Signage system for the navigation of autonomous robots in indoor environments

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Abstract—In many occasions people need to go to certain places without having any prior knowledge about the environment. This situation may occur when the place is visited for the first time, or even when there is not any available map to situate us. In those cases, the signs of the environment are essential for achieving the goal. The same situation may happen for an autonomous robot. This kind of robots must be capable of solving this problem in a natural way. In order to do that, they must use the resources present in their environment. This paper presents a RFID-based signage system, which has been developed to guide and give important information to an autonomous robot. The system has been implemented in a real indoor environment and it has been successfully proved in the autonomous and social robot Maggie. At the end of the paper some experimental results, carried out inside our university building, are presented.

Index Terms—Signage system, smart homes, building automation, RFID, wayfinding, navigation, autonomous robot, social robot.

I. INTRODUCTION

One of the main research goals of social robotics is the incorporation of robots in environments surrounded by people, for example, at home, hospitals, museums, offices, factories, etc. In those places, the autonomy of a social robot plays a key role and navigation is one of its needed skills.

Frequently, people need to go to a particular place without having any prior knowledge of the environment (it is our first time in that place, or we do not have a map). The human process of orientation, searching, and following a way toward a specific goal, is a cognitive process extensively studied in fields such as psychology [1][2], anthropology [3], and geography [4]. This cognitive process is known by the term “Wayfinding”.

There are many daily situations which motivate us to activate this process. For example, when we are at an unknown airport and we need to go to a certain boarding gate. In this case, we need to find the signs around, and follow their indications to reach our goal. As already said, with no previous knowledge of the path to follow, the information given by the environment is essential to find the right way. As humans must deal with this kind of situations, an autonomous social robot, which is intended to move in the same environment as humans, must be able to solve this problem. That is, it must be capable of searching for signs and, using their information, finding its goal.

The main objective of this work is to design a signage system for autonomous robots. This system will facilitate the navigation of the robot in different environments, such as, homes and buildings, in situations where it must fulfill a navigation mission and it has no previous knowledge about those places. It is expected that the robot uses the signage system in a natural way as humans do during the wayfinding process.

The majority of the smart homes applications are oriented to make the environment more comfortable for people [5]. However, our objective is to incorporate Radio Frequency Identification (RFID) technology in those environments to facilitate the navigation of autonomous robots, as future human companions. In order to implement the proposed signage system, it is necessary to slightly modify the environment by adding the signals. Therefore, the robot has access to the needed information to guide itself in the environment and to carry out its navigation task successfully.

Moreover, in this paper, a navigation algorithm is also presented. This algorithm specifies the searching process of the signals and their interpretation. Then, the skills of the robot are coordinated in order to arrive at the specified destination.

The proposed signage system has been implemented in a real environment, our university department, an indoor environment with a main corridor and several offices. Moreover, the navigation algorithm has also been implemented in a real social and autonomous robot named Maggie. At the end of the paper, some experimental results are shown.

This paper is organized as follows: Section II shows some related works which use signals as support for navigation tasks, mainly those using RFID technology. Next, the design of the signage system is explained in Section III and its implementation in a real robot is described in Section IV. Section V presents the developed navigation algorithm which uses the information stored in the signals of the environment. Later, some experiments, carried out with the social robot Maggie in a real environment, are shown in Section VI. Finally, in Section VII, the main conclusions and some future works are presented.

II. RELATED WORK

The main goal of a signage system is to guide and inform users in order to arrive at their destinations. The design of a signage system depends on the needs of the users and in this case, the users are autonomous robots. These robots must be able to easily access to the information given by the signals in order to successfully navigate without disturbing others (people or other robots).

There are some related works which use signals in the environment to support navigation. Some of them use marks
III. SIGNAGE SYSTEM

Signage can be defined as the set of elements situated in the environment that, through sensorial indications, guides and help users to navigate in an area or building. It serves as support for the orientation and helps the accessibility to the required services, which gives security during displacements and actions.

In this context, the signal can be defined as a type of sign situated in the environment to identify an element or place, or to give an advise or indication. Moreover, the signal serves to guide the user in the environment.

The proposed signals have been designed considering the following:

- The information of the signal must facilitate the required knowledge through a clear message.
- The information must not be confusing or excessive.
- The signals must be easily accessible. In the case of robots, this will depend on the sensor which receives the information, in this case, it will depend on the features of the RFID system.
- The signals must not affect the environmental harmony, that is, they must not affect the environment aesthetically, nor make the navigation difficult.

The information used from the environment will depend on: the sensory system of the robot, the structure of the environment, and the information required by the robot to arrive at its destination. In the case that the robot does not have a previous knowledge of the environment, the information of the signals must give answers to the following questions: where I am?, How can I get there?, and where can I go to?.

1) Where I am?: one of the main problems that must be solved by an autonomous robot is its localization. Then, it is necessary to design Identifying Signals indicating the name of the place where the robot is, or any other identifying feature, for example, indicating the functionality of that place. The information can be:
- Geometrical: corresponding to \((x; y; \theta)\) coordinates of the robot in relation to the reference system.
- Topological: this localization situates the user in relation to the representative element of the environment. For example: “you are at the Robotics Lab in front of the head’s department office”.

2) How can I go there? and 3. Where can I go to?: As already said, one of the objectives of a signage system is to determine the actions (indications) needed by the user to move and to facilitate his arrival at his destination. The kind of signal used for this purpose is the Indicator Signal. Those signals are composed by two types of information: a direction and a place. This type of signals are frequently found in our environment, for example, at the airport, we will find a specific boarding gate by following signals such as the one shown in Fig. 1.
Each building is divided by zones which are identified by letters from A to J. Moreover, every office or room is also identified by an alphanumeric code. Each place of the building is then defined as:

- **Zone:** The zone is a region or particular area of the environment with a name and an alphanumeric identifier.
- **Place:** The place is the hierarchical representation of the nested zones which contain it. One or several zones form a place.

$$p_i = \{z_1, \ldots, z_n\}$$  \hspace{1cm} (1)

If several zones form a place then, they are nested, as shown in (2):

$$z_1 \subseteq z_2 \subseteq \ldots \subseteq z_n$$  \hspace{1cm} (2)

For example, when we refer to the “Office 1.3.B.15” at the UC3M, the place will be formed by the following zones:

- \(z_1 = \text{Office 1.3.B.15}\)
- \(z_2 = \text{Zone B 1.3.B}\)
- \(z_3 = \text{Third floor 1.3}\)
- \(z_4 = \text{Betancourt Building}\)

The most specific zone \(z_1\) has an id given by an alphanumeric character, which will be called \(\text{id}_1\). The next zone \(z_{n+1}\) has an id with a higher level of abstraction than the one used for \(z_1\) (see Fig. 4).

### Fig. 4. Representation of the place “Office 1.3.B.15”.

2) *Where can I go to?, and How can I get there?:* Two concepts are defined, for the signage system, that indicate the robot where it can go to, and how to get there:

- **Connection:** A place can be connected directly or indirectly to another place. A connection is then defined as the possible place or places that the robot can go to from its current place.
- **Action:** It indicates the action that the robot must execute to get the place indicated by the connection. The action can be:
  - Topological: for example: “turn right”, “move forward”, “keep to the left”, etc.
  - Geometrical: in the case that a geometric map is available, then, the indication may tell the robot to go to a specific coordinate \((x, y, \theta)\).

Finally, a signal \(s_0\) is formed by a place \(p_0\), which indicates a current place, and a connection \(c_i\) or a list of connections \(c_1, \ldots, c_n\). A connection \(c_i\) indicates the place \(p_i\) where the robot can go to from the place \(p_0\) indicated the signal by executing an action \(a_i\) \((i = \{1, 2, \ldots, n\})\) (see Fig. 5).

### IV. IMPLEMENTATION IN AN AUTONOMOUS ROBOT

In social robotics, the Human Robot interaction (HRI) is intended to be “easy” since must be oriented to non-expert users, without a technological background. The main applications of social robots are related to domestic assistance, disabled or elderly assistance [18], health care [19], guidance [20], entertainment, among others [21]. Maggie is the social robot developed by the Robotics Lab of the Carlos III University of
Madrid [22]. As shown in Fig. 6, Maggie has been designed in order to have an attractive appearance for the users. The movement of Maggie is possible thanks to a wheeled base.

In previous works, [23] [24], a preliminary design of the signal detection system was shown. In those works high frequency (HF) antennae were selected, in the current work, it has been decided to use UHF RFID readers. The reason is because those readers give a greater reading range (80 cm approximately) and it is possible to use tags with no battery (passive tags). Hence, two UHF RFID readers have been placed at both sides of Maggie (see Fig. 6). Due to the features of the antennae, it is possible to situate the RFID tags in the walls of the environment (our department at the university). Therefore, the robot navigates in a safer way without requiring the high precision demanded by the HF system.

Fig. 6. The robot Maggie with the UHF antennae.

A. RFID tags information

The RFID tags store the following information:

- An id that represents the type of information stored by the tag: navigation information or useful information for object recognition.
- The signal information: place, connections, and actions.

The basic structure of a signal is modeled using a XML file with the following tags:

1) **Place**: A place is identified by the element `<place>`. This is the main element and contains the different zones that form the place. The definition of a place in XML is made as follows:

```xml
<place>
  <zone>
    <label>Name of the zone l</label>
    <ID>Id of the zone l</ID>
  </zone>
  ...
  <zone>
    <label>Name of the zone n</label>
    <ID>Id of the zone n</ID>
  </zone>
</place>
```

2) **Connection**: A connection is formed by a place and an action. In XML the following structure is used to define it:

```xml
<connection>
  <place>
    <zone>
      <label>Name of the zone l</label>
      <ID>Id of the zone l</ID>
    </zone>
    ...
    <zone>
      <label>Name of the zone n</label>
      <ID>Id of the zone n</ID>
    </zone>
  </place>
  <action>
    <name>Action <name>
    <type>int</type>
    <code>int</code>
  </action>
</connection>
```

Therefore, a **signal** is formed by:

- A place that indicates the current place indicated by the signal (`<place>`).
- A connection, or list of connections, which shows the places that can be reached from the place indicated by the signal, and the actions needed (`<connection>`).

V. NAVIGATION ALGORITHM

The main objective of the proposed navigation system is that the robot can imitate the human behaviour using the existing signals of the environment. This signals must be used as references during the navigation to arrive successfully at the final destination.

The developed algorithm starts from the following premises:

1) The robot has an assigned goal or destination.
2) The environment is unknown.
3) The robot does not memorize the visited places.
4) In order to reach the goal, the system will only use the information given by the signage system.

The orientation and goal searching process in a robot is basically similar to the one executed by humans in the same situation. As a first step, we search for a sign with the needed information (signal searching). Next, once the information is obtained, we analyze it and we execute the action to arrive at our destination.
The RFID tags, used as the signals for the navigation system, are situated in the environment and accessible for the robot during the navigation. Since the robot has a predefined destination, then, the robot starts to explore its environment searching for the signals. When one signal is found, the robot reads it and analyzes the obtained data to execute the right actions to reach its goal.

There are different situations or cases:

A. Case 1: the goal coincides with the current place.

This is the most basic case. The robot finds a signal ($s_i$), reads it and interprets the information. Then, the robot compares the name and/or the id of the assigned goal ($p_G$) with the current place indicated by the tag ($p_0$). In this case, $p_G = p_0 \Rightarrow$ the robot has arrived at its destination, see Fig. 7.

![Fig. 7. Case 1: The goal coincides with the current place](image)

B. Case 2: the goal is directly indicated in one connection.

If $p_G \neq p_0$ then, the goal place $p_G$ must be compared with the place indicated by each connection $c_i$ of the signal.

In case of existing a connection that indicates the goal, the robot executes the indicated action and moves toward it.

Example: If the current place is “Office 1.3.B.15” and the connections are given by $((p_c, id_c), a_c)$:
- $c_1=\{(Organization\ Engineering\ Department, 1.3.A), Move\ to\ the\ right\}$
- $c_2=\{(Robotics\ Lab\ 1.1.3.C.12), Move\ to\ the\ left\}$

If the goal is $p_G = (Office\ 1.3.B.15)$, then the robot checks that the goal does not coincide with the current place, nor with the connections, then, it will look for a similar id. That is, it will search for a generic id contained in the goal id:

The id $1.3.A.05$ is decomposed and the robot now compares each part sequentially, in the following order, until it finds a coincidence:
- $1.3.A.05$
- $1.3.A$

Then, it compares the zone $1.3.A$. If this zone corresponds to one of the connections, then, the robot executes the action indicated by the signal. If not, the id is decomposed again until all the comparisons are made. In the example, the robot finds the connection to zone $1.3.A$ and executes the indicated action: $c_1 = Move\ to\ the\ right$. After that, the robot will find another signal and will repeat the algorithm until it reach the goal, see Fig. 8.

![Fig. 8. Case 2: The goal coincides with a connection.](image)

C. Case 3: the goal is indirectly indicated in a connection.

In this case, the signal does not explicitly indicate how to get the goal, so we use the id of each zone to guide the robot to the goal.

D. Case 4: The goal is not indicated.

If none of the previous cases happens, then, the robot can select among the following actions:
- To explore searching for a signal.
- To execute the last action indicated by a signal, in case 2 or 3.
- To wait to be assigned with a new goal, or to receive external information (e.g. through HRI).

In real life generic signals are used to indicate common places such as, the “Exit” signals, the “All directions” found in highways, etc. In our design, connections to generic places are proposed. Therefore, the robot has other options in case...
of being in case 4 so, if it want to go to another floor, it will look for the “Elevators” generic signal.

In summary, the process can be described as follows:

1) The assigned goal is compared with the place indicated by the signal.
2) If there is a coincidence then, this means that the robot has arrived at its destination.
3) If the current place does not coincide with the goal place then, the robot look for a connection which indicated how to get to the goal.
4) In case of coincidence, the action (or set of actions), to reach the goal or the next signal, is executed.
5) In case of no coincidence, the robot can select among the actions previously explained in case 4.

VI. EXPERIMENTAL RESULTS

This section presents two experiments made to prove the successful performance of the signage system and the navigation algorithm proposed in this paper. These experiments were carried out on the third floor of the Betancourt building of the Carlos III University of Madrid. Fig. 10 shows a view of the navigation area of the robot and its initial location.

A. Experiment 1

Objective

The robot must go to the Robotics Lab II (1.3.C.13).

Description

Initially, the robot is beside the photocopier, which is located in the corridor in the zone C. The robot does not know its own location until it reads the signal (RFID tag) also situated next to the photocopier. This experiment tests the behaviour of the robot when a mobile obstacle is situated at the goal’s position. Therefore, the robot will not be able to read the signal’s goal.

Input data

- Assigned goal: Robotics Lab II– 1.3.C.13
- First detected signal: place: photocopier – 1.3.C.f

Process

Initially, the robot detects the first signal and reads the information about its current location and the possible places where the robot can go to from that place. Fig. 11 shows the information stored in this first signal.

As already explained, the robot compares the assigned goal with the place indicated by the signal. If those places are different, then it starts to compare the goal with the places indicated by the connections. In this occasion, the assigned goal corresponds to one of the connections. Then, the robot activates the “follow the wall on your left” skill and is executed until it finds a new signal.

As shown in Fig. 12, when the robot arrives to its destination, it is not able to read the correspondent signal since there is an object (the grey square) in front of it. Therefore, the robot continues navigating executing the last indicated skill. However, when it finds the next signal (situated at 1.3.C.12), the assigned goal is indicated in one connection. Hence, the robot executes the signaled skill: “follow the wall on your right” and turns round. Now, the obstacle is not longer at the
corridor, so the robot successfully finds the signal situated at the destination place, see Fig. 13.

Fig. 12. Experiment 2: Obstacle situated at the destination place

Results

Although the robot did not detect the signal at the goal location due to the presence of an obstacle, using the proposed navigation algorithm, the robot finally fulfilled its navigation task: “Go to the Robotics Lab II”.

B. Experiment 2

Objective

The robot must go to its lab (1.3.C.12) and turn the TV off.

Description

Again, the robot is initially situated beside the photocopier and it does not know its own location until it reads the signal. The robot must go through the corridor, enter the Robotics Lab I (Maggie’s Lab) 1.3.C.12 and turn the TV off.

Input data

- Assigned goal: TV of the Robotics Lab I– 1.3.C.12.TV
- First detected signal: place: photocopier – 1.3.C.f

Process

In this experiment the robot task is composed of two objectives:

1) “Go to the TV of the Robotics Lab I”.

2) “Turn the TV off”.

Objective 1: “Go to the TV of the Robotics Lab I”:

As already said, the robot is initially situated next to the photocopier (1.3.C.f). The robot reads the first signal and compare the connections with the assigned goal. As in the previous experiment, Fig. 11 shows the information stored in this first signal.

As can be observed, there is not an exact coincidence with the goal point id “1.3.C.12.TV” (Case 3). Therefore, the system looks for a generic zone that approximates it to the goal. In this case, the most suitable connection is “Robotics Lab I 1.3.C.12”.

The robot navigates through the environment using the detected RFID signals. It stops when it finds its partial goal: Robotics Lab I – 1.3.C.12. Once the robot arrives at 1.3.C.12 (it detects the correspondent signal), the robot search for a connection which corresponds to the goal point. As shown in Fig. 14, there is a connection which says the robot to “Enter” the lab.

For this experiment, another signal was situated inside the 1.3.C.12 lab, next to its entrance. In Fig. 14, the information stored in this signal is also shown. The added connection specifies the goal place (TV of the Robotics Lab I) and the required action to get there (Go to point (-0.2,-1.0,-1.7)).

In this experiment, apart from using topological actions, the robot is also using a geometric action. The geometric information is used when the topological one is not sufficient, or if the robot is in a non-structured environment. This is the case of our lab since there are tables, chairs, and other objects.

In the XML file of the signal inside the lab, the geometric connection is specified using the following elements:

- <name>: specifies the action’s name. In this case GTP (-0.2,-1.0,-1.7) indicates that the robot will activate the skill “Go to Point”, where the coordinate is: \( x = -0.2, y = -1.0, \theta = -1.7 \), expressed in meters and radians respectively.
- <GeometricMap>: In order to activate the “Go to Point” skill, the system requires a geometric map of the environment. This map has been previously made and stored in the URL indicated by <direccion>.
- <localization>: this field indicates the geometric localization of the robot. This localization is in relation to the geometric map when the signal is detected. Therefore, the robot localize itself and executes the “Go to Point” skill.

Objective 2: “Turn the TV off”:

Once the robot is in front of the TV, it activates its remote control system based on IR
techniques to learn the already visited places and paths, finally, the robot could ask for help to the people around.

Moreover, since the signage system is intended for social robots, it would be quite interesting to include a signal-writing method based on HRI. Therefore, the social robot will be able to write and modify the content of the signals following the instructions given by a person.

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