16] files, are not assimilable for average human being. Instead, one uses concise and easy to understand documentation, like a simplified sketch of a floor plan or a list of offices located in a building.

[11] http://www.cs.cmu.edu/motionplanning/papers/sbp_papers/integrated2/owen_landmark.pdf.
[12] Radio Frequency Identifiers, http://www.rfidsolutions.pl/.
[13] Quick Response Code, http://www.qrcode.com/en/.
[14] http://www.lirec.eu.
[15] http://www.flash-robotics.com/.
[16] Building Information Model, http://www.buildingsmart.org/.