Understanding social conventions for socially aware robot navigation

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Navigation is an essential skill for autonomous robots, and it becomes a cumbersome task in human-populated environments. Robots need to perform their tasks without disturbing the people around them.

Digital Object Identifier 10.1109/MPOT.2020.3026969
Date of current version: 5 May 2023

Robots navigating in a human-populated environment need to ensure people's comfort and safety.

Social awareness is the key to robot navigation in human-centered environments. It is essential to comprehend social conventions for establishing effective socially aware robot navigation (SARN). This article discusses the different aspects of social conventions that need to be understood before deploying autonomous robots in any human-centered dynamic environment.

The need for social awareness

The applications of robotics are growing day by day. Robots are no longer limited to industry environments. With advancements in technology,

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they are moving into social settings, like homes and workplaces. The advent of robots in social structures will bring a wide range of opportunities for social robotics. However, the success of these applications will be highly dependent on how robots adapt their behavior based on social expectations.

One of the crucial factors in how a robot will adjust to its surroundings as per social conventions is navigation. Human-aware robot navigation can be considered as the intersection between robot motion planning and human–robot interaction (HRI). As humans and robots are going to share the same physical space, robot navigation needs to be not only safe but sociable as well.

In any case, if a robot does not perform movements properly as per social navigation norms, it can cause an unfavorable social response (Hamilton, 2018). Here, *social navigation norms* refers to robots behaving in a civilized way while navigating among humans. For example, all together, for a robot to explore a workplace setting, it must be completely customized, programmed, and aware, as per the environmental factors. However, the equation completely changes when humans become part of that environment setting. Without a careful comprehension of or the capacity to recognize its condition, a robot can experience some significant obstructions by which individuals might get injured.

Further, robot navigation strategy can also take into account the cultures and social constructs for the different countries/regions where it is being deployed. That is why the navigation of any mobile robot in a social environment plays a very important role and needs to be understood completely while designing an SARN framework for any environment.

The integration of social conventions and newly developed methods can lead to social awareness. These techniques will depend upon the environment, social behavior cues, shape of the robot, and type of task it is performing (Repiso et al., 2020).

Furthermore, along with social conventions, there are various other components that need to be considered when thinking of a design for a socially aware navigation framework, as shown in Fig. 1. Every component is connected to a computation block

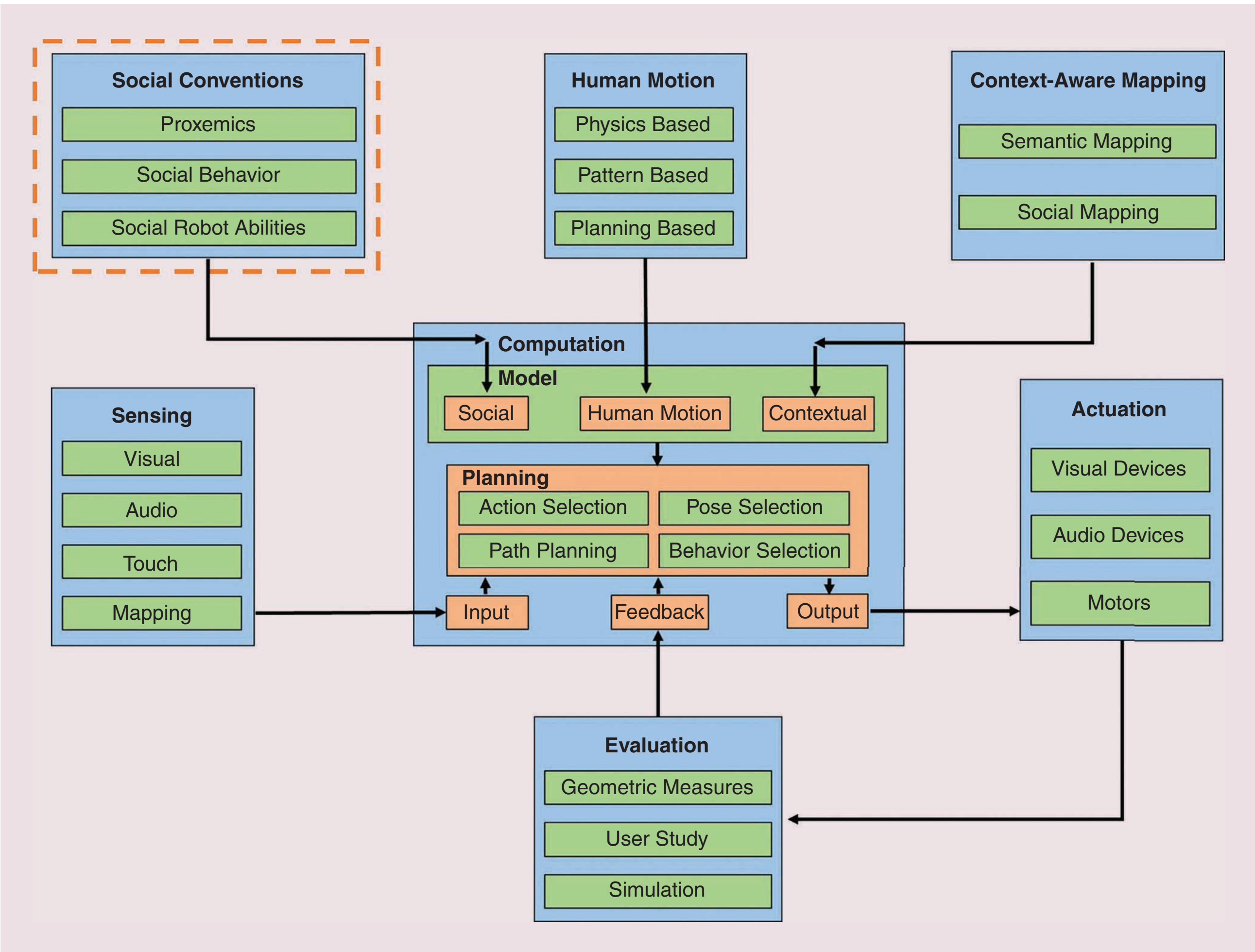

FIG1 The components of a SARN framework.

TABLE 1. The linkage of social signals to social cues.

	SOCIAL CUES							
SOCIAL SIGNALS	HEIGHT	BODY SHAPE	HAND GESTURES	WALKING	FACIAL EXPRESSIONS	GAZE BEHAVIOR	VOCALIZATION	DISTANCE
Emotion			✓		✓	✓	✓	
Personality		✓		✓	✓	✓	✓	✓
Status	✓			✓	✓	✓		✓
Dominance	✓	✓		✓	✓	✓	✓	
Persuasion			✓		✓	✓	✓	✓
Regulation			✓		✓	✓	✓	

that ultimately processes every piece of data to actuate output devices to perform SARN. Although every component has its own significance for gaining acceptance in human society, robots need to respect the social conventions. Therefore, it is very important to understand human spatial behavior and expectations. This article discusses different aspects of social conventions that should be taken into consideration while designing a SARN approach.

Social conventions

Behaviors created and acknowledged by society that help humans comprehend the goals of others and encourage correspondence are called *social conventions*. The conventions required for robot navigations should possess safe and understandable behavior. We have further divided them into three areas—i.e., social behavior, proxemics, and social robot abilities—which are discussed in detail in the following sections.

Social behavior

There are different perspectives from which human behavior can be studied, for example, anthropology, psychology, sociology, and so on. To design a navigation strategy for robots in a human-populated environment, it is very important to understand how the surrounding space is managed by people while moving.

When the personal space of an individual is invaded by another person, he or she does not try to escape or attack but informs the other person via social cues, like face expressions, gestures, and so on (Bera et al., 2020). Therefore, the term *social cue* encompasses verbal and nonverbal messages. These cues can be derived from proximity, body posture, facial expressions, and so forth. Current sensing technologies are already performing well in detecting social cues.

The real challenge lies in connecting the right social cue to the correct social signal. Furthermore, context plays a crucial role in establishing this connection. Many researchers have tried to connect social signals to social cues, as shown in Table 1 (Vinciarelli et al., 2008; Singh et al., 2019). The navigation behavior of a robot must lead to *social comfort*, which can be defined as the absence of stress and irritation while interacting with robots. As per the earlier discussion, social comfort is a very subjective matter and cannot be measured directly. There are various studies that make use of distance; visual behavior; and, more specifically, proxemics to empower the SARN system to cater to social comfort (Narayanan et al., 2020).

Proxemics

The study of maintaining spatial distances in various interpersonal and social spaces is called *proxemics*. A robot in socially aware navigation should be able to manage four kinds of spaces: i.e., the space related to individuals, space related

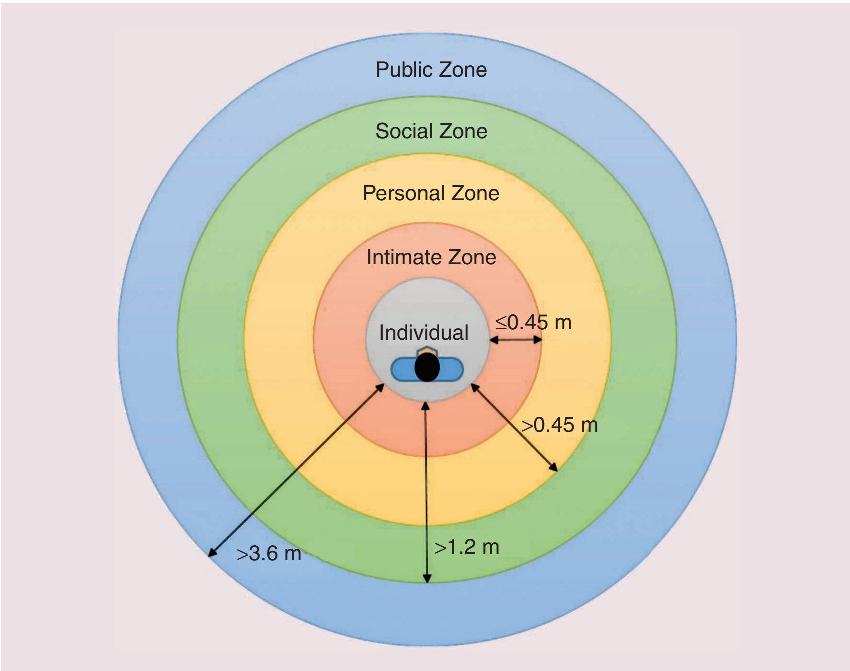

FIG2 The classification of personal space.

to groups, interaction space between humans and objects, and HRI space (Lindner, 2015). The *personal space* related to individuals can be defined as the minimum space that individuals maintain to avoid discomfort. A classification of the space around an individual is shown in Fig. 2.

As far as the space related to groups is concerned, it is the coverage of space when two or more individuals are engaged in conversation. The communication between individuals can be verbal or nonverbal. Usually, group space configurations can be divided into seven types (Vega et al., 2019), as shown in Fig. 3.

One also needs to consider that the idea of space around an individual is situation dependent and dynamic in nature. Another aspect is the information process space, which is nothing but the space that individual maintains from obstacles while planning his or her trajectory. It has a strong relation with eye contact, which is further affected by culture and gender as well.

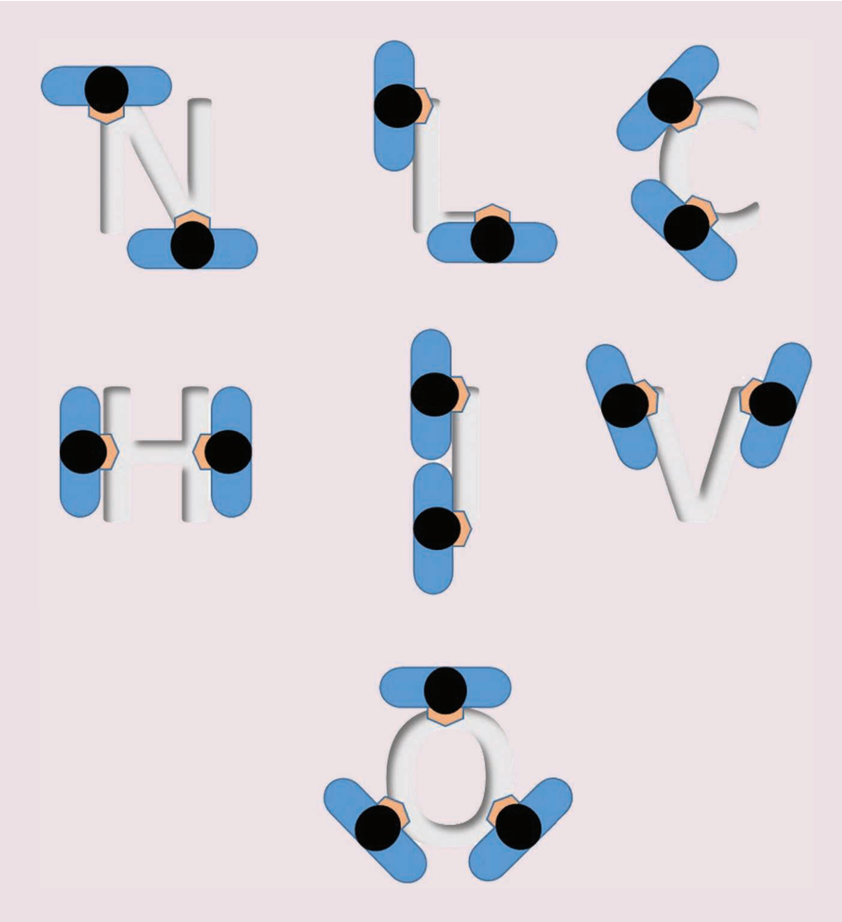

FIG3 Different types of group space configurations.

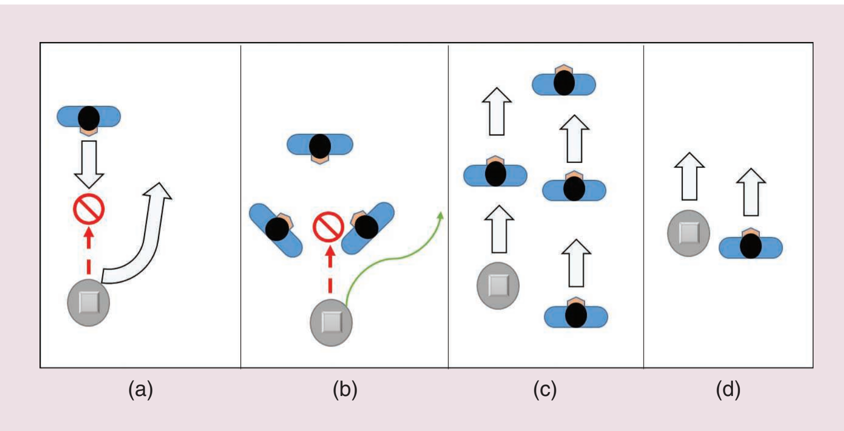

FIG4 (a) Avoiding a collision as well as (b) passing, (c) following, and (d) moving along with humans.

Proxemics go hand in hand with other factors, like robot appearance, speed, and approach direction. Many experiments (Singh et al., 2019; Narayanan et al., 2020; Vega et al., 2019; Repiso et al., 2020) have been conducted for understanding human-aware robot navigation. Although it depends on the situation, in many experiments, it has been demonstrated that a slower speed for the robot compared to a human is preferred. While closer distances are acceptable, in the case of a robot that looks like a humanoid, it is considered more effective for the robot to rotate its head before initiating motion.

Social robot abilities

To effectively deploy SARN, robots must establish natural interactions similar to those of humans. Robots must consider social requirements while navigating, like human comfort, needs, and preferences. They must be aware of the surroundings and treat humans differently from objects while navigating. Robot navigation must be predictable and easily understood by humans; only then it will it considered as SARN in real terms. Social robot abilities can be further classified into four types, i.e., avoiding collision, passing humans, following humans, and moving along with humans (Hu et al., 2019), as shown in Fig. 4.

Collision avoidance is established by a social force model that constantly monitors human trajectories and personal space when people approach the robot from the opposite direction. In passing humans, the robot calculates the cost for every trajectory it can select by considering parameters like distance and choosing between a left or right pass when people are stationary. While following individuals in a crowded scenario, the robot carries out navigation by considering a target location and selecting a human leader to follow. Moving along with people is carried out in environments like museums, airports, and so on while taking optimum robot speed and braking into consideration.

On the whole, a detailed knowledge of human representation and space affordances can help to plan effective SARN. A few real-world experiments (Chen et al., 2017; Truong and Ngo, 2017; Vega et al., 2019; Mehta et al., 2016) have been conducted by different institutes in the domain of SARN while taking social conventions into account, as illustrated in Table 2, which reports the study designs, number of participants, and quantities measured during each experiment. Further, it details the type of experiment—i.e., whether it is simulation based or a real-world demonstration—and environment, including the type of surroundings and group space configurations, as discussed in proxemics section. Finally, it also reports the abilities of the robot deployed in the respective experiments, as discussed in the "Social Robot Abilities" section.

Conclusion

The scientific community is working very hard in robotics, and soon it will be a part of our everyday lives. Making robots understand social conventions will play a key role in turning this into reality. This article discusses various aspects of social conventions from the SARN point of view. Furthermore, it gives a brief comparison of SARN experiments considering social conventions that have been conducted by various institutes. Roboticists need to work along with people from other domains of design, artificial intelligence, and psychology to better define social conventions in HRI. Finally, these conventions have to be mapped in a suitable software process to achieve the desired SARN.

TABLE 2. The SARN experiments by different institutes.

INSTITUTE	STUDY DESIGN	EXPERIMENT TYPE	ENVIRONMENT	ROBOT ABILITIES
• Massachusetts Institute of Technology • IBM Research Center (Chen et al., 2017)	Subjects • Many pedestrians Measures • Time to goal • Minimum separation distance	• Simulation • Real world	Crowed, pedestrian-rich environment with movement everywhere	• Avoiding collision • Passing humans • Following humans • Moving along with humans
• University of Brunei (Truong et al., 2017)	Subjects • Three participants Measures • Distance • Human velocity • Robot velocity	• Simulation • Real world	Laboratory room with stationary individuals in various group space configurations	• Avoiding collision • Passing humans
• Universidad de Extremadura • Aston University (Vega et al., 2019)	Subjects • Two participants Measures • Euclidean distance • Crowd density	• Real world	Laboratory room with stationary individuals in various group space configurations	• Avoiding collision • Passing humans
• University of Michigan (Mehta et al., 2016)	Subjects • Nine participants Measures • Relative distance • Robot velocity • Time to goal	• Simulation • Real world	Corridor setting with moving and stationary individuals in various group space configurations	• Avoiding collision • Passing humans • Following humans
• Institut de Robòtica i Informàtica Industrial, Spain (Repiso et al., 2020)	Subjects • Two participants Measures • Distance • Angle • Area	• Real world • Simulation	University campus area	• Collision avoidance • Adapting velocity
• University of Maryland • University of North Carolina (Bera et al., 2020)	Subjects • Eleven participants Measures • Additional time • Performance • Intrusions avoided	• Real world • Simulation	University lab setting	• Classifying pedestrian (happy, sad, angry, and neutral)

Read more about it

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