Modeling human-like robot personalities as a key to foster socially aware navigation

Modeling human-like robot personalities as a key to foster socially aware navigation *

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Abstract—**This work aims to investigate if a "robot's personality" can affect the social perception of the robot in the navigation task. To this end, we implemented a dedicated human-aware navigation system that adapts the configuration of the navigation parameters (i.e. proxemics and velocity) based on two different human-like personalities, extrovert (EXT) and introvert (INT), and we compared them with a no social behavior (NS). We evaluated the system in a dynamic scenario in which each participant needed to pass by a robot moving in the opposite direction, showing a different personality each time. The Eysenck Personality Inventory and a modified version of the Godspeed questionnaire were administered to assess the user's and the perceived robot's personalities, respectively. The results show that 19 out of 20 subjects involved in the study perceived a difference among the personalities exhibited by the robot, both in terms of proxemics and velocity. Furthermore, the results highlight a general preference of a complementary robot's personality, helping to suggest some guidelines for future works in the human-aware navigation field.**

I. INTRODUCTION

Personality has been defined as a coherent pattern of behaviors, affects, and cognition processes [1]. It is considered a core element to predict and understand human behavior [2]. Indeed, personality traits could affect the way people interact with others in social settings [2]. Due to its importance, robotic systems should be incorporated with social intelligence that allows them to comprehend the user personality and to adapt their behavior accordingly. Among the human-adaptive behaviors that a robot should exhibit, social navigation must be included. As compared to traditional autonomous navigation, which allows the robot to reach the goal by indiscriminately avoiding obstacles, social navigation aims to navigate in the environment considering human sociability, naturalness, and comfort [3]. As mentioned in [4], most of the studies on human-aware navigation focused on the robot's distance from individuals to shape a socially acceptable navigation task. These studies have benefited from the work of Hall [5], who theorized that the relative distances between people (i.e. proxemics) are dictated by 4 proximity zones: public (> 3.6 m), social (from 3.6m to 1.2m), personal (from 1.2m to 0.45m), intimate (< 0.45m). The dimensions of these zones are dynamic, depending on several factors, among them the personality traits of the individuals [5]. In the human-robot context, despite the expectation that some of the robot's characteristics (i.e. appearance, shape, height, voice) may influence the proxemics [6], previous studies demonstrate that individuals share spaces similarly both in the presence of a robot and when another person is present [7]. The works described in [6], [8], [9] analyzed the relationship between a human's personality and proxemics in human-robot interaction. Namely, they aimed to determine the optimally comfortable distance at which a robot should stop when approaching a person based just on personality [6], [8] or personality in tandem with user activity [9]. These works proved that extroverted people (who like social interactions) may prefer a closer distance to the robot than introverted people (who don't like social interactions) [2]. As described in [6], the proxemics of the people strongly depends not only on the personality traits but also on personal experiences with robots and pets. In these previous works, the robot was maneuvered in a Wizard-Of-Oz paradigm (WoZ) with the user stationary at a fixed location and ready to explicitly stop the robot by voice command (static scenario).

Based on these findings, our study aims to investigate human-robot proxemics from a different perspective. On one side, we investigate the role of the user's personality and his/her previous experiences in a more realistic and dynamic scenario in which both human and robot are moving in opposite directions. On the other side, we overcome the Wizard-Of-Oz method by implementing different human-aware navigation modalities on-board. Based on the insight of proxemics studies [5]–[7], [10], we associated two different personalities to the robot behavior, extrovert (EXT) and introvert (INT), and we compared them with a no social behavior (NS). We understand the words introvert and extrovert are broad and have several definitions; when we use those words in this paper related to the robot, we are specifically referring to the characteristic of spatial motion (i.e. extrovert tends to pass closer to people, while introvert chooses to keep a distance). Different from previous works which implemented robot's personalities through speech prosody and body movements [2], the personalities of our robot are characterized by varying robot-human distances only. The main aim of this study is to associate the robot with a human-like personality and to investigate whether the personality could implicitly explain the behavior of the robot to the people populating the environment due to its resemblance with their attitudes. This design allows us not

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only to check if the individuals recognize the personality of the robot, but also to investigate the user-robot personality matching. The research questions of this study can be summarized as follows:

- RQ1: Can the personality of a robot be expressed in terms of proxemics in a navigation task?
- RQ2: Does the human-like personality of the robot affect people's perception of the robot ?
- RQ3: Is the people's perception of the robot influenced by their personality traits and/or other factors (e.g. personal experiences)?
- RQ4: Do people prefer that personality of the robot which matches their own?

The paper is organized as follows: Section II describes the robot and the implemented system. The experimental setting, the specifications on the participants, and the evaluation methods are reported in Section III. Sections IV and V describe the data analysis and the results, which will be discussed in Section VI.

II. SYSTEM OVERVIEW

The robot used in this study is CloudIA robot, designed by DIDA Lab (University of Florence, Italy). The robot is mounted over the MoVeR1 platform (Co-Robotics, Italy), a two-axle autonomous vehicle with two front driving wheels and two rear omni-drive wheels. The dimensions of the robot base are 49x75x43 cm. As shown in Fig. 1, CloudIA is a ROS-based robot capable of autonomously navigating in the environment by following the approach described in [11], which utilizes the ROS navigation stack. The 2D occupancy grid map of the environment is built using the SLAM algorithm [11] which takes as input the laser and pose data collected by the robot. The global planner uses Dijkstra's algorithm is used by the global planner to find the optimum path, while the Trajectory Rollout algorithm [12] is used as the local motion planner.

The human-aware navigation was implemented by integrating the *social_navigation_layers* package described in [13]. It is a layered approach, which works by overlapping several costmaps which are semantically separated. Namely, each costmap tracks one type of obstacle or constraint [13]. In the present study, the obstacle, inflation, and proximity layers were added to the 2D occupancy grid map. The obstacle layer collects data from the laser and places obstacles on the map. It is useful to determine the free space on the map. The inflation layer inserts a buffer zone around each moving and fixed obstacle marked as lethal. The proximity layer adds a cost with Gaussian distribution [14] around the detected people which makes paths closer to a person less probable to be chosen, thus discouraging the robot to get too close to the person. In the present study, the *people_tracker* package [15] was used to detect a person from the laser scan data.

B. *Robot's personalities*

We endowed the robot with a no social navigation modality (NS) and two personalities: extrovert (EXT) and introvert (INT). The personalities of the robot were obtained

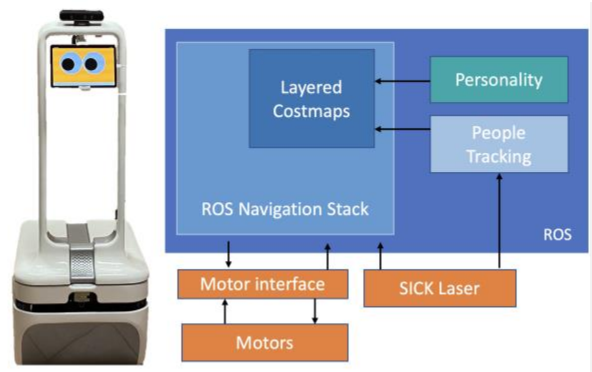


Figure 1 Robot CloudIA and system architecture.

by configuring the navigation parameters. In the NS case, the proximity layer was deactivated while only keeping the obstacle and inflation layers. It allowed the robot to detect a person only as a moving obstacle and to behave with no social intelligence. To enforce this behavior, we set the inflation radius to 40 cm, which was a bit greater than half of the maximum length of the robot's base. To avoid any collision or dangerous situations, we limited the maximum velocity of the robot to 0.2 m/s. Extrovert and introvert personalities were obtained by decreasing the inflation radius to 10 cm, activating the proximity layer (along with obstacle and inflation layers), and tuning the amplitude and the covariance of the 2D Gaussian distribution. The EXT case was characterized by a narrow and tall Gaussian shape (amplitude: 130, covariance: 0.15), to allow the robot to pass by the moving person at a shorter distance (i.e. to mimic the human social behavior described in [2]). On the contrary, the INT case was characterized by a wide and short Gaussian shape (amplitude: 60, covariance: 0.60) to increase the avoiding distance from the person. When exhibiting the EXT and INT personalities, the trajectory of the robot changes according to the participant's motion. While in the EXT case, the path is characterized by slight curvatures, the INT navigation mode is characterized by large curves, which makes the robot most avoid crossing the participant's path. Both avoiding distances allowed the robot to traverse the social zone [5]. In both cases, the maximum velocities were kept low due to safety issues (i.e. 0.15 m/s in the EXT behavior and 0.25 m/s in the INT behavior).

III. EXPERIMENTAL SETTING

A. *Procedure*

The system has been evaluated in a dedicated experimental session that took place in one room of the BioRobotics Institute. The procedure was composed of 3 phases. The first phase (Ph0) consisted of bringing the participants into the experimental space and asking them to fill out a demographic form and a personality questionnaire, which will be explained in subsection III.B. At the end of this phase, the experimenter sat on one side of the room (Point C) and explained the robot's functionalities to the participants. To avoid any bias, the experimenter advised the participants that the experiment was about testing different navigation tasks, without mentioning the robot's personalities. During the second phase (Ph1), the experimenter asked the participants to walk towards the robot starting from point B. During this task, the participants were free to walk at their normal speed and to stop at a comfortable distance from the robot, which was stationary at point A. The third phase (Ph2), called the dynamic scenario, was composed of 3 tasks. In the first task, the participants were asked to walk from point B to point A while the robot was commanded to navigate to point B while exhibiting the NS personality. During the second task, the participants were instructed to walk from point A to point B, passing by the robot, moving in the opposite direction while exhibiting the EXT personality. As final task, the participants walked from point B to point A passing by the robot, which showed the INT personality. Once the final phase was completed, the experimenter conducted a brief interview. Each participant was rewarded with a snack at the end of the experimentation.

B. *Questionnaires*

During Ph0, a revised socio-demographic questionnaire was administrated. Since we were also interested in participants' past experiences with robots, we included the following questions taken from [16]: "Do you have any experience interacting with robots?", "Please, specify what kind of experience you have with robots (if any) [as a participant in another experiment, observer, developer, researcher, not at all]". The participants could answer the first question on a 5-point Likert Scales, where 1 corresponded to "not at all" and 5 corresponded to "very much". Additionally, we included a question about previous experience with pets ("Have you ever had a pet?") with three possible choices ("Yes, in the past", "Yes, in the present", "No"). These additional details helped us to investigate the influence of additional characteristics on the proxemics in the navigation task (RQ3). To evaluate the participant's personality, we used the Eysenck Personality Inventory (EPI) [17]. Even if this self-report questionnaire could assess "high" and "low" level of extroversion and neuroticism dimensions, in this work, we just focused on the extrovert dimension. Namely, high values in extroversion are associated with a social, carefree, and optimistic personality, while low scores are generally associated with a quiet, introspective, and reserved one.

To assess the perceived personality, we administered a modified version of the Godspeed questionnaire (GQ) [18]. The Godspeed questionnaire aims to measure five key concepts in HRI: anthropomorphism (ANT), animacy (ANI), likeability (LIK), perceived intelligence (PEI) and perceived safety (PES). The modified version, administered in your study, included three additional dimensions described in [19]: emotion (EMO), social intelligence (SOI), and extroversion (EX). The participants could rate each item on a 5-point Likert Scale. A total of 34 items composed the complete version of the modified Godspeed questionnaire, administered at the end of Ph1 (GQ1) and the end of the experimentation (GQ2) to collect initial and final opinions about the robot. A reduced version with 27 items was administered to rate the personality of the robot at the end of each task of Ph2 (i.e. GQ_NS, GQ_EXT, GQ_INT). In the reduced version, just one item of ANT (i.e. moving elegantly) and of ANI (i.e. interactive) domains are kept with respect to the complete questionnaire. It allowed the participant to focus on the personality traits of the robot. To obtain a general overview of the perceived robot's personalities, a brief interview was conducted at the end of the experiment. The interview was composed of the following questions: (a) "Did you notice any difference among the robot's behaviors? If yes, which one?"; (b) "Did you prefer any of them? Why?"; (c) "Would you trust a robot exhibiting one of the performed navigation modalities in a real scenario?"; (d) "Did you feel in danger?" (e) "Could you associate a personality or an adjective to each robot behavior?".

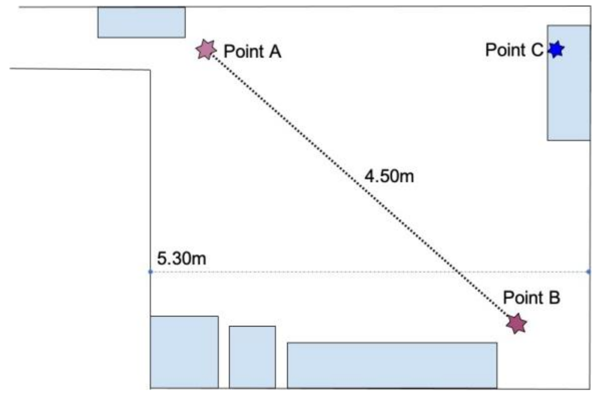


Figure 2 Environment of the experimentation session.

C. *Participants*

A total of 20 young healthy subjects (8 women and 12 men, avg age=28.4 years old, std age=3.15 years old) were recruited from the BioRobotics Institute. All the participants had a master's degree, except three participants who had a Ph.D.'s degree. Six participants (30%) stated that they had no prior experience interacting with robots, four of them (20%) had few experiences and the rest of them (50%) had several experiences interacting with. Participants with several experiences with robots were mostly researchers (70%), and, to a lesser extent, participants in previous experiments (20%), and developers (10%). Furthermore, 13 participants (65%) either owned a pet at the time of experimentation (30%) or in the past (35%), while the remaining had never owned one (35%). By counting up the responses to the corresponding 24 items of the EPI questionnaire, the results revealed that the pool of participants was composed of a balanced presence of extrovert and not extrovert participants (min=6, max=14, avg=10.7, std=2.18), posing a threshold value of 10. Namely, 11 participants were characterized by a "high" level of extroversion (Ext) and 9 participants characterized by a "low" level of extroversion (No Ext). All the participants signed the consent form before entering the test. The study was conducted in accordance with the Declaration of Helsinki.

IV. DATA ANALYSIS

As a baseline, we conducted the analysis of proxemics in the static scenario by processing the data collected from the *people_tracker* package during Ph1. It allowed us to estimate the comfortable stop distance of each participant from the robot and his/her average walking velocity. The results were expressed through the mean (avg), the standard deviation (std), the minimum (min), and the maximum (max) values. The Spearman correlation index (ρ) was computed to find any correlation between the walking parameters (i.e. proximity and velocity) of the participants and their personal characteristics (i.e. extroversion and previous experiences).

To provide an answer to RQ1, firstly, we quantitative evaluated the performance of the navigation system in terms of the percentage of successfully completed navigation tasks (i.e. success rate) in each task of Ph2, where completion means reaching the assigned destination goal. Secondly, we investigated RQ1 by checking the answers provided to questions (a) and (e) of the final interview. Namely, we clustered the adjectives, provided by the participants to describe the personality of the robot, that emerged from the question (e) into the "Big-Five" factors, as described in [20]: (I) Extroversion, (II) Agreeableness, (III) Conscientiousness, (IV) Emotional Stability, and (V) Openness. To investigate the perception of the robot (RQ2) and the elements that may influence it (RQ3), the answers to the Godspeed questionnaires were considered. The final score of the GQ was computed by summing up the evaluations of the eight domains, while each domain was evaluated by summing the corresponding items. Each domain ranged from 0-20, except the ANT and ANI domains of the reduced version, which ranged from 0 to 5.

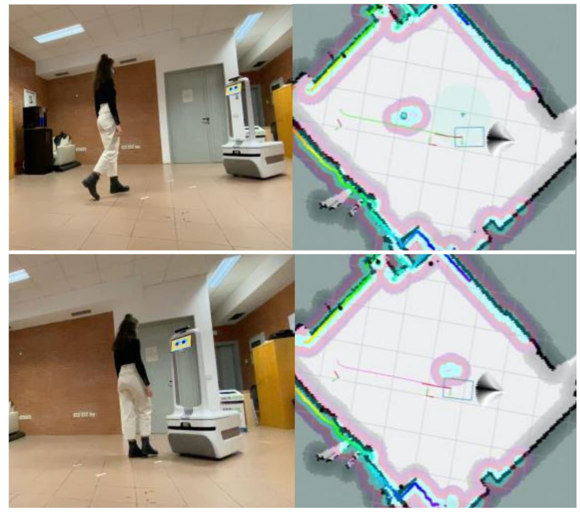
Descriptive statistics were computed for all GQs for the overall population, the extrovert and the non-extrovert group of participants. Mann Whitney U test for the independent variable was applied to investigate if there are differences in the answer of GQ1 and GQ2 considering all the participants (ALL) and it was applied to assess if there are differences in the answer to GQ_NS, GQ_EXT, and GQ_INT domains according to the experience with domestic pets (if any) and social robots. Regarding the latter analysis, we consider two cohorts of respondents, namely who had or has a pet and persons that have never had a pet. Spearman correlation index (ρ) was computed to find any correlation between the GQ domains and personal experiences (i.e. with pets and social robots, respectively). Similarly, the Mann Whitney U test was applied to verify if there were differences in the GQ domains evaluation by the two cohorts of participants (i.e. extrovert and non-extrovert) over the three selected behaviors. Additionally, Spearman correlation index was computed between the EPI extroversion scale and the GQ domains. The alpha level of significance (p) was set to 0.05 for all statistical tests. To quantitively assess the perceived robot's personality, we also computed the normalized navigation cost (NC) was also computed:

$$NC = \frac{GQd_b - GQd_{NS}}{GQd_{NS}} \cdot 100$$

where GQ_d is the score of the GQ domain computed for the NS behavior and the EXT or INT (b) behavior. To investigate whether there are differences in the perception of the three navigation behaviors according to the personality (RQ4), the answers collected from questions (b)-(d) of the final interviews were analyzed to investigate the personality matching.

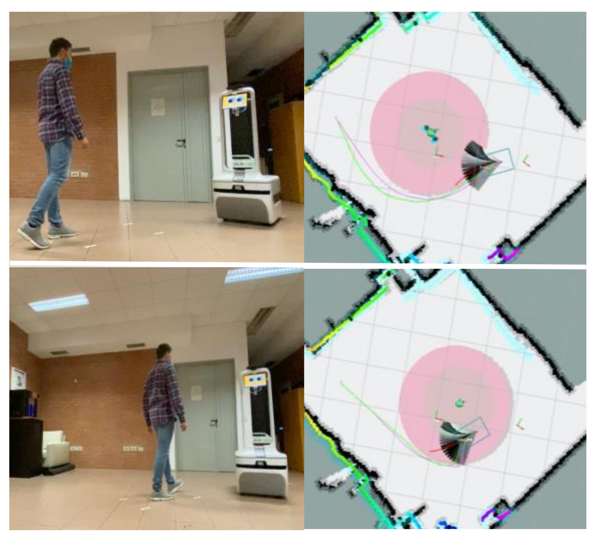
V. Results

During the Ph1, the measured stopping distances were in the intimate, personal, and social interaction spaces (min=0.37m, max=1.49m, avg=0.87m, std=±0.33). Additionally, we observed that the walking velocity of the selected participants in Ph1 were on average 0.84 m/s (std=±0.12, min=0.63 m/s, max= 1.03 m/s). Statistical



(a)

(b)



(c)

Figure 3. Person and robot move passing by each other. The robot exhibits the different personalities: (a) no social, (b) extrovert, (c) introvert. While in (a) the person was forced to change the trajectory to reach her goal, in the remaining situations (b-c) the robot avoided the human by changing its trajectory online.

analysis informs that velocity and stopping distance from the robot were neither correlated with the extroversion dimension of the users nor with their personal characteristics (i.e. previous experience with pets and/or robots). No significant differences in the stopping distances were reported.

The robot successfully exhibited the three distinct personalities during the Ph2. The success rate was equal to 100% both in NS and EXT behaviors. In the NS behavior (see Fig. 3a), the robot detected the participant only as a moving obstacle, thus keeping a close-to-straight trajectory. The emergency stop was activated if the robot was too close to the participant and deactivated only when the participant was far enough from the robot, allowing the robot to move again. As shown in Fig.3c, since the participant was walking, it was observed that the robot found itself in the forbidden zone causing misbehaviors (i.e. set proximity distance not kept). Due to it, the success rate of the INT behavior was equal to 75%.

The interview's answers highlighted that 19 out of 20 participants detected some differences in the robot's behaviors. Fourteen participants noticed a difference among the three behaviors, in terms of velocity ("*in the third case, the robot was moving faster*", User 5), proxemics ("*the robot progressively increased the avoiding distance*", User 1), and avoiding phase ("*progressively the robot started rotating earlier*", User 10). On the contrary, one user did not notice any difference among the three behaviors, another user did not perceive any difference only between INT and EXT behaviors, and the remaining four participants did not notice a difference between NS and EXT navigation modalities. The cluster analysis on the adjectives used to describe each navigation modality highlighted that the participants mostly associated "high" agreeableness (i.e. II+) and

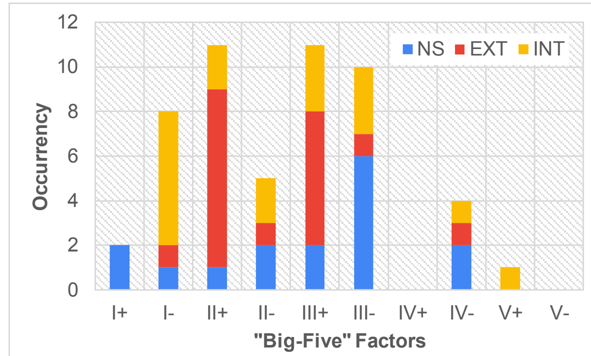


Figure 4 Stacked column chart of the traits of personalities associated to the robot's behaviors (i.e. NS, EXT, INT). The personalities are "high"(+) and "low"(-) traits of: (I) Extroversion, (II) Agreeableness, (III) Conscientiousness, (IV) Emotional Stability, and (V) Openness.

conscientiousness (i.e. III+) to the EXT behavior, "low" conscientiousness (i.e. III-) to the NS behavior, and "low" extroversion (i.e. I-) to the INT behavior. None of the adjectives fell into the "high" emotional stability (i.e. IV+) and "low" openness (i.e. V-) clusters (see Fig. 4).

The descriptive statistic of the GQs is reported in Tab. I. As for the comparison of the GQ1 and GQ2 (RQ2), the respondents liked more the robot after the experiment (overall score GQ1=104.15; overall score GQ2=112.45). Indeed, the statistical test remarks significant differences in the ANI and PEI domains. The ANI domain of GQ2 was also the only domain correlated with the extroversion trait of the participants (ρ=0.51). The overall population slightly preferred the capabilities of the EXT robot, rating it with 83.3 points. The scores of the NS and the INT behaviors were rated 82.7 and 83.1, respectively. As for the personal

TABLE I. RESULTS OF THE GQ COMPUTED AFTER THE THREE TRIAL FOR THE GROUP OF PARTICIPANTS. THE TABLE REPORT THE MEAN VALUE AND THE STANDARD DEVIATION (IN BRAKLETS) FOR EACH DOMAIN. ASTERISKS HIGHLIGHT SIGNIFICATIVE DIFFERENCES AND SIGNIFICATIVE CORRELATION COEFFICIENTS.

EPI	**GQ**	**GQ Domains**								
		ANT	***ANI***	***LIK***	***PEI***	***PES***	***EMO***	***SOI***	***EX***	***Total***
ALL	GQ1	10.50 (2.55)	**12.75**[a] (4.65)	19.70 (3.58)	**15.95**[a] (2.39)	8.55 (1.41)	13.15 (3.00)	11.85 (4.19)	11.70 (2.95)	104.15
ALL	GQ2	11.50 (2.37)	**15.60**[a] (2.78)	20.15 (2.76)	**17.90**[a] (3.25)	9.10 (0.92)	13.60 (2.39)	13.25 (2.67)	11.35 (3.03)	112.45
ALL	GQ_NS	2.45 (1.10)	3.05 (1.00)	18.35 (3.80)	16.95 (3.38)	8.85 (1.23)	12.15 (3.51)	9.1 (2.45)	11.8 (2.09)	82.7
	GQ_EXT	2.65 (1.27)	2.95 (1.10)	18.10 (3.91)	17.25 (3.58)	9.05 (1.05)	**12.35**□ (3.05)	9.55 (2.35)	11.4 (2.58)	83.3
	GQ_INT	2.9 (1.12)	3.25 (0.85)	17.55 (3.98)	17.10 (3.18)	9.05 (1.00)	13.05 (2.14)	**9.10**Θ (2.40)	11.10 (3.13)	83.1
Ext	GQ_NS	3.00 (1.48)	3.00 (1.18)	17.73 (5.04)	15.82 (5.36)	9.27 (0.79)	11.73 (4.15)	8.91 (2.84)	12.00 (2.90)	81.5
	GQ_EXT	2.64 (1.12)	3.27 (1.35)	19.00 (3.58)	17.82 (3.40)	9.00 (1.61)	12.91 (3.18)	9.73 (2.10)	11.18 (2.79)	85.6
	GQ_INT	2.91 (1.38)	3.64 (1.12)	**19.36*** (5.16)	**18.55*** (4.11)	**9.45*** (1.63)	**14.27*** (3.47)	**10.55*** (1.97)	**11.73*** (3.10)	90.45
No Ext	GQ_NS	2.56 (1.13)	3.22 (1.30)	17.22 (3.11)	16.11 (4.40)	9.33 (1.41)	11.22 (3.99)	9.22 (2.44)	12.11 (2.71)	81
	GQ_EXT	3.00 (1.00)	3.78 (1.09)	19.00 (1.80)	18.33 (3.24)	9.00 (1.00)	14.11 (2.15)	10.11 (1.36)	12.56 (2.24)	89.9
	GQ_INT	2.78 (0.83)	3.67 (0.87)	**17.67*** (4.44)	**16.00*** (4.92)	**8.78*** (1.20)	**12.89*** (3.41)	**8.89*** (2.52)	**11.22*** (3.15)	81.9

[a]. Significant differences at the beginning and at the end of the trial.*. Significant differences between the participant with Ext and No Ext participants. □Significant differences between people that has/have previous experience with a domestic pet. Θ. Significant correlation of the results with the EPI extroversion score.

TABLE II. NAVIGATION COST FOR EACH DOMAIN IN PERCENTAGE (%).

Domain GQs	Ext (EPI score)		No Ext (EPI score)	
	EXT	*INT*	*EXT*	*INT*
ANT	-12.12	-3.03	17.39	8.70
ANI	9.09	21.21	17.24	13.79
LIK	7.18	9.23	10.32	2.58
PEI	12.64	17.24	13.79	-0.69
PES	-2.94	1.96	-3.57	-5.95
EMO	10.08	**21.71**	**25.74**	14.85
SOI	9.18	18.37	9.64	-3.61
EXT	-6.82	-2.27	3.67	-7.34

experiences, there is a significant difference in the emotion domain (i.e. EMO) of GQ_EXT between people who have/had a pet and those who never had a pet. No differences were identified according to sex. Several significant and negative correlations were identified between the GQ domains and the perceived experience with social robots for NS and INT navigation behaviors. Particularly, for NS behavior, the correlated domains are: ANI (ρ=-0.46), PEI (ρ= -0.48), SOI (ρ=-0.54); for the INT behavior the correlated domains are ANT (ρ=-0.44), ANI (ρ=-0.50), PEI (ρ=-0.48), EX (ρ=-0.50). No correlation between previous experience and EXT navigation behavior was found. These results suggest that more experience with the robot is translated into a lower evaluation of such domains. The extrovert cohort preferred the INT modalities (overall score GQ_INT=90.45) rather than NS (overall score GQ_NS=81.5) and EXT (overall score GQ_EXT=85.6). On the contrary, non-extrovert people preferred more the EXT robot personality (overall score GQ_EXT= 89.9), than the others (overall score GQ_INT= 81.9, overall scores GQ_NS=81.0). For GQ_NS, GQ_EXT, and GQ_INT, the overall score is not correlated with the personality of the respondents. There are some correlation at micro-level, namely between the domains' evaluation and the EPI score of the respondents (see Tabl. I). Extrovert EPI score is correlated with the SOI for the INT behavior (ρ=0.45). The high value of extrovert personality corresponds to the high value of the SOI domain. There are significant differences ($p<0.05$) in the answers between the Ext group and No Ext group for the INT behavior for six out of eight GQ domains (i.e. LIK, PEI, PES, EMO, SOI, EX). On the contrary, any domain of EXT robot behavior is not correlated with the EPI score. The navigation cost (NC) index gives an overview of the differences in the evaluation of the robot navigation with respect to the NS modality (see Tab. II) and allows a comparison of the performance. It is worth mentioning that the extrovert people (i.e. Ext) evaluated with the highest NC value the EMO domain for the introvert behavior; similarly, non-extrovert people (i.e. No Ext) evaluated more the EMO domain of the EXT behavior.

Regarding the preferences (RQ4), the EXT behavior was liked the most (55%) with respect to the NS (15%) and the INT (25%) behavior. The remaining 5% of the participants were formed by a user who did not have any preferences and another one who liked the proximity kept by EXT and the velocity of the INT behavior. The robot exhibiting the EXT personality was perceived as aware of the presence of the person and very "human-like" in avoiding the person. On the contrary, the INT personality was appreciated due to its fast velocity and smoother trajectory. These results were also reflected by the trust aspect. In general, most of the users (14 out of 20) would trust the robot and its behaviors in a real scenario. The exceptions were two participants that would not trust a robot exhibiting the NS personality, two participants who would not trust the INT personality, and two participants who would not trust any behavior. On the contrary, most of the participants (70%) felt safe during the interaction with the robot because the "*speed was low*" (statement of User 8). The NS and the INT modes were perceived as a bit more dangerous.

VI. DISCUSSION

This study described a novel way to associate a personality to a robot by taking into account the social interaction parameters related to the navigation task (i.e. proximity and velocity). We moved forward with the WoZ control, presenting a human-aware navigation system that should be replicable on any ROS-based robotic platform and we evaluated it in a dynamic scenario. As baseline of this study, we investigated the proximity behavior of the users when the robot was present in the environment (Ph1). Our results show that the average stopping distance (i.e. 0.87 m) is in the personal zone, while the maximum human-robot distance is in the social zone (i.e. 1.49 m). These results may be related to the fact that people who have prior experience with robots tend to stand closer to it [6], even if it was not proved by the statistical analysis. The experiments in the dynamic scenario demonstrated that our approach reliably generated paths that respect the social distance of a person passing by the robot (i.e. success rate ≥ 75%).

Our study successfully provided an answer to RQ1. Most of the participants perceived a difference among the personalities exhibited by the robot in Ph2. This claim is highlighted both by the differences expressed on the GQ_NS, GQ_EXT, and GQ_INT questionnaires and by the answers provided by the participants to the interview. It is also supported by the result that the INT robot personality was mostly described by adjectives characterizing "low" extroversion (see Fig. 4). Regarding RQ2, this study supports the idea that the perceived capabilities of the robot change after the individuals have interacted with it (i.e. higher GQ2 score). In detail, this study finds out that there was a significant difference in the scoring of the animacy and perceived intelligence of the platform. By focusing on each human-like personality associated with the robot, our results show that the NS behavior is the less accepted (i.e. GQ_NS got the lowest score and just 3 participants preferred the NS behavior), while the EXT navigation modality got the higher number of perceived capabilities (total score of GQ_EXT=88.3) and it was the most preferred navigation modality. The INT personality of the robot was appreciated due to its faster velocity, but it was also mentioned as one of the most dangerous ones, due to some misbehaviors.

The results on the correlation of the questionnaires' score with the characteristics of the individuals involved in the study suggest that there exist some extra-factors that could influence the proxemics (RQ3), also in the dynamic scenario. Even if the experience with pets influenced the EMO aspect of the robot's behavior, the main factor which influenced the perception of NS and INT behavior was prior experience with robots. Namely, people who had previous experience with social robots evaluated less the extroversion of the INT behaviors as well as the social intelligence of the NS navigation modality. When considering the extroversion of the individuals involved in the study, the navigation costs show that personality traits have also an impact on the perception of the robot's abilities. Indeed, there are generally positive differences in the answer of GQ_EXT and GQ_INT with respect to the GQ_NS. The results of this study provide a negative answer to RQ4. The participants do not highlight any user-robot personality matching, since the general trend followed the complementarity attraction rule, as in [21]. Namely, No Extrovert people tend to prefer the EXT personality of the robot, and vice-versa. However, we find a significant difference in the answer only for the INT behavior, the other is just a trend confirmed by the NC score.

These results help us to propose some guidelines for future works in the field. Our results suggest that the EXT configuration should be exhibited by a robot that is not aware of the personality traits of the people populating the environment. This is because the interview statements reported the EXT personality as the preferred and more trustful one and there are no statistical differences in the rating among the two cohorts of participants. On the contrary, when the personality traits of the people are known, it is advisable to endow the robot with a complementary personality.

One of the limitations of this work is that the velocity of the robot was constrained due to safety requirements. We would like to like to increase the velocity of the robot (e.g. up 1.0m/s as the velocity of the pedestrians) and to model the velocity profile based on the personality of the robot in the future. Furthermore, in this work, we just focused on one specific personality trait, extroversion. This limitation may be overcome by integrating several aspects (e.g. Big-Five model) to describe the personality of human beings. The presented study could be improved by inferring the personality of the individuals online, adopting one of the techniques described in [22]. Additionally, we would like to extend the pool of participants, by involving participants of different ages. It will enforce our results while avoiding any bias effect.

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