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Experimental Investigation on Active Personal Space for a Human-Robot Working Cell

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Abstract

Active personal space (APS) means the space that should be maintained between human and robot during their direct interaction in a cooperative working cell for ensuring safety and comfort. This research looks into some basic parameters to determine the size of the APS. The parameters are grouped into three categories. They are: i) age of a human and his knowledge level about robotics, ii) robot-emotional state and robot structure and iii) relative dynamic condition. The analysis from the experimental investigation shows how the APS is varied with the parameters. The results show that all the parameters have a reckonable impact on the size of APS.

Keywords: *Active personal space (APS); Human-Robot Interaction (HRI); Emotional state.*

1. Introduction

Human-Robot Interaction (HRI) is an interesting research field with the blending of psychology, cognitive science, artificial intelligence, computer science, robotic engineering, and other related fields. One of the basic goals of the research is to investigate the natural way by which a human interacts and communicates with a robot. It is happened in some situations that robots and humans need to coordinate their activities in real-time and in 'face-to-face' orientation. The quality and success of such interactions depend on the method of human–robot interaction. Many researchers have already investigated on human detection, motion planning, scene reconstruction, intelligent behavior, etc. which have a relation to APS. Some parameters that are commonly believed to have impact on the changing of APS are considered in this research work. The objectives of the research are: i) to select some of the important parameters which determine the APS ii) to verify the impacts of the parameters through experimental methods and iii) to determine APS based on the selected parameters. The results obtained about APS values will be helpful to design a layout for human-robot working cell.

In this paper, Section 2 discusses the related works that have been performed by different researchers. Experimental procedures and robot's structures that have been used for this research are discussed in Section 3. The experimental results are presented and discussed with the analysis of APS values in Section 4. The characteristics of APS and the parameters that are liable to change APS values are also discussed. Finally, Section 5 concludes the research outcome with a further indication of future possibilities of the research.

2. Review Works

Psychologically, Personal space is regarded as the region surrounding a person which he/ she considered as his/her own. When the personal space is occupied or disturbed with others, most

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people feel discomfort, anger, or nervousness. Here in the research, APS means the space that should be maintained between human and robot during interaction for ensuring safety and comfort. That means, there should be a safe distance between the robot and the human while performing interactive and cooperative tasks.

Usually, a person feels discomfort if any one moves into his personal space (PS). So, it would be fine if a robot has an avoidance algorithm while interacting with human to avoid the personal space [1]. Additionally, when a robot interacts with a human, there should be a sense of personal space for the robot itself for comfortable and safe interaction. This personal space (human territory) has been studied in the field of cognitive science as mentioned by Sack [2], Malmberg [3] and many others. They found that the shape of this space can be modeled as an oval form which has wider space toward the direction of the person's eyes (face to face interaction).

Nakauchi and Simmons [4] studied about personal space while interacting with moving robots. According to their results with humans, the personal space can be about 82 cm and 38 cm respectively for two extreme cases-the longest and the shortest in the direction of the eyes. Some other experiments were conducted by Walters *et al* [5] using adults and children with a robot of mechanistic appearance called *PeopleBotR* to find the personal space zones, initial distances for robot-human interaction, etc. The context of the encounters and the human's observation of the robot worked as a social being. They found that the children showed dominant responses to prefer the "social zone" with compare to the distances people adopt when talking to other humans. From the adult studies, they found that, a small number of people preferred the "personal zone" though remarkable minorities digress from this pattern. In [6], the authors focused on the determination of APS for a service robot based on emotional status. This is required for human-robot communication at ease for taking any service from the robot.

In this research, APS means the active distance (relative distance during interaction and action) between the robot and the human. APS is a function of emotion prevailing in the human and in the robot. The other parameters which are considered here are age, familiarity with robot (robot knowledge), robot's structure, and relative motion between robot and human. The changes in APS with respect to the factors are shown with graphs. In this experiment, two emotional states (joy and anger) are considered. The causes of variations of APS are also explained in this paper.

3. Experimental Setup

To bring the impression of a working cell, the whole experiment was conducted in a manufacturing cell consisting of CNC milling machine, CNC drilling machine, Lathe machine, 3D printer and the robots themselves. The whole working environment was clearly explained to each of the participants.

In order to find the APS between human and robot, three robots (toy like robot, cutter robot and humanoid structured robot) are considered to be used for the experiments. The two modes of emotion (joy and anger for cutter robot and humanoid structure robot) are in the consideration of interest for each interacting person. All the human subjects (sample size was 25) are confronted with the robots one by one. During the experiment, one is asked to move towards the robot as if he or she needs to interact with it. Every person is asked to stand along the scaled line (as shown in Figure 1, which is similar to the setup of [7]), to look at the robot face and then to move closer to it until the proximity is such that he/she feels uncomfortable/unsafe. Then, this distance between the robot and human is recorded as APS for that interaction. This step is carried out with all robots for all participating human. The APSs between human and robot are measured on the scale in the case of ‘moving human and standing robot’.

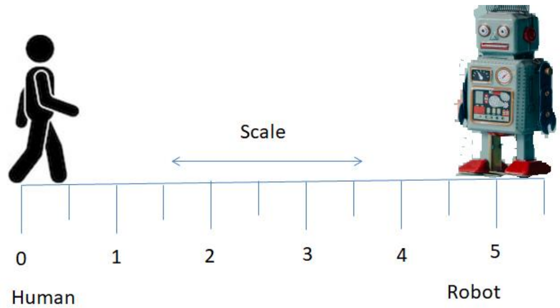

Figure 1. Experiential setup.

Another experimental procedure is performed where everything is the same as earlier except that, this time the robot is moving and the human is standing at a position. He is asked to say ‘stop’ when he feels discomfort/unsafe. At that moment, the distance is recorded as APS value for that interaction. In this way, all the data are recorded for further analysis.

3.1 Robot structure

To find the impact of robot’s structure on the size of APS, one toy like robot, on cutter robot (which is a symbolic representation of robot which may cause harm during work) and one humanoid structured robot (as service robot) are considered as shown in Figure 2. The toy is used with usual mode (no emotional state), but the other two robots are switched between joy and anger mode. In this experiment, modes are shown by Light Emitting Diodes (LEDs) which are set at the center position of the eyes. Here, two types of LED are used: red color and green color. Red color LEDs are used in eyes to express the facial expression with anger mode and in the same way, green color LEDs are used in eyes to express the facial expression with joy mode (shown in Figure 3). Velocity is also represented in two modes like: i) busy mode that indicates the high velocity of robot (equal to 3 m/s or higher) and ii) normal mode that indicates the low velocity (less than 2 m/s) of robot as shown in Table 1. For the case of human, normal mode is his usual walking speed and higher than the walking speed is considered as busy mode. The three main structures (Humanoid, Cutter, and toy robot) are totally portable and can easily be set on the base structure. Screws are used to assemble the portable bodies on the base structure.

3.2 Experimental procedure

The experiment has been set up to observe the APS between human and robot. A certain number of human subjects of different ages have participated in data collection through their consent. Data have been collected in several steps. The first step of data collection procedure requires one human to move towards the static robot along the scaled line and look at the robot face and move closer to it until he/she feels unsafe and uncomfortable. This step up is taken in two emotional conditions of robot: one is robot’s joy condition and another is robot’s angry condition with two velocities as shown in Figure 4. But no emotional state is considered for toy robot. Second step was also similar except that the robot moved toward human and had been moving until human feels unsafe and uncomfortable. Thus, eight interaction distances for one person has been collected for each cutter robot and humanoid robot. In this way, all the interaction distances have been collected. Initially, the robot was placed 250 cm away from the human subject, and then asked him to stand (while robot is moving) or move toward the robot (while robot is standing).

a) Toy robot b) Cutter robot c) Humanoid structured robot

Figure 2. Three types of robot.

Joy Anger Joy Anger

a) Cutter robot b) Humanoid structured robot

Figure 3. Emotion representation of robot.

Table 1. Two values of the robot's velocity.

High Velocity (Hv)	Low velocity (Lv)
3 ms^{-1} (min)	2 ms^{-1} (max)

Figure 4. Some scenario of data collection.

4. Results and Discussion

For collecting APS data, four interaction cases are considered for Robot 1 (Toy robot) as shown in Table 2 and for other two robots, eight interaction cases are considered for each one as shown in Table 3. These data only show the frontal (face to face) APS for every case as shown in Table 2 and Table 3. The APS values are the average response of the people who have participated in the experiments. The people are considered here fall in two groups: Group 1(17-22 yr) who are less acquainted with robots and less knowledge about robotics and Group 2 (23-45 yr) who are acquainted with robots and some knowledge about robotics. From Table 2, it can be seen that people in Group 2 have always less APS than the Group 1 as they are familiar with robots. Also for both group, there is a high APS value at high velocity. It means that they want to avoid collision from kinetic inertia by maintaining a higher value of APS. The individual responses for the case of 'robot moving & person static' are shown in Figure 5.

Table 2. Interaction Status for Robot 1(Toy robot) without any differential mode.

Interaction (Int.) No	Human	Robot	Average APS (cm)	
			Age Group1 (17-22 yr)	Age Group2 (23-45 yr)
1 (Int.1)	Moving (with Lv)	Static	33.3	23.0
2 (Int.2)	Moving (with Hv)	Static	44.0	39.3
3 (Int.3)	Static	Moving (with Lv)	66.1	64.7
4 (Int.4)	Static	Moving (with Hv)	99.2	90.0

Table 3. Interaction Status for Robot 2 (Cutter robot) and Robot 3(Humanoid robot) with differential mode.

Interaction No	Human	Robot	Robot Emotional Status	Average APS (cm)			
				Robot 2		Robot 3	
				Age Group1 (17-22yr)	Age Group 2 (23-45yr)	Age Group 1 (17-22yr)	Age Group 2 (23-45yr)
1 (Int.1)	Moving (Lv)	Static	Joy	92.9	87.4	53.7	51.0
2 (Int.2)	Moving (Hv)	Static	Joy	114.7	109.9	73.9	70.0
3 (Int.3)	Moving (Lv)	Static	Angry	132.9	110.1	75.4	70.5
4 (Int.4)	Moving (Hv)	Static	Angry	168.0	136.6	98.8	97.8
5 (Int.5)	Static	Moving (Lv)	Joy	100.5	87.4	92.9	83.2
6 (Int.6)	Static	Moving (Hv)	Joy	131.4	97.6	114.7	109.9
7 (Int.7)	Static	Moving (Lv)	Angry	132.9	114.5	130.7	110.2
8 (Int.8)	Static	Moving (Hv)	Angry	168.1	149.0	152.2	136.6

From Table 3, it can be seen that for each of the interactions (for both robots) the APS values are always higher when the relative velocity between the robot and human is high. A second important finding from Table 3 is that robot's appearance (structure) has a great impact on APS values. As the robot 2 (Cutter robot) seems to be dangerous in its appearance, the APS values are always higher than the robot 3 (humanoid shaped robot). It seems that people want to keep them safe by maintaining a higher value of APS. Another important finding from the APS data of Table 3 is that the emotional state of each robot is also a determining factor of APS. For example, Int.1 & Int. 3, Int. 2 & Int. 4, Int. 5 & Int. 7 and Int. 6 & Int. 8 are different in emotional state only. For each case, the APS value is higher for angry emotional state. So, emotional state also can be used for determining the APS for layout development when the emotional state will be used as a communication media for multi-agent systems to perform cooperative tasks. Individual responses of the people for each of the interactions (as in Table 3) with both robots are also plotted. Out of them, two cases are shown in Figure 6 and Figure 7.

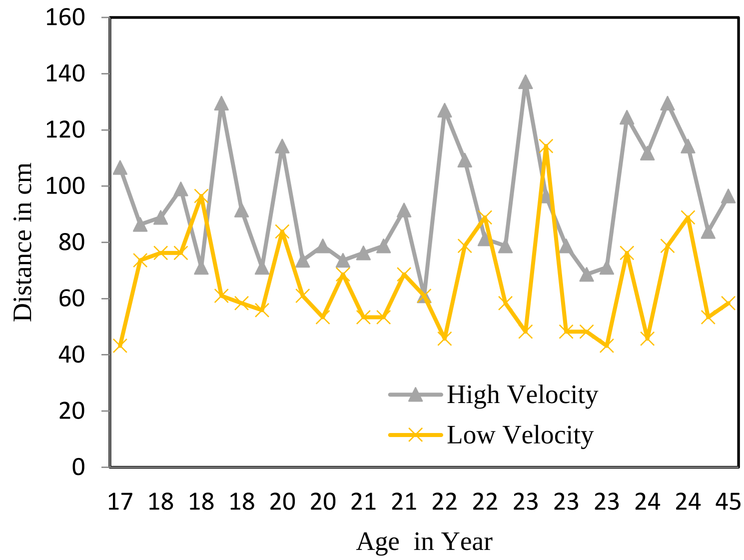

Figure 5. Distance for Robot 1 (toy robot) when Robot Moving and Person Static.

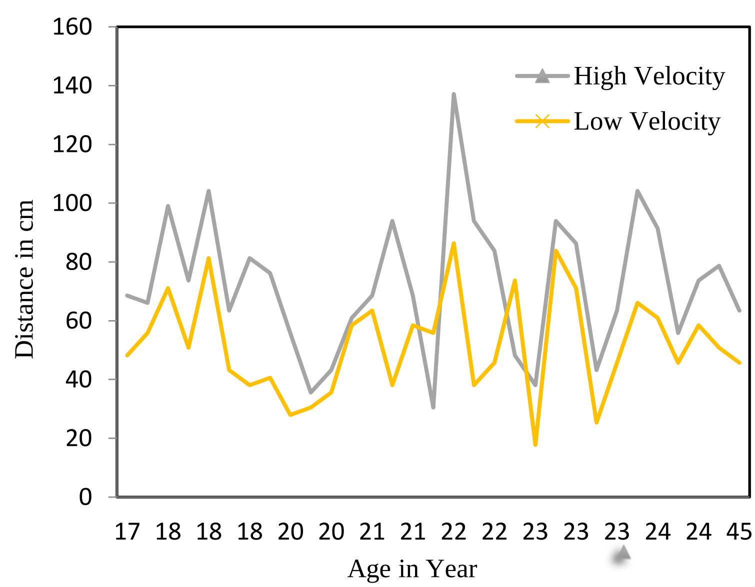

Figure 6. Distance for Cutter Robot when Robot Static & Joy Mode, Person Moving.

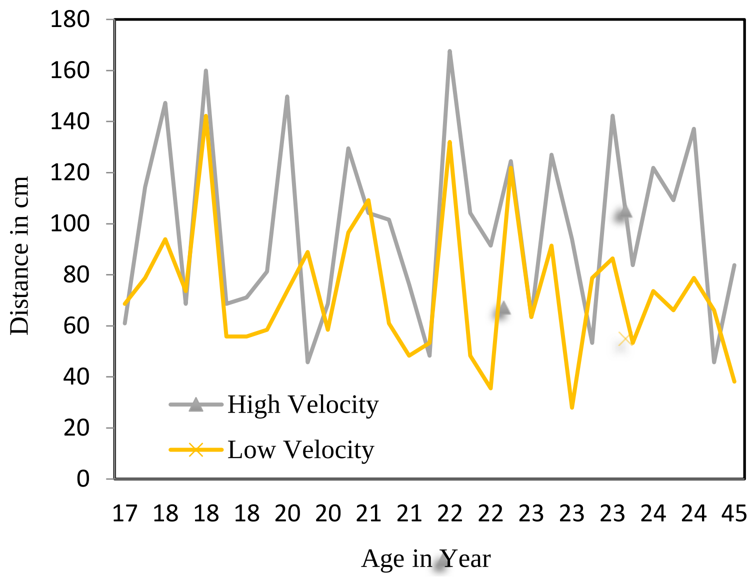

Figure 7. Distance for Cutter Robot when Robot Static & Anger Mode, Person Moving.

5. Conclusions

This research paper has represented the outcomes obtained from experimental investigation on APS for face-to-face situation of interaction between human and robot. The experimental results have revealed the effects on APS due to the factors like age, knowledge about robotics, structure of robot, emotional states of robot and dynamic states. This is the preliminary state of the research which is targeted to develop a dynamic model of a 360^0 APS between human and robot. This model will help to develop the layout in a work-cell where human-robot interactions will be occurred. The experimental results show some differences with the study of Nakauchi and Simmons [4] study. They suggested that active personal space can be about 82 cm and 38 cm respectively for two extreme cases-the longest and the shortest in the direction of the eyes when interacting human and mobile robots. However, this paper has shown that the APS can be even more depending on the factors that are discussed in the paper. Finally, a Fuzzy model will be developed to determine the size of APS in dynamic environment.

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