Light Signaling for Social Interaction with Mobile Robots

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Abstract

To give autonomous mobile robots some kind of "social intelligence", they need to be able to recognize and interact with other agents in the world. This paper describes how a light signaling device can be used to identify another individual and to communicate simple information. By having the agents relatively close to each other, they share the same perceptual space, which allows them to sense or deduce implicit information concerning the context of their interaction. Using a vision- and sonar-based Pioneer I robot equipped with a colored-light signaling device, experimental results demonstrate how the robot can interact with a human interlocutor in a ball-passing game.

1 Introduction

Our research goal is to design autonomous mobile robots that operate in real world settings like in our homes, offices, market places, etc. Robots operating in such conditions require the ability to interact with various types of agents, for instance humans, animals, robots and other physical agents. To do so, they must have some sort of "social intelligence".

According to Dautenhahn [6], social robotics has the following characteristics: 1) agents are embodied; 2) agents are individuals, part of a heterogeneous group; 3) agents can recognize and interact with each other and engage in social interactions as a prerequisite to developing social relationships; 4) agents have 'histories' and they perceive and interpret the world in terms of their own experiences; 5) agents can explicitly communicate with each other; 6) the individual agent contributes to the dynamics of the whole group (society) as well as the society contributing to the individual. Communication is very important in social robotics since it allows to compensate for the inherent limitations of the robots: sensing is imprecise, perception of the environment is incomplete, actions may not always be executed correctly, and real-time decision making is also limited. By having the ability to communicate, a robot can collaborate with other agents to deal with a difficult situation or to accomplish a task, and also acquire information about the environment, unknown to the robot but known by others.

But communication is not enough: robots also need to recognize other agents in the world in order to interact with them. In group robotics, this has been mostly done using IR, explicit radio communication of the positions of the robot obtained from a positioning system (GPS or radio triangulation), and vision [5]. Vision is the most interesting of these methods since it does not limit interaction to specific environments, and it is something that humans and animals have, as for an increasing number of robots. For instance, gesture recognition is a more natural way of communicating that does not involve special modifications of the environment. The problem for the robot is then to be able to visually identify, using simple real-time process, other agents of various shapes, sizes, and types.

One possible solution is to use visual cues such as color to identify other agents. However, confusion may occur if other objects with the same color are present in the environment. In addition, discrimination of the identity of the agents is limited by the number of specific colors or combination of colors that can be detected by the vision system. Colored objects are also subject to variations of the lighting conditions like shadows or influences from other illuminating sources (natural or artificial). To resolve these difficulties, we propose using a colored-light signaling device. Compared to colored objects, a light-emitting system is more robust to lighting conditions in the environment. The coding protocol used to generate signals allows to distinguish another agent from an object (which should not be able to communicate), and the identity of another agent can be communicated to discriminate between individuals operating in the environment. Also, if this coding protocol is simple enough, humans can easily interpret what is being communicated by the robots, and can communicate too if they have a signaling device (a flashlight for example) at their disposal. Finally, by having the agents relatively close to each other, they share the same perceptual space, which allows them to sense or deduce implicit information concerning the context of their interaction.

This paper describes how an autonomous mobile robot can use a visual signaling device to identify and interact with another agent. The robot uses a colored-light signaling device that it can turn on or off according to a coding protocol, to socially interact with a human interlocutor in a ball-passing game. The game is used only to illustrate that some informations do not need to be communicated when agents are able to identify their position relative to one another, and that they share the same perceptual space. The paper is organized as follows. Section 2 explains the approach developed for the ball-passing game with visual communication using a light signaling device. Section 3 presents the experimental setup used for the ball-passing game and observations made during the experiments. Section 4 summarizes the strengths and the limitations of visual communication, followed by related works described in Section 5.

2 Ball-Passing Using a Light Signaling Device

Our experiments are performed on a Real World Interface Pioneer I mobile robot shown in Figure 1. The robot is equipped with seven sonars, a Fast Track Vision System (with a regular camera, not a pan/tilt/zoom camera), a gripper and the visual signaling device (on the right). The signaling device is simply a 12 Vdc bulb controlled using a power transistor connected to one digital output of the robot and to a PWM circuit that affects light intensity. A simple colored piece of paper is put in front of the light, inside a cylinder to limit the diffusion of the signal. An external battery is used by the device so that it does not affect the energy consumption of the robot. The vision system has three channels that can be trained to recognize specific colors. Processing done by the vision system evaluates the position and the area of blobs detected with these channels. The robot is programmed using MARS (Multiple Agency Reactivity System), a language for programming multiple concurrent processes and behaviors [4].

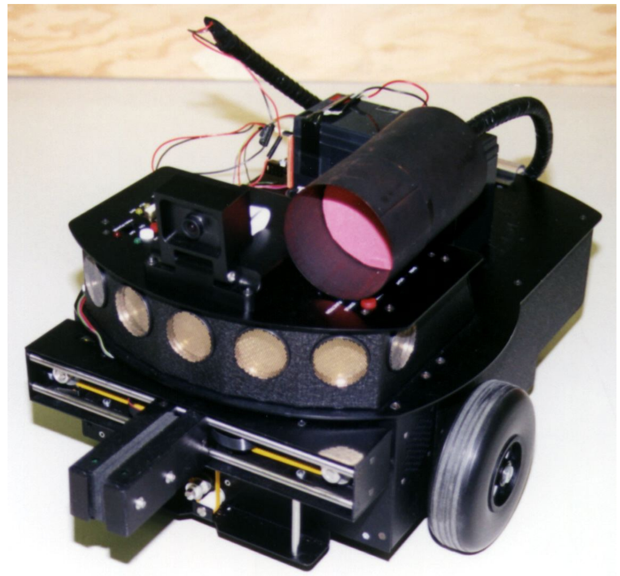

Figure 1: The Pioneer I robot used in our experiments, equipped with the visual signaling device on the right, next to the camera.

To experiment how visual signaling communication can be used for social interactions between two heterogeneous agents, i.e., a robot and a human, we decided to use a simple ball-passing scenario. The robot can be in one of three modes:

1. **Search mode**. When the robot does not have the ball, it searches for it.

2. **Passing mode**. If the robot finds the ball, it continues to move in the environment and signals its intent of passing the ball. When the human interlocutor indicates to the robot that he is ready to receive the ball, the robot communicates the direction of the pass, and makes the pass.

3. **Receiving mode**. If the robot receives an indication that the human interlocutor wants to pass the ball, the robot waits to receive the direction of the pass and goes in that direction.

This scenario is implemented using a behavior-based approach coupled with a *Visual Communication Module* to interpret and encode visual messages. The approach is represented in Figure 2 and is described in the following subsections.

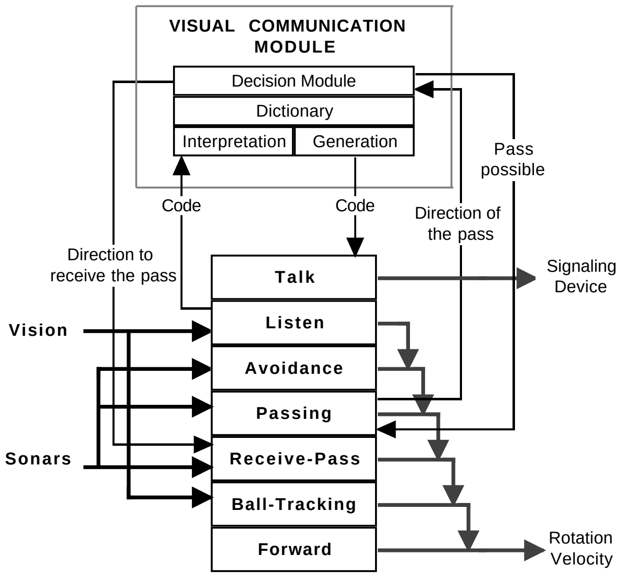

Figure 2: Approach used for ball-passing using visual signaling. Gripper control is done by *Passing* and *Ball-Tracking* and is not represented on this figure.

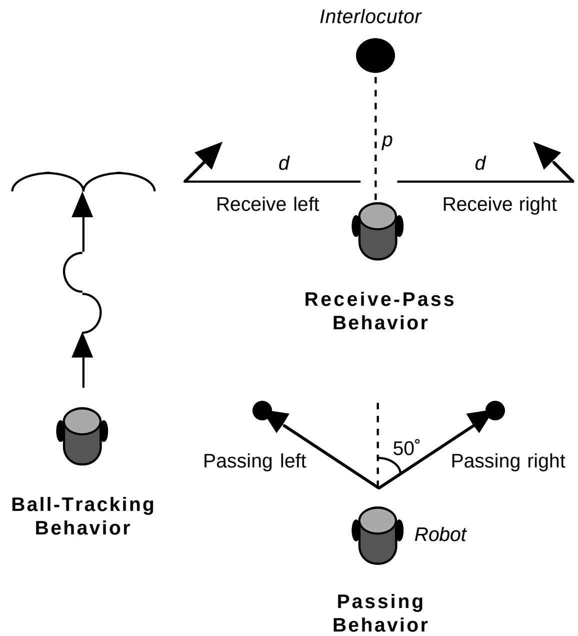

Figure 3: Trajectories generated by *Passing*, *Receive-Pass* and *Ball-Tracking*.

2.1 Behaviors for the Ball-Passing Game

Using Subsumption [3] as the arbitration mechanism, five behaviors are used to implement the behavioral scenario for ball-passing. With *Forward* and *Avoidance*, the robot is able to move forward at a desired speed while avoiding obstacles. The following three behaviors are more specific to the ball-passing game. *Passing* makes the robot pass the ball by turning 50^0 toward the direction less obstructed and by pushing the ball at full speed for one second, and then stop. The direction in question is communicated using the signaling device to the receiver, before making the pass. When a direction to receive a pass is interpreted, *Receive-Pass* evaluates the distance p with the interlocutor (using sonar readings) and calculates the distance d the robot should travel to receive the pass using the formula $d = p \cdot tan(50)$. Finally, *Ball-Tracking* makes the robot repeat a search pattern to find the ball, go toward the ball and grab it using a gripper. Figure 3 represents the trajectories generated by these three behaviors.

The other two behaviors are used for visual signaling. *Listen* is used for positioning the robot in front of its interlocutor by tracking the visual signal. It also perceives and translates the sequence of visual signals into codes made up of short (0.1 to 0.8 sec, represented by [.]) and long (0.9 to 2.4 sec, represented by [–]) signals, with a silence of 0.1 to 1.4 sec in between signals. At the start of each signal, a maximum of 3 sec is allowed for detecting the start of the following signal: when reached, this indicates the end of the code transmitted. Finally, the *Signal* behavior simply turns on (for generating a signal) or off (for making a silence) the signaling device for a certain amount of time according to the code to transmit.

2.2 Visual Communication Module

The *Visual Communication Module* is programmed to implement an encoded message communication protocol [10]: the robot decides to communicate a message; it encodes the message using a dictionary and transmits the corresponding code using the signaling device (via the *Signal* behavior by giving it the code); the listener then tries to decode (also using the same dictionary) the message perceived and determines how it affects its actions. For the ball-passing experiments, only the direction of the pass is required. The message *Left*, encoded [..], indicates that the receiver must go to its right to receive the pass, while the message *Right*, encoded [–.], is for making the receiver go left to receive the pass. The selection of the codes for *Left* and for *Right* is made based on different tests revealing that interpretation performance is better for codes made of short signals and small sequences of signals. This is caused by real-time processing issues of the robotic platform, and not by our algorithm.

The communication protocol implemented operates in half-duplex mode according to four steps:

1. **Communication request**. The signaler indicates its intention of communicating a message by transmitting a 'communication code', turning on the signaling device for 1 sec every 7 sec.

2. **Communication acknowledgment**. When a listener perceives a possible signal, it decodes it. If it recognizes the intent code, the communication code is transmitted back to the signaler.

3. **Message communication**. When the signaler recognizes the acknowledgment from the listener, the *Visual Communication Module* (in the case of the robot) gives the code to transmit to the *Signal* behavior. The interlocutor decodes what is perceived, interprets the code and determines how it influences its behavior.

4. **End-of-communication**. The listener stops listening if: a valid direction is received; an 'end-of-transmission' code [.–] is interpreted; it cannot recognized the code; or that no signal is perceived for 10 seconds. The listener can also decide to stop the communication by sending the 'end-of-transmission' code to the signaler.

3 Experiments

The human interlocutor is equipped with a regular flashlight of about 12 cm in diameter. A cylinder made in black paper also surrounds the flashlight to limit the diffusion of the signal. Red colored signals can be easily trained to be recognized by the Fast Track Vision System, but blue and yellow colors were also recognizable by the robot's vision system. In the experiments reported in this paper, red is the color of the robot's signaling device, while yellow light signals were generated with the flashlight.

The robot is able to perceive signals from the flashlight at a distance of 2.4 m in illuminated conditions (3.2 m in darker conditions), a maximum angle between the robot and the flashlight of $\pm 45^0$ (which is the limit of the field of view of the camera), and a maximum angle of 15^0 for the orientation of the flashlight toward the robot. Note that the perceptual range of the light signal would be very different if a pan/tilt/zoom camera would have been used.

Figure 4: Ball-passing game between a Pioneer I robot and a human interlocutor.

Figure 4 illustrates the ball-passing game between the Pioneer robot and a human interlocutor. An orange ball to play street hockey is used. Several passes were exchanged over more than two hours of testing. During those tests, all the codes communicated were correctly interpreted. This indicates that the implementation is robust to time variations for short and long signals when a human interlocutor communicates using a flashlight. It takes approximately 12 seconds from the time the listener indicates its acknowledgement to an intent signal, and the time the listener takes to interpret the message of the direction to take to receive the pass.

Problems experienced by the robot during these tests were not caused by the communication method, but were more related to the task. It revealed quite difficult to synchronize passing (by the human) and receiving the ball (by the robot). Two strategies were elaborated. The first was to make the robot search for the ball right after it completed its trajectory to receive the pass. About 12% of the passes were correctly received by the robot, the others hitting the side of the robot or going elsewhere in the pen. The second strategies consisted of making the robot stop at the end of the trajectory made to receive the ball. 52% of the passes were then correctly received by the robot, depending on the human's ability to aim the ball toward the robot. So with the first strategy, since the human correctly aims the ball about 50% of the time, the robot would catch the ball once every four passes correctly thrown in its direction. Improving the *Ball-Tracking* behavior by evaluating the trajectory of the ball instead of only using the perceived (x, y) coordinates of the orange blob would result in better performance. Another problem occurs when the robot cannot reach the receiving position because of the presence of an obstacle. In dynamic environment, this problem cannot be prevented and the only thing left to do for the robot is to start searching for the ball. On the bright side, the robot is then oriented in the right direction to search for the ball.

4 Strengths and Limitations of Visual Signaling

Compared to other communication medium like radio link or other electronic media, visual signaling communication has obviously important limitations in range and bandwidth. Also, since electronic communication methods are usually not motion-related (i.e., communication does not require particular positioning of the robot) [7], they do not impose any constraints on the proximity of the interlocutors and their position relative to each other. But the primary reason of using visual communication is not the same as with electronic mediums: it is not the amount of data exchange but the importance of the information gathered during the communication act. The fact that agents are able to recognize each other and share the same perceptual space helps establish the context of the communication without having to communicate a complete description of the situation. Agents can perceive additional information not communicated about what is actually experienced by the interlocutor. This makes it less important to have high bandwidth capabilities. Low bandwidth may even be considered an advantage for robots since it requires less processing load. Balch and Arkin [2] already established that complex communication strategies offer little benefit over simple ones. In human society, visual signals are used in various situations: signaling the intentions of a driver to stop, turn, etc.; traffic lights; semaphore and morse code, etc. In these examples, without telepathic ability (which can be related to robots using electronic medium to communicate), humans cannot communicate directly with each other, and these simple methods allow them to do so and help manage their social interactions. The fact that visual signals can also be used as a simple way to make robots recognize other physical agents and discriminate them is another advantage justifying our research.

5 Related Work

The use of visual signaling for communication has been studied by few researchers, and only in simulation. Wang [12] presents a low bandwidth message protocol using "sign-board" communication, displayed by a device on each robot and perceivable only by nearby robots [1]. The sign-board model is a decentralized mechanism and is considered a natural way of interaction among autonomous robots [12]. Murciano and Millan [9] also present a learning architecture for multi-agent cooperation by using light signaling behaviors. Balch and Arkin [2] discuss how a conic mirror camera and marker lights can enable robots to discriminate between other robots, attractors and obstacles. But again, no experimental results with physical robots are reported.

With simulation environments, the effects of constraints such as limitation of the field of view, lighting conditions, positioning of the robots, interpretation time and the dynamics of real-world environments cannot be adequately taken into consideration in the communication process. Our work makes it possible to investigate the feasibility of implementing such approaches on actual robots. Using a light signaling device to implement the work of Steels [11] on emergent adaptive lexicon would be an interesting research topic. In previous work [8], we have shown how a human interlocutor can issue requests that affect the goals of a robot, again by using a light signaling device for visual communication. The human interlocutor was the one that mostly initiated communication by asking the robot to do specific tasks. The robot only initiated communication when it was not able to get out of a difficult situation. The experiments reported in the current paper present a more interesting situation in which both the robot and the human interlocutor can initiate communication. The approach uses a simpler communication protocol with a dictionary of three words instead of seven, and in which the listener does not wait for an 'end-of-communication' code to take action. The robot also considers the distance with the interlocutor to make a pass, as sensed by its sonars. This demonstrates how implicit information not communicated can be taken into consideration when physical agents can identify each other and share the same perceptual space.

6 Summary and Conclusions

The principal benefit of the approach presented in this paper is that visual signaling can be an interesting way of explicitly communicating simple information to others, and at the same time be a rich source of implicit information, i.e., information gather directly from the observation of others [2], for recognizing and interacting with physical agents. Even though it has low bandwidth, the signaling protocol allows to discriminate potential interlocutor with other entities that have the same color of the light signal. Simply by flashing a colored light to encode messages, we have shown that a robot can acquire information from and gives indications to other agents. It also contributed to the believability in the autonomy of the robot, and we actually enjoyed communicating with the robot this way, from any location in the operating environment. No complex devices or pre-engineering of the environment are required. The ball-passing game used in our experiments demonstrates how visual signals can be useful to generate social behavior between a robot (an embodied agent) with a human (also embodied but heterogeneous compared to the robot). In addition of detecting the presence of a receiver and transmitting the direction of the pass, the communication device allows both interlocutors to share the same perceptual space. By being close to the human, the robot is able to use the distance between itself and the interlocutor to calculate the trajectory to receive the pass. This implicit information extracted based on the communication signal decreases the amount of explicit information to transmit.

Other natural communication methods can be used to generate human-robot interactions. Communication between humans is multimodal and can be non-verbal (e.g., visual cues) or verbal (e.g., speech). In future work, we want to used multimodal communication methods in a group of mobile robotic platforms, to study how visual signaling for recognition and identification of the interlocutor can complement electronic methods for high bandwidth communication.

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