An Exploratory Study of Group-Robot Social Interactions in a Cultural Center

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***Abstract*— This article describes an exploratory study of social human-robot interaction with the experimental robotic platform MASHI. The experiences were carried out in La Bòbila Cultural Center in Barcelona, Spain to study the visitor preferences, characterize the groups and their spatial relationships in this open and unstructured environment. Results showed that visitors prefers to play and dialogue with the robot. Children have the highest interest in interacting with the robot, more than young and adult visitors. Most of the groups consisted of more than 3 visitors, however the size of the groups during interactions was continuously changed. In static situations, the observed spatial relationships denotes a social cohesion in the human-robot interactions.**

I. INTRODUCTION

As robots are increasingly closer to the activities of daily living, making their way towards the so-called social robot, they must have the ability to communicate with people closely and fluid [1] both in verbal and non-verbal way.

Social human robot interaction (sHRI) experiments in natural environments are scarce due to technical difficulties to match execution times for robot skills and that expected interaction time from the user side. Therefore, it is usual in the study of sHRI the use of robotic telepresence platforms [2] as well as robots using Wizard-of-Oz techniques to simulate autonomous intelligent systems [3].

Moreover, social and service robots present several challenges when evaluating sHRI in open field. In open environments (e.g. museums or malls), it is expected that many people of a wide range of profiles – ages, familiarity to technology – will interact with the robot [4]. The interaction with the robot is not supposed to be necessarily one-to-one but with groups – static or walking groups – of different sizes, social density is variable, places are often crowded, and not always people behave cooperatively (e.g. sometimes explore the boundaries of the system [5] and deliberately interfere the robot's performance). In these open environments, robotic museum guides like MINERVA [6], ROBOVIE [7] and REEM [8] do quite well in addressing people and keeping their attention. However, interaction between robots and humans is still limited due to the highly challenging environment.

Some techniques exist in the literature to evaluate HRI in an automatic way [9], [10]. However they present difficulties for use in natural and complex environments. From psychology, use of questionnaires is very usual for assess the HRI [11], but its use is limited basically to one-human-one-robot interactions. From social psychology, direct observation techniques can be valid tools for the study of HRI in natural environments, allowing an objective and ecological exploration of interactive behavior [12], [13].

In this paper we perform an exploratory study in order to evaluate HRI in a natural environment, La Bòbila Cultural Center, using observational methods to explore group preferences, their description and their spatial arrangements when interacts with the robot.

The remaining paper is organized as follows: The background of relevant concepts to evaluate HHI and related research in sHRI is given in the next section. In Section III the exploratory study is detailed. Results and discussion are exposed in Section IV. Conclusion is finally exposed in Section V.

II. BACKGROUND

Social robots as physical entities that co-inhabit a place with people in HRI (eventually, sHRI) are involved in what is known as *spatial relationships* [3], [2]. Spatial relationships are a combination of distance, relative position and spatial arrangement that occur naturally whenever two or more people engage in an interaction [14] and convey significant and relevant social information (e.g. how each of them is involved) and also define an interpersonal space for developing activity.

Many disciplines can contribute to our understanding of spatial relationships in HRI in open and crowded natural scenarios. Below relevant concepts such as proxemic behavior, F-formations and group behavior are introduced and discussed for their possible significance in HRI.

A. *Proxemic Behavior*

The term *proxemics* was introduced by anthropologist Edward T. Hall in 1966 [15] to refer to *"the interrelated observations and theories of man's use of space as a specialized elaboration of culture"* [ibid, p. 1]. In this regard, Hall defines 4 kinds of interpersonal distances, each with

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its own significance in a social context: intimate, personal, social and public. These interpersonal distances may vary depending on culture. Appropriate distances found by Hall in western culture for adults are displayed in Table I.

TABLE I: Interpersonal distances by Hall.

Distance	Value (meters)	Reserved for...
Intimate	$0 - 0.45$	Embracing, touching, whispering
Personal	$0.45 - 1.2$	Friends
Social	$1.2 - 3.6$	Acquaintances and strangers
Public	> 3.6	Public speaking

B. F-formations

The *F-formation* system was proposed by Adam Kendon [16] to study the spatial structures, both in position and orientation, that are generated when two or more people interact and affirm that *“behaviour of any sort occurs in a three dimensional world and any activity whatever requires space of some sort ”* [ibid, p. 1.] This space allows an organism to perform any activity and is differentiated from other spaces [14]. According to Kendon, in any scenario is common that several individuals are co-present, but the way they are positioned and oriented in relation to the others reflects directly how they can be involved together. Based on his observations, Kendon finds a transactional space, known as o-space, defined as the space where people can interact and manipulate shared objects. In dyadic interactions, Kendon observed two types of formations: ’vis-a-vis’ (individuals who are facing one each other) and ’L-shape’ (individuals are standing perpendicularly to each other facing an object). When the interaction occurs between two or more people, Kendon observed three types of formations: ’circular form’ (when all people are looking each other), ’side-by-side’ (when people stand closely together and facing the same segment of the environment), and horseshoe shape (a kind of compromise between side-by-side and circular form). There are also typical spatial arrangements of occasions where there is an unequal distribution of rights to start a conversation or action, for example, in the ’performer-audience’ interaction. When a group of people do not have any spatial arrangement between them is known as ’cluster’.

Empirical studies in robotic applications have identified the management of spatial relationships between people and robot as a main issue in order to improve the quality of interaction taking into account that interpersonal distances convey significant and relevant social information[2]. An interesting conclusion is that when physical constraints (e.g. narrow passages) in combination of navigational requirements unable the robot to maintain the convenient spatial behavior, it can compensate this situation with other interactive behaviors (e.g. verbally apologizing for an inappropriate distance or reducing the eye-contact) to maintain an overall degree of desired intimacy.

C. Group Behavior

An interesting approach related to spatial relationships, but in crowds of pedestrians, was conducted in [17]. In this work, the group behavior is analyzed from a socio-psychological perspective in terms of groups, the basic elements which the crowd is composed of, and proxemics, chosen as an analytical indicator of spatial behavior dynamics within the crowd. Based on the observations of proxemic behavior of walking groups, the work focused on: spatial arrangement (degree of alignment and cohesion, e.g. line-abreast, v-pattern and river-like), walking speed, level of density, group size and gender.

III. THE IN-FIELD STUDY

A. Objective

The main goal was to observe *in the wild* social human-robot interactions with a guide-robot in the context of a cultural center. Our research questions related in this context can be expressed as:

- What is visitors’ preferred use?
- What are the characteristics of people who interact with the robot in this social scenario?
- What is the spatial arrangements of groups while interacting with the robot?

B. Method

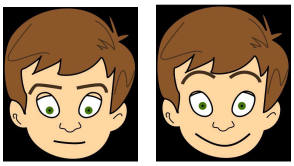
1) The robot: Mashi is an experimental robotic platform for social human-robot interactions research. With an anthropo-morphic and lightweight structure, the robot is 1.5 m tall and weighs about 15.0 Kg. The upper part of the robot comprises a torso and a motorized head with yaw, pitch and roll movements (Fig. 1a). The front of the head features a 7” inches wide angle display that serves to show an animated face (i.e. eyebrows, eyes and mouth), as seen in Fig. 2 to support non-verbal communication by its facial expressions. At the torso level the robot has a stereo speaker and a microphone. The mobile base has 2 degrees of freedom, with two powered wheels and two caster wheels for its stability. In this study, Mashi attempts to move at 0.16 meters per second and seeks to turn at 0.74 radians per second. The robot is endowed with two webcams, one just above the robot’s monitor coupled with a fish-eye lens to give a panoramic front view and one at the top with an omnidirectional lens to have a panoramic 360 degrees view. In the operator’s side, the teleoperation system is developed under the WebRTC platform, which allows a full-duplex and real-time communication of both audio, video and data (Fig. 3). The operator could move the robot base back and forth and rotate left or right, make pitch, yaw and roll head movements, and play music, using the keyboard or buttons in the interface. The teleoperator room was just next the main hall in a private room inaccessible for visitors(Fig. 1).

2) Scenario and setup: La Bòbila Cultural Center, in L’Hospitalet-Barcelona, is a three floor building containing multiple facilities for education and leisure: a library, an auditory, different rooms for lessons and other activities and a hallway with temporary exhibitions.

The robot was deployed in the main hall, an area of about 8 meters wide and 6 meters long near the main access from the street (see Fig. 1b and Fig. 4).

(a) The MASHI robot (b) Main hall at La Bòbila

Fig. 1: Robot and scenario.



(a) Neutral (b) Happy

Fig. 2: Robot facial expressions examples.

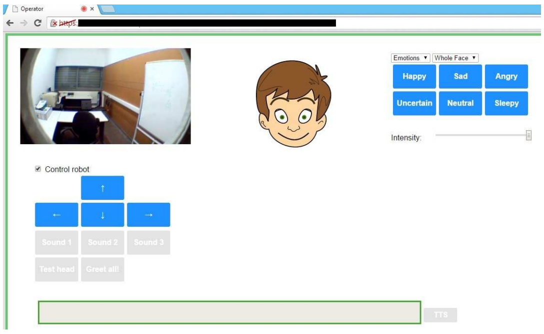


Fig. 3: Operator interface.

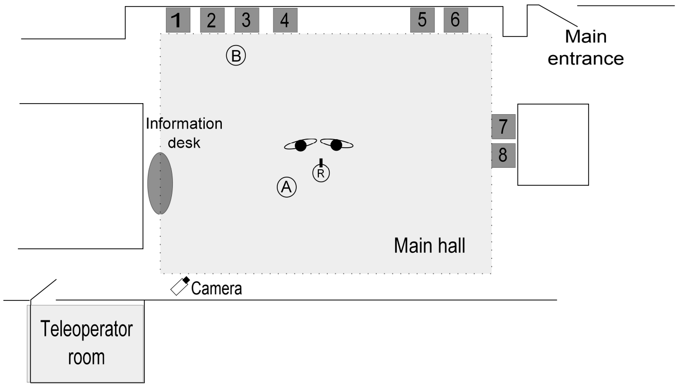


Fig. 4: Layout of the Hall showing the robot.

Two locations (A and B) were defined as the main possible destinations. Point A is the initial location of the robot in the center of the hall and in front of the information desk. Point B represents the exhibition guiding area, comprising eight works of jewelry (see Fig. 4).

The field study was carried out from 14th to 30th April for about 2 hours per day at the evenings (from 19:00 to 21:00) coinciding with a temporal exhibition of jewelry called "2". No adaptation of the physical environment was implemented to maximize the study ecological validity preserving the natural every-day conditions and routines except from a zenital camera placed in the second floor out of sight of visitors at a height of approximately 3m in order to have an aerial overview covering the observed area (Fig. 4)

3) Procedure: The robotic platform was used in a Wizard-of-Oz setup thus the robot's head movements,displacements, dialogues with visitors and interections where totally teleoperated by the operator that remains out of visitors? sight inside the operator room.

According to its role the general function of MASHI is to enrich visitor's experience by exhibiting itself as an attraction, providing entertainment and eventually guiding through the exhibition. The robot's role is deployed in three activities: dialogue, guidance and entertainment. Initially the robot is in a predefined position and on standby mode. Once visitors have got robot's attention, the robot greets visitors and, according to a script, it offer's guidance and information or otherwise offer to play or to engage in a placement (as seen in Fig. 5).

Taking as an example a guided exhibition (see Fig. 6), in the first instance the robot is in a standby state (i.e. robot starting position and facial expression sleepy)(Fig. 6a). Once one or more visitors come to the robot, it changes to Welcome mode (i.e. neutral facial expression and utters an spoken message of welcome) (Fig. 6b). In the case of people wishing the exhibition guide service, the robot will tour and explain each exhibit case (Fig. 6c-6f). Once the tour is completed, the operator ask visitors if they want guidance again or if they wish to play or have any questions. If any further service is requested, the robot say goodbye and return to its point of departure (Fig. 6g-6h).

No briefing or instruction was given to visitors, and the intervention of technical staff at the local environment was exclusively aimed at recovering the robot for eventual breakdowns and discouraging misuse to enhance people safety and to prevent robot's damage.

C. Measures and coding behavior

All the session were continuously video-recorded and the video source downloaded and stored daily for further processing and analysis to characterize visitors? groups (i.e. size and composition) and their spatial relationships.

Therefore, all the measures were estimated. Due to the imprecise nature of estimation, the measures were expressed in categories (see Table II). The identification of group description and spatial relationship in the images was performed using human interpretation of non-verbal communication such as body orientation, gestures and group spatial cohesion.

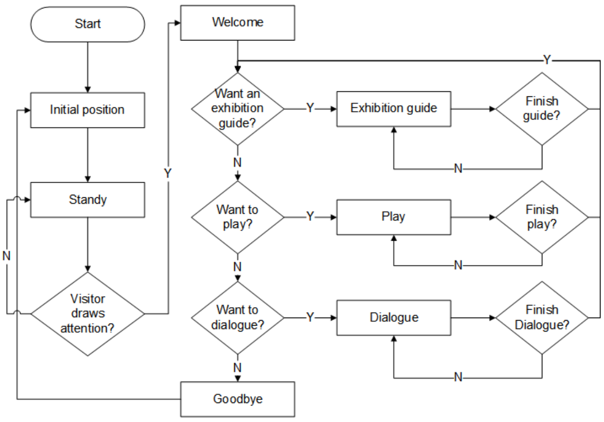


Fig. 5: Flowchart of robot’s role.

For data analysis only it took into account the recordings of six days of the zenital camera, with a total of about 480 minutes of recording. The analysis of the episodes were made by a single coder.

TABLE II: Group characterization and spatial relationships.

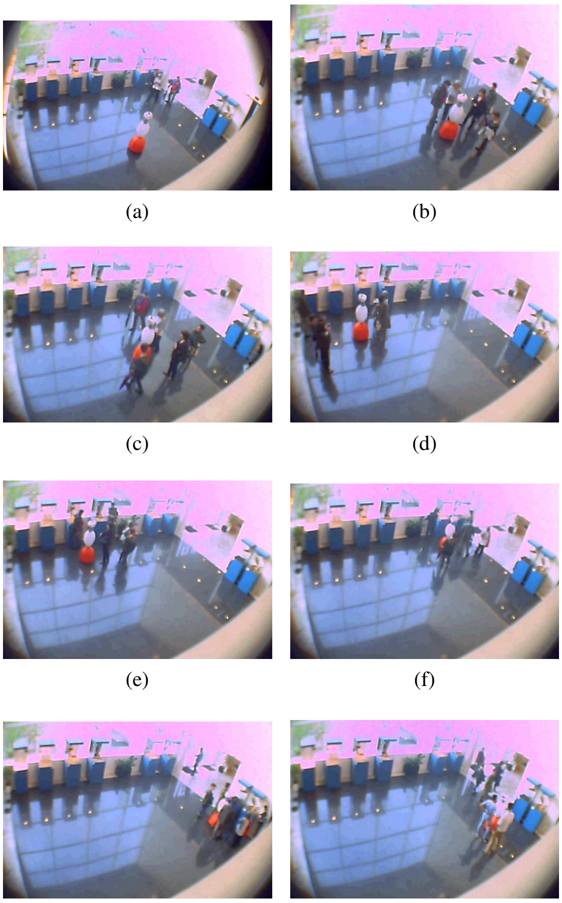
Dimensions	Variables	Categories
Group characterization	Size	Single Couple Triple Larger
	Composition	Children Young Adults Mixed
Spatial relationships	F-formations	’Via-a-vis’ (dyadic) ‘L-shape’ (dyadic) ‘Circular form’ ‘Horseshoe shape’ ‘Side-by-side’ ‘Performer-audience shape’
	Proxemic behavior	Intimate Personal Social

IV. RESULTS

From the observed data, 32 human-robot interactions or episodes were detected with a total time 325 minutes approximately, representing an occupancy rate of 67.7% of the total time that the robot was in the hall.

It should be noted that given the dynamics of the interaction in this public setting, you can see different compositions of groups and spatial relationships within the same episode, for what the percentages below reflect a degree of occurrence for each behavior.

A descriptive analysis of data showed that 38.9% of visitors prefer to play with the robot, 36.1% prefer to maintain a dialogue, and the 25.0% prefer the robot as an exhibition guide (see Figure 7 and Table III).



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 6: An exhibition guide episode example.

TABLE III: Visitor’s preferences

Item	Occurrences	Percentage
Play	14	38,9%
Dialogue	13	36,1%
Exhibition guide	9	25,0%

Concerning the group composition, 69.7% of groups that interact with the robot were children, 12.1% were young, 15.2% were adults and 3.0% were a mixed group composed by children and young visitor’s. Talking about the group size, 15.6% of the people interact alone with the robot, 3.1% interact in triples, 56.3% interact in larger groups and 25.0% interact in mixed group’s size (see Table IV).

Visitors who interact alone with the robot were 9.1% children, 3.0% were young and 3.0% were adult; triples were 3.0% children. Larger groups were composed by 36.4% children, 6.1% young, 12.1% adults and 3.0% mixed ages. Mixed group sizes were formed by 21.2% children and 3.0% young visitors (see Table V).

F-formations encountered during interactions, the dyadic ‘vis-a-vis’ and ‘l-shape’ arrangements were observed at 17.6% and 2.0% of the interactions, respectively. ‘Circular form’ was observed at 49.0%, ‘horseshoe shape’ at 13.7%, ‘performer-audience’ distribution at 9.8%, while the 7.8% were ‘side-by-side’ arrangements (see Figure 8 and Table VI).

Regarding the proxemic behavior, 26.8% of interactions were in the intimate space, 53.7% were in the personal

(a) Playing (b) Dialogue (c) Exhibition guide

Fig. 7: Interaction preferences.

TABLE IV: Group Composition

Item	Occurrences	Percentage
Children	23,00	69,7%
Young	4,00	12,1%
Adults	5,00	15,2%
Mixed	1,00	3,0%

space while 19.5% were in the social space (see Table VII). Examples can be seen in Figure 8.

V. DISCUSSION

Due to the highly dynamic nature of this open environment, the groups formed during interactions could continuously change both in structure and their behavior. The changes observed in groups during interactions were given mainly in their size, their spatial arrangements and their proxemic behavior. It was observed, however, that during interactions the group age don't vary substantially. For example, if a group of children initiated the interaction, although it could vary their dimension and spatial behavior, usually the age group was maintained until the end of the interaction.

Unlike the results obtained in [18], where several arrangements were observed during displacements, in this study were few occasions when some kind of spatial arrangement was detected in the exhibition guide. Two factors that can influence this issue could be physical constraints of the environment and the reduced robot's speed. In this context the masterpieces of the exhibition were very close to each other, and when the robot began to move slowly compared to the visitors speed was evident the next position of the robot; so the groups were often ahead to that position.

TABLE V: Group composition vs. group size

	Size					
	Single	Couple	Triple	Large	S+C+T+L	**Total**
Children	3 (9,1%)	0 (0%)	1 (3%)	12 (36,4%)	7 (21,2%)	23 (69,7%)
Young	1 (3%)	0 (0%)	0 (0%)	2 (6,1%)	1 (3%)	4 (12,1%)
Adult	1 (3%)	0 (0%)	0 (0%)	4 (12,1%)	0 (%)	5 (15,2%)
Mixed	0 (0%)	0 (0%)	0 (0%)	1 (3%)	0 (%)	1 (3%)
Total	5 (15,2%)	0 (0%)	1 (3%)	19 (57,6%)	8 (24,2%)	33 (100%)

TABLE VI: F-formations

Item	Occurrences	Percentage
Vis-a-vis	9	17,6%
L-shape	1	2,0%
Circular form	25	49,0%
Side-by-side	4	7,8%
Horseshoe shape	7	13,7%
Leader	5	9,8%

TABLE VII: Proxemic behavior

Item	Occurrences	Percentage
Intimate	11	26,8%
Personal	22	53,7%
Social	8	19,5%

(a) (b) (c)

(d) (e) (f)

Fig. 8: Several spatial arrangements: (a) 'vis-a-vis', (b) 'circular form', (c) 'horseshoe shape'; and proxemic behaviors: (d) intimate, (e) personal, and (f) social distances.

VI. CONCLUSIONS

An exploratory study on group-robot interaction in the context of a Cultural Center was carried out in order to observe visitor's preference, their characteristics and their behaviors.

The robot succeeded in developing roles as an exhibition guide, playing with people and maintaining dialogues, using wizard-of-oz technique. 32 interactions were observed and analyzed. The analysis was focused on visitor's as a groups more than as an individual. Groups were described according to their age and size, while the behavior were analyzed in terms of f-formations and proxemic behavior. Observational methods applied to evaluate group-robot interaction provide fruitful insight to understand the group-robot interaction by means of spatial relationships.

Future work includes analyze the interactive behavior that visitors shows when interact with robot, which can includes eye contact, smiles and greetings.

APPENDIX

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TABLE VIII: Episodes sequence coding

Episode	Time (hh:mm:ss)	Preferences[1]	GroupSize	Composition	Spatial arrangements[2]	Proxemics
1	0:14:44	g	couple, larger	children	c,h, le	personal
2	0:01:01	d	larger	adult	c	personal
3	0:07:52	g	larger	adult	h, s	social
4	0:06:45	g	triple	children	c,h, s	personal
5	0:03:32	d	larger	children	c	social
6	0:09:51	p	triple, larger	children	c, le	intimate
7	0:10:52	d	triple, larger	children	c	intimate, personal
8	1:18:10	p,d	larger, single	children	c, le, v	intimate, personal
9	0:00:19	d	single	adult	v	social
10	0:04:10	d	larger	children	c	intimate
11	0:02:30	d	single	children	v	social
12	0:02:45	g	larger	children	le	intimate, personal
13	0:43:46	d,p	larger	children, mixed	c, le	intimate, personal
14	0:02:24	p	larger	young	c	social
15	0:11:45	g	larger	adult	c, h	social
16	0:09:13	g, d, p	couple, single	young	c,v	personal
17	0:07:49	g	larger	children	c, h	intimate, personal
18	0:02:39	p	larger	children	c	personal
19	0:04:42	g	single/triple	children	v, s, h, c	intimate, personal
20	0:07:20	p	larger	children	c	social, personal
21	0:34:24	p	larger	children	c	personal
22	0:10:40	p	larger	children	c	intimate
23	0:07:13	d	single	children	v	personal
24	0:00:47	d	single	young	v	personal
25	0:12:09	p	single/couple	children	v	personal
26	0:02:04	p	larger	adult	c	social
27	0:05:27	p	larger	children	c	personal
28	0:09:06	g	single	children	v, s, l, c, h	personal
29	0:03:58	p	larger	children	c	personal
30	0:01:00	p	larger	young	c	personal
31	0:03:33	d	larger	children	c	intimate, personal
32	0:02:36	d	single, triple, larger	children	c	intimate, personal

[1] Preferences: (g)uide, (d)ialogue, (p)lay music/game

[2] Spatial arrangements; (v)is-a-vis, (l)-shape,(c)ircular form, (s)ide-by-side, (h)orseshoe, (le)ader, (cl)uster

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