Investigation of Human Emotional State in Human-Robot Collaboration

Fairul Azni Jafar
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, 76100 Melaka, Malaysia
Email: fairul@utem.edu.my

Nurhidayu Abdullah, Mohd Nazrin Muhammad, Nurul Azma Zakaria and Mohd Najib Ali Mokhtar
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, 76100 Melaka, Malaysia
Email: {nurhidayu, nazrin, azma, najibali}@utem.edu.my

***Abstract*—In order for humans and robots to interact in an effective and instinctive manner, robots must obtain information about the human emotional state in response to the robot's actions. This is important as the presence of robot in human living environment has become tremendously increasing. Consequently, we believed that it is necessary to investigate how human feel about this situation and if robot can understand those human emotions, collaboration with human can be much better. In order to investigate the human emotions, we applied a *kansei* survey method based on a *kansei* engineering technology. We request a number of participants to take part in our experiment where they will be in the same environment of where a robot is working on some tasks. The participants will answer those questions in the survey based on what they feel about working together with moving robot. The overall goal is, in fact, to predict in the least possible time which area in the vicinity of the robot the human is heading to. This paper describes the results of our findings about how human feel when collaborating with robot(s).**

***Index Terms*—Emotion, Kansei Robotics, Human-Robot Interaction**

I. Introduction

Industrial robots have been well-established in the manufacturing sector for over thirty years, employed for tasks such as stacking, casting, painting, sorting, welding, component soldering and so on. This use context highlights the core value proposition of an industrial robot: performing tasks continuously and accurately in work environments and scales difficult for humans.

While robots were initially used in repetitive tasks where all human direction is given a priori, they are becoming involved in increasingly more complex and less structured tasks and activities, including interaction with people required to complete those tasks [1]. This complexity has prompted the entirely new endeavor of Human-Robot Interaction (HRI), the study of how humans interact with robots, and how best to design and implement robot systems capable of accomplishing interactive tasks in human environments. As robots and people begin to coexist and cooperatively share a variety of tasks, "natural" human-robot interaction that resembles human-human interaction is becoming increasingly important.

Right now, safety of the users interacting with industrial robot manipulators has been addressed by segregation between robots and people. Researchers are exploring in the area of HRI with the intention to reduce problems that subsist in the safety aspect in manufacturing environments. Study had found that to make a good interaction between human and robot, first need to understand the abilities of each. Then, the chemistry of working together can be nourished. Many facets of HRI research relate to and draw from insights and principles from psychology, communication, anthropology, philosophy, and ethics, making HRI an inherently interdisciplinary endeavor [1].

The purpose of this paper is to observe how humans feel about cooperating or working together with robots in an environment. As the background of people who working with robot is miscellaneous, we would like to study whether all people may have the same feeling towards working with robots or not. And perhaps, with the finding results obtain, we would be able to come out with a decision about the kind of feelings that human possess in human-robot collaboration.

Though, the main focus of this research work is on using emotion state estimation during real-time human–robot collaboration, to improve the safety and perceived safety of the collaboration by improving the robot responsiveness to inherent communication messages from human.We hope that the result of this study would help to develop a robot system which can understand human feeling in future.

This paper is organized as follows. Section 2 discusses the role of robots in collaborative tasks. In section 3, we briefly review about the emotion in human-robot collaboration. Section 4 will present the experiment results and wrap up by the conclusion through section 5.

This work was supported in part by Universiti Teknikal Malaysia Melaka under Grant No. PJP/2012/FKP S1067
Manuscript received June 24, 2013; revised June 1, 2011; accepted July 1, 2011.

doi:10.4304/jcp.9.3.668-677

II. Human Robot Collaboration

Typical conventional robot systems and applications require fast motions and absolute accuracy, without external sensing, provided that the operational environments are perfectly known. The most important change of perspective is related to the optimality criteria for the considered manipulators: *safety* and *dependability* are the keys for direct interaction, and to pave the way to a successful introduction of robots into human environments [1]. Only dependable robot architectures can be accepted for supporting "human-in-the-loop" conditions and human–robot teams, and the safety of humans cooperating with robotic systems is the main need for allowing physical Human–Robot Interaction (pHRI). In addition, physical safety has to be complemented by the "mental safety", i.e., by the awareness of robot motion, avoiding scaring postures and abrupt movements [2].

Working environments where powerful industrial robots and humans work together in a cooperative fashion has manifold difficulties. Areas safe for people outside of the robot's working area need to be demarcated and are usually reinforced with physical or sensor-based barriers. If people need to work in close proximity or within the work area of a running robot, it needs to operate at a slow speed so that the risk of physical harm is reduced. Because of these limitations, cooperative working is often restricted through a turn-taking protocol, with paramount risk lying in the transition between turns.

To make robots capable to work together with human in different domains of manufacturing environment like assembly, maintenance and other services, it is necessary to analyze and model man-machine interaction forms, which can be used as well between humans and robots as in multi-robot systems. Inagaki *et al.* [3] propose that humans and robots can have a common goal and work cooperatively through perception, recognition and intention inference. One partner would be able to infer the intentions of the other from language and behavior during collaborative work. Morita *et al.* [4] demonstrated that the communication ability of a robot improves with physical and informational interaction synchronized with dialogue.

Natural human-robot collaboration requires the robotic system to understand spatial referencing. Tversky *et al.* [5] observed that in human-human communication, speakers used the listeners perspective when the listener had a higher cognitive load than the speaker. Tenbrink *et al.* [6] presented a method to analyze spatial human-robot interaction, in which natural language instructions were given to a robot via keyboard entry. Results showed that the humans used the robot's perspective for spatial referencing. To allow a robot to understand different reference systems, Roy *et al.* [7] created a system where their robot is capable of interpreting the environment from its perspective or from the perspective of its conversation partner. Using verbal communication, their robot Ripley was able to understand the difference between spatial references such as my left and your left. The results of [3]-[7] illustrate the importance of situational awareness and a common frame of reference in spatial communication.

With all the findings, to make a good collaboration entrainment between human and robot, and to achieve an ideal safety environment, *communication* plays a vital role. With the emerging of the new *Kansei* Engineering technology, it is believed that other than verbal communication, *emotion* can also be the medium of communication between human and robot. Robot should able to have emotions like human and at the same time able to understand the emotions of those humans collaborating together in the same environment so that a "communication" will exist between human and robot. When the "communication" is happening between the collaborating human and robot, robot can take the appropriate actions according to the human emotion.

III. Human Emotion In Human-Robot Interaction

In manufacturing industries which deal with industrial robots, it is seen that humans (workers) are working together with the robots. For those who have been working with the robots for certain period, they might not have problems dealing with the robots. But, what about those people who have not experience dealing with robot? They might face some difficulties to deal smoothly with robots. Therefore, it is believed that if robots are able to understand human emotion (feeling) when cooperating together, robot can be left to perform with considerations to let the humans feel safe and comfortable to work together with robots.

Presently, research studies on developing robots with emotions are rapidly increasing. This new technology is called *Kansei* Robotic. Previously, *Kansei* Engineering is used as a tool for product development. It translates feelings and impressions into product parameters so that the products can be designed to bring forward the intended feeling. Meanwhile, *Kansei* Robotic is a newly introduced technology that makes robot (which work with human) understands the environment with multi-modal sensing ability just as human do.

One of the several researches which related to the *Kansei* Robotic is conducted by H. Kobayashi *et al.* [8]. In their research, they had developed a robot that have a human face platform which can shows several face expression or emotion when communicate with the human. From the experiments of human-robot interaction using the emotional synchronization (KAMIN-FA1), which has been developed by Hashimoto and Morooka [9], it is understood that human feeling became comfortable when the robot made the synchronized facial expression to human emotion. Through his research result [10], Hashimoto confirmed that emotional synchronization in human-robot interaction based on *kansei* factor could be effective to keep a comfortable state.

This technology of *Kansei* Robotic is to create a robot that works with human and perceive the surroundings with multi-modal sensing ability simply as human do. In these processes, active *kansei* intelligence is created on the robot to permit it to perform collaborative works with the human smoothly and flexibly. To attain this target, *kansei* factors in human have been studied. Russell's circumplex model of emotion in Figure 1 is utilized to express human and robotic emotions in the recognition part. From this model, Russell *et al.* [11] advocate the feeling of a human is conveying to a robot. A *kansei* factors existed in this condition is the set of feeling that been adapted to a robot.

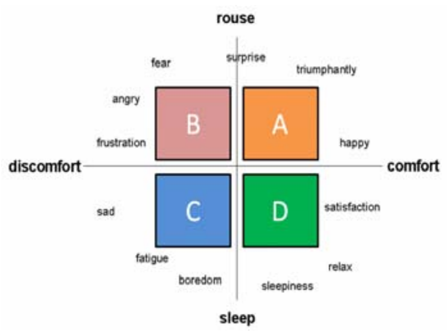


Fig.1. the Russell's circumplex model of emotion.

For that, it is believe that robots should understand human feeling (emotion) in order to create a better working environment between robot and human. If robot able to have emotions and at the same time able to understand human's emotions, better human-robot collaboration can be achieved. It cannot be deniable that *kansei* is taken into account in making a robot system.

Therefore, the purpose of this study is to analyze the human-robot collaboration in manufacturing environment based on *kansei* factors. *Kansei* method is an analysis method which tries to investigate human emotions that can give affects to certain aspects. Affective engineering, where *kansei* method is originally from, is the study of the interactions between customer and the product (in this case, the robot) at a physical level, usable at a psychological level and should be attractive at a subjective, emotional level. As the study in this research work is trying to see how human feel in working together with robots, *kansei* analysis method is found to be the most appropriate method for the research work.

The future expectation is that when the *kansei* factors are adapted, the gesture or impression of humans will let robot to change its emotional state. Therefore, if the robot had the same mind (intelligence, emotion, and will) as human, it would be much easier for the robot to perform the cooperative works with human. Hence, the robot should be aware of human so that it can improve the quality of the working environment.

To create safety and dependability robots who can understand human emotion, first, it is important to investigate those emotions occur in humans. We can't provide all human emotions to the robot as it might burden the robot system, thus analysing the most affected human emotions in human-robot collaboration is necessary. As human feelings are varies among different persons, and furthermore it's much depending on the environment, the task of the robot as well as the type and number of robot, investigation of how human feel about working together with robot must be conducted in different ways and environments as well as different type of humans involving those who are and who are not familiar with robots.

We have conducted a series of experiments where we are trying to analyze how human feels about working in the same environment with robot. In these experiments, we select and provide a number of emotions that we believe exist in human-robot collaboration, and we let the participants to show us how they feel.

IV. Experimental Setup

The experiments were conducted in the Robotics Laboratory of the Faculty of Manufacturing Engineering at our university. The robot type used in the experiments is *Smart NS* (16-1.65). *Smart NS* is one of the *Comau* family robots, designed to address applications in manufacturing such as light-duty handling, arc welding, etc. The robot consists of an anthropomorphic structure with 6 degrees of freedom.

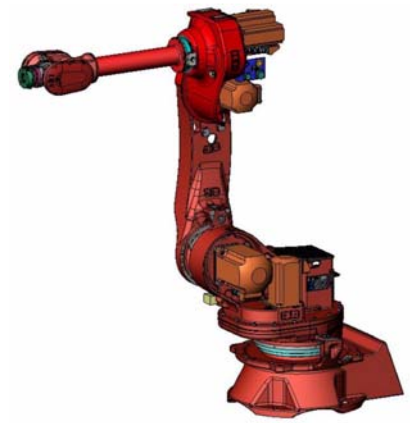


Fig.2. The Comau Smart NS Robot used in the experiment.

30 participants were involved in the experiments. Participants are grouped into three groups, where the first group consists of 10 final year students of the Robotics and Automation course, the second group has 10 final year students from other courses and the participants of the third group are the Technicians group.

Selections of participants are based on their experiences working with robots. Most of the students from the first group are familiar with robots which exist in the laboratory, while in the second group, students which are majoring in other courses might not familiar with robots as good as the first group. Maybe some of them have never been in the same environment with robots before. Ultimately, the third group is supposedly luxurious with experiences working with robots in the same environment. Participants are expected to give feedback from survey questions based on their experience.

The survey questions were constructed from a collection of 20 *kansei* words, which are determined from human's feeling and emotion. The *kansei* words are collected from sources such as internet, books/journals, Russell's Circumplex Model, and also from the discussion among group members.

Table 1 shows the *kansei* words used in the survey questionnaire. Participants will express their level of feeling of each selected *kansei* word when they are under the condition of 'working' together with robot. The level (shown by the numbering) of feeling is decided in 5 levels; Strongly Disagree = 1, Disagree = 2, Neither = 3, Agree = 4, Strongly Agree = 5.

TABLE I.
THE SELECTED *KANSEI* WORDS WHICH REPRESENT THE HUMAN EMOTIONS

1	Anxious	11	Hesitant
2	Apathy	12	Ignored
3	Bored	13	Impressed
4	Cautious	14	Inspired
5	Confident	15	Panic
6	Distracted	16	Peaceful
7	Excited	17	Pressured
8	Exhausted	18	Relaxed
9	Fatigue	19	Satisfied
10	Fear	20	Thrilled

In order to ensure that we could obtain convincing results, and furthermore, considering that human feeling might change according to the changes in environment surrounding, as well as situation happen on that time, we have decided to conduct 3 different types of experiment. The explanation of the differences among the experiments and the steps conducted during the experiment is detail here.

A. *First Experiment*

In the first experiment, the robot will only move once the participants enter the laboratory (the experiment area). The robot will be arranged in its original position first before the participant is allowed to enter the laboratory.

Figure 2 shows the flow chart of the experiment. In this experiment, a robot is programmed to move in normal speed. First, the robot is program based on certain motions and then, participant enters the laboratory before the robot starts performing the tasks based on the programming. At the same time of the robot is moving, participant is required to fill up the survey questions provided.

B. *Second Experiment*

Figure 3 illustrate the second experiment. This experiment does not much differ from the first experiment. The difference is that when participant enter the laboratory, the robot already start performing the given task. The following sequence of operation is similar to the first experiment's operation.

In this experiment, we also planned for another experiment of higher speeds of the robot motion in order to observe whether speed can be an impact factor to the state of human feeling. For that, with the same sequence of robot operations, we conduct another experiment to the participant but with a bit higher speed of robot motions when the participant enters the laboratory.

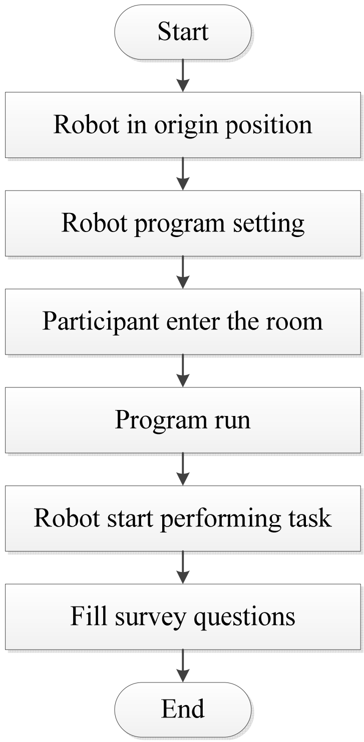


Fig.3. Flow of the 1st experiment.

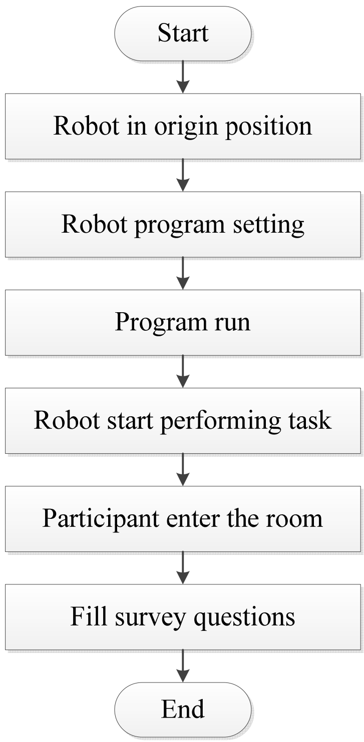


Fig.4. Flow of the 2nd experiment.

C. *Third Experiment*

In the last experiment, which is shown by the flowchart in Figure 4, the participants will not only participate as the subjects to the experiment, but rather they will also involve directly to the robot. In other word, in this experiment, participant is required to write the robot program with the assistance of the experiment's members. Participant will be taught to write the simple program of the robot to let the robot moves following the same given task. Perhaps the feeling of participant when working individually with robot will donate to different feeling that differs from previous experiments.

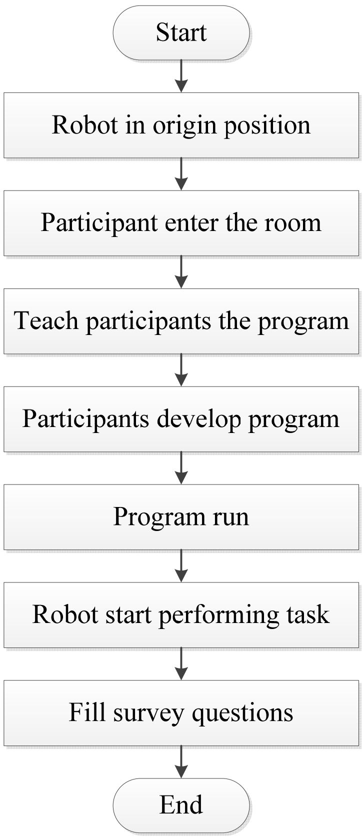


Fig.5. Flow of the 3rd experiment.

V. Operation of Robot

Smart NS robots come in a variety of versions to cover all application requirements. While differing in terms of characteristics such as payload, work area and reach, all robots in the *Smart NS* family feature a highly modular design and are based on the same operating principles. Dedicated to applications where highest accuracy and rapidity are required, as assembly, handling, and arc welding processes.

Figure 5 shows the sequences of the robot operation. First, the robot should be in origin position. The planned operation is very simple where the robot needs to move from point1 to 4 while grinding the edge of the used material. According to the program, the robot end effector (complete with air die grinder attachment) will move from the origin position towards point 1. The air die grinder is switching on and it will start touching the edge from point 1, then moves toward point 2 accordingly until point 4. After finish all points, air die grinder is switched off and the robot will back to its origin position before start operating back for the next incoming material. The operation will be repeating until the participant finish answering the survey.

The material used for this experiment is aluminum profile and the air die grinder will grind the edge of it. Figure 7 shows the flow chart of the robot program. Robot will be programmed to follow the sequences. All experiments will be used this program in it tasks.

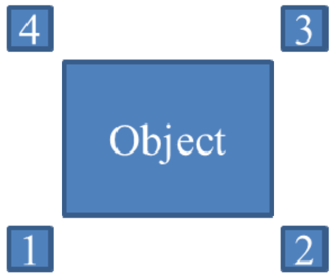


Fig.6. Sequence points of the robot operation.

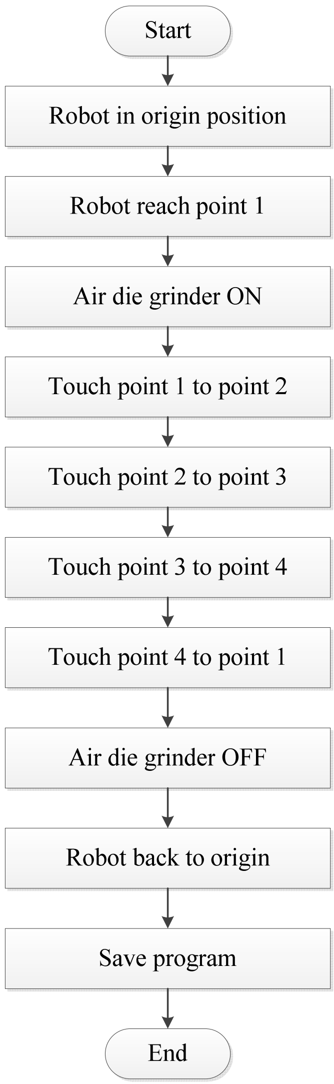
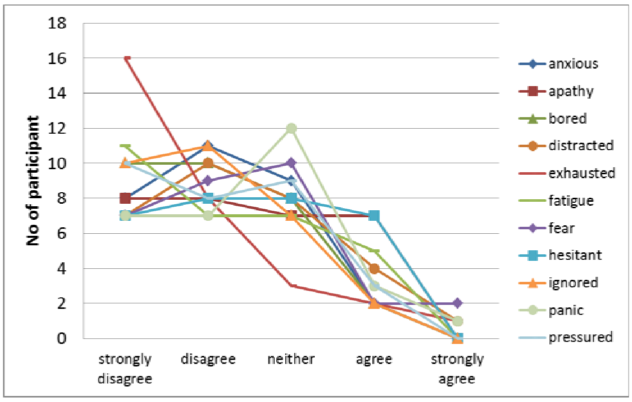


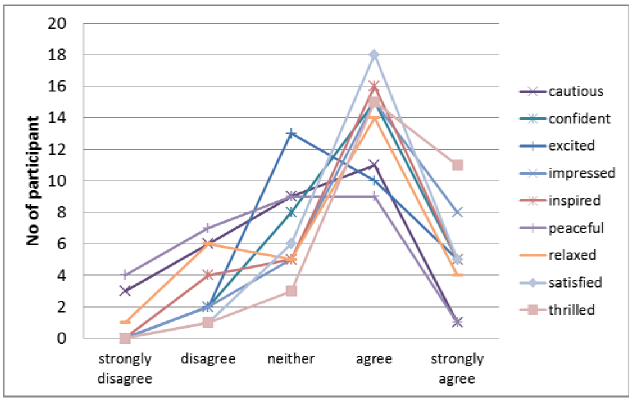
Fig.7. Flow of the robot program.

VI. Experimental Results

The experiment results are shown in Figure 8-11. From the tested 20 emotions, we have divided the result into two graphs based on the first experiment result, where the first graph is the collection of emotions that the participants are more towards the disagree condition and the other graph is for the oppose result. The results show that most of the participants have the same feeling towards the situation of working together with robot(s) in the same environment, either they agree or not, or either they feel the emotion or not. This is proven by the result in Figure 8 where most of the participants are showing the same reflection of either agree or disagree towards the same emotions.



(a)



(b)

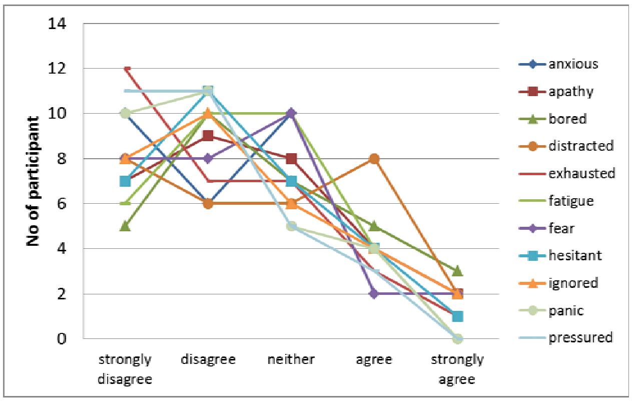
Fig.8. The result of First Experiment; (a) More towards disagree feeling, (b) More towards agree feeling.

The same pattern can be observed from the results of the Second and Third Experiment (see Figure 9-11). These proof our hypothesis that human (the participants) have almost the same feelings towards working together with robot(s). Furthermore, they are much firmed with their feelings as their reflection of feeling do not changed much even though the sequence or condition of the experiment step is differ between one experiment and another. In other word, whether the robot already starts operating or not when the participant enters the laboratory, it does not give any effect to human feelings.

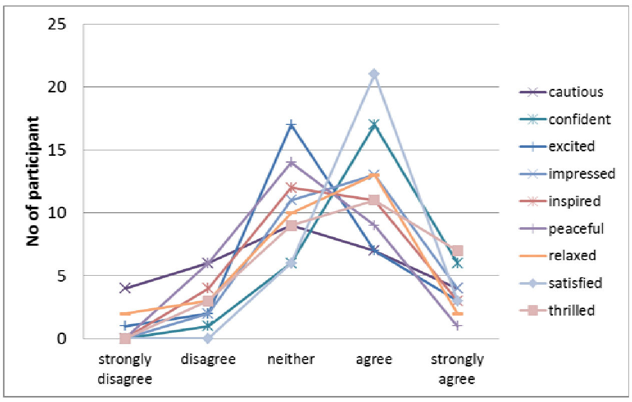
From the first graph (a) in each result, we can see that the participants are less anxious, they do not afraid of working together with robot and they were not pressured dealing with robot as most of the participants were not agree that they are feeling anxious with the moving robot. This is probably due to the fact that most of the participants have some experiences of working with robot previously, if not many. In fact, those participants from the second group who have less experience dealing with robot also showed that they are not afraid working together with robot. This is supported by the graph shown in Figure 12, which is the detail result of the anxious feeling.

Moreover, through the result shown in the first graph (a) of each result, most of the participants show that they are not afraid, panic or even distracted when working near to the moving robot. In fact, the participants enjoyed, inspired, thrilled and feel impressed of being in the same environment with robot as proved by the result in the second graph (b) of each result.

From all the finding results, we can say that people who have experiences dealing with robot would not feeling afraid and yet, they feel delight in working with robot. However, those emotions like exhausted and fatigue need to be further clarify as the experiments were conducted in short time. We would like to see how the condition of participant in terms of exhaustibility or fatigueness after dealing with the robot for a long time.

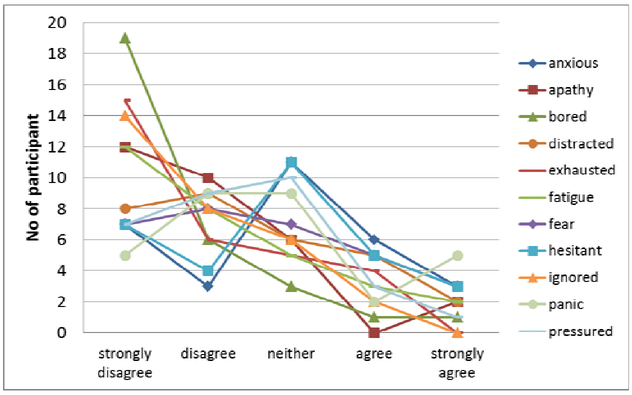


(a)

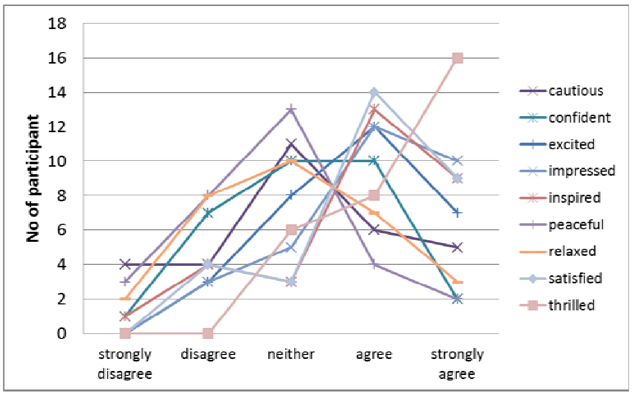


(b)

Fig.9. The result of Second Experiment (Normal Speed); (a) More towards disagree feeling, (b) More towards agree feeling.

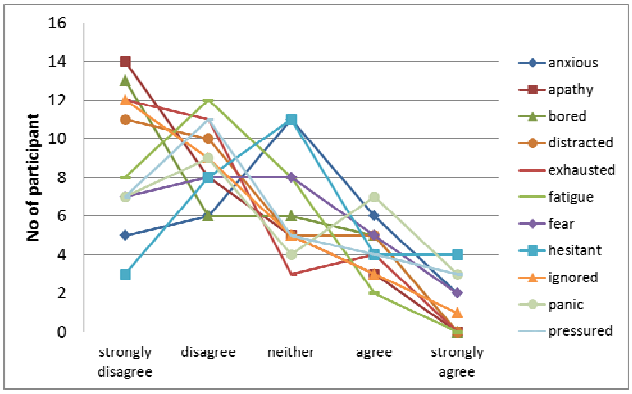


(a)

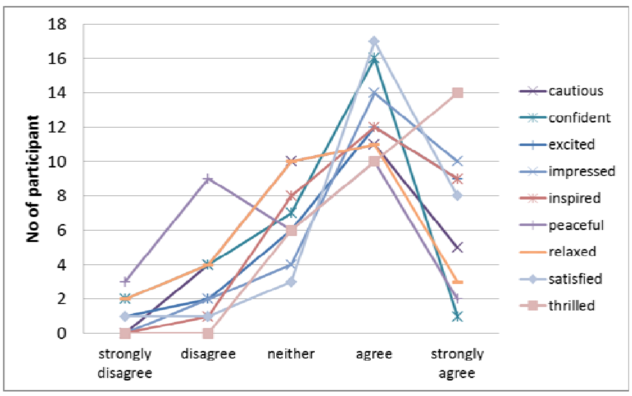


(b)

Fig.10. The result of Second Experiment (Higher Speed); (a) More towards disagree feeling, (b) More towards agree feeling.

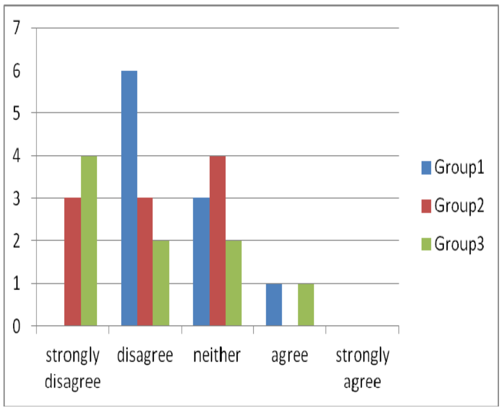


(a)



(b)

Fig.11. The result of Third Experiment; (a) More towards disagree feeling, (b) More towards agree feeling.



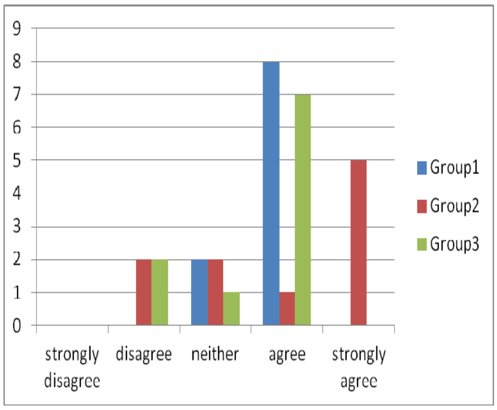


Fig.12. Detail results of anxious (top graph) and inspired (bottom graph) feeling of the First Experiment.

In our further analysis (see result in Figure 13-15), we found out that there are slightly changes occurred in the result of anxious and cautious from the First Experiment till the Third Experiment, where we can see that the numbers of agree results are increasing gradually in Second Experiment (normal to higher speed), as well as the Third Experiment. This phenomenon indicates that there is a possibility human feels more anxious and cautious when the motion speed of the robot is higher. So as when they deal directly with the robot (making the program on their own), the feel more anxious and cautious compared to just working around the robot. In this situation, there is a possibility that human intention of not to create damages on the robot system are higher, hence lead to the increment of agreement feeling of these two feelings when humans participate in the Third Experiment.

Meanwhile, result of impressed feeling shows that more participants agree that they are impressed when they deal directly with the robot. Although they already impressed working with robot during the First Experiment, the result of the Third Experiment reveals that more participants feel impress when they have the opportunity to deal directly with robot.

The result of this supplementary analysis need to be further study as it might indicate that there are some emotions which may be significant in term of human-robot collaboration among the 20 emotions tested in the experiments of this research study.

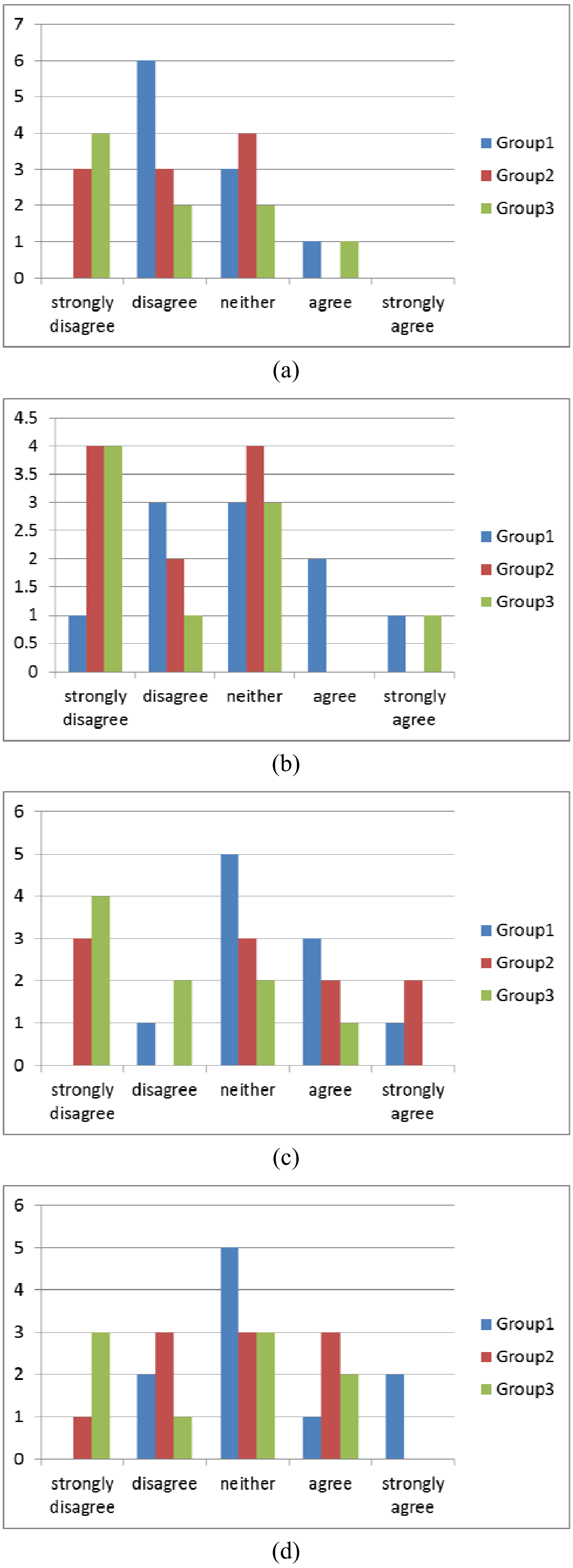


Fig.13. Detail results of **anxious** emotion; (a) 1st Exp, (b) 2nd Exp (Normal Speed), (c) 2nd Exp (High Speed), (d) 3rd Exp.

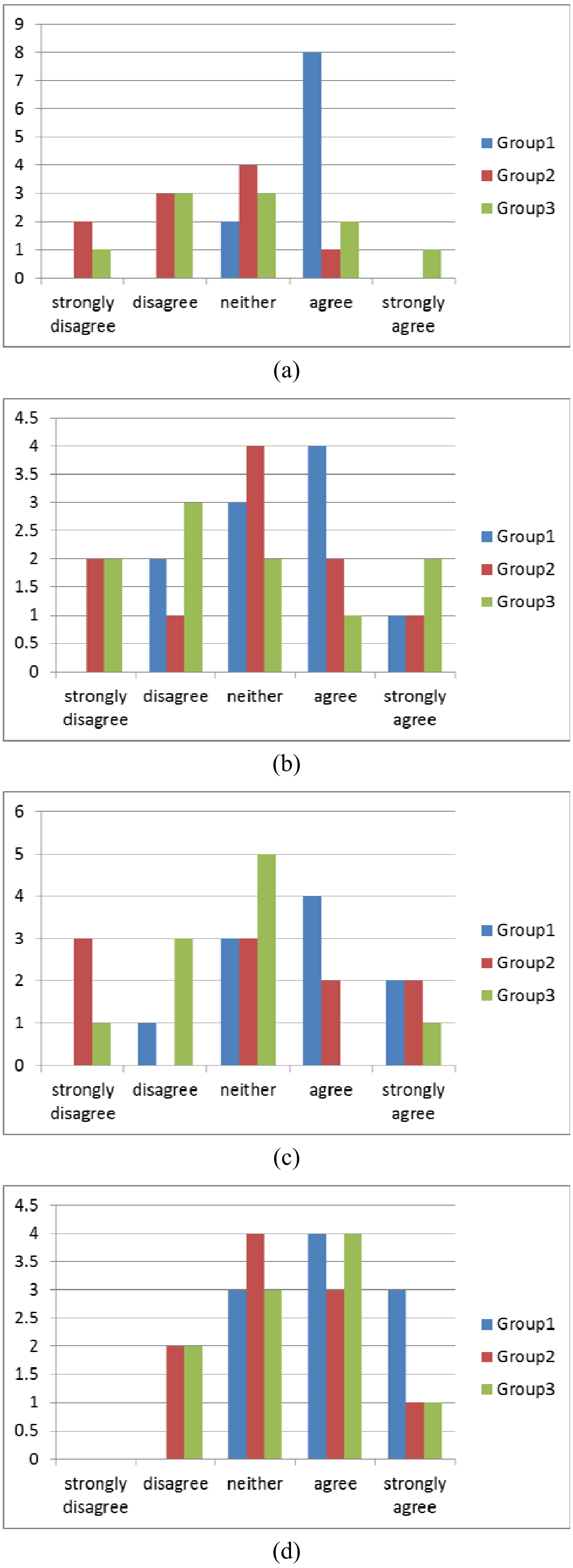
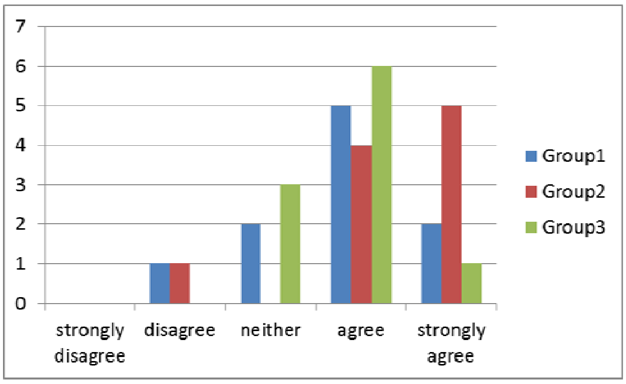
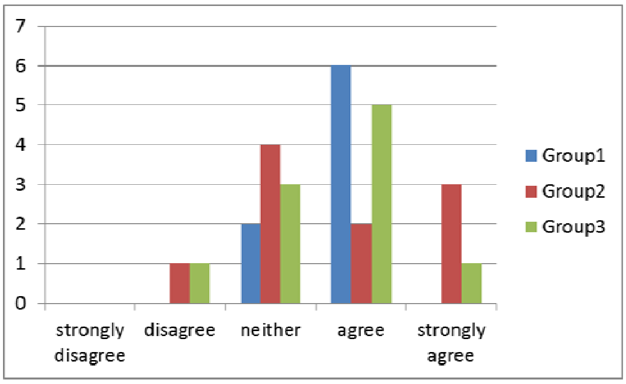


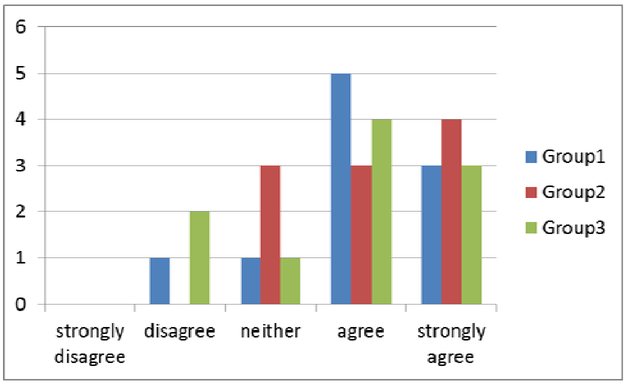
Fig.13. Detail results of **cautious** emotion; (a) 1st Exp, (b) 2nd Exp (Normal Speed), (c) 2nd Exp (High Speed), (d) 3rd Exp.



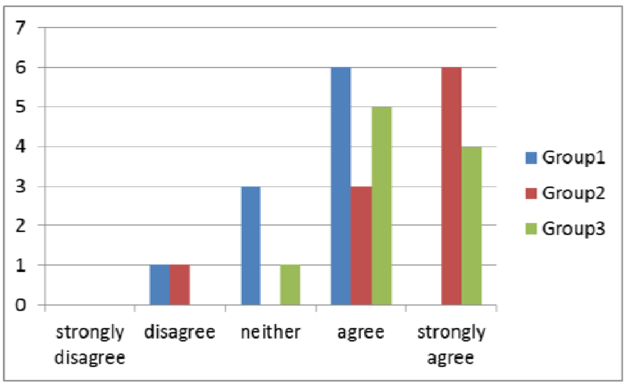
(a)



(b)



(c)



(d)

Fig.13. Detail results of **impressed** emotion; (a) 1st Exp, (b) 2nd Exp (Normal Speed), (c) 2nd Exp (High Speed), (d) 3rd Exp.

As an overall, we can say that humans have various feelings towards collaborating with robot, other than just feeling afraid or anxious, which was our expectation before conducting this research work. This is why we need to find or analyse the human emotions in order to dig out the emotions that really affect the human-robot collaboration.

VII. Conclusion

Results of the study conducted in this paper have showed that humans have various feelings when collaborating with robots. However, humans are much firmed about how they feel in the collaboration as the results of the experiments show that most of the participants have the same reflection (either agree or disagree) towards each *kansei* factor (emotion). In spite of that, we also realized that some people felt cautious and some other do not so, where they feel peacefully against the robot. Meaning that, some people feel that they have to be cautious with the robot and some other people are just enjoy working together with robot.

All these findings need to be taken into consideration when developing any robot system, with consideration that robot must be able to understand those humans' emotions. This is important in order to create a better and safety environment for human-robot collaboration.

However, further analysis need to be performed in order to justify whether there is any significant emotions among the tested emotions or not, so that it could be important considerations if a robot systems which can understand human feelings is going to be developed in future.

We are planning to further this study by conducting similar experiments on more number of participants, especially against people who are totally without experience of working together with robot. We would also like to further our investigation on different type of robots with different type of speeds.

Acknowledgment

This work was supported in part by Universiti Teknikal Malaysia Melaka under Grant No. PJP/2012/FKP S1067.

References

[1] J. Heinzmann and A. Zelinsky. *Quantitative safety guarantees for physical human–robot interaction*. In Int. Journal of Robotics Research, vol. 22, (2003) 479–504.

[2] S. Nonaka, K. Inoue, T. Arai, and Y. Mae. *Evaluation of human sense of security for coexisting robots using Virtual Reality*. In 2004 IEEE Int. Conf. on Robotics and Automation, vol. 3, (2004) 2770-2775.

[3] Y. Inagaki, H. Sugie, H. Aisu, S. Ono, and T. Unemi. *Behavior-based intention inference for intelligent robots cooperating with human*. In 1995 IEEE Int. Conf. on Fuzzy Systems, vol. 3, (1995) 1695-1700.

[4] T. Morita, K. Shibuya, and S. Sugano. *Design and control of mobile manipulation system for human symbiotic humanoid: Hadaly-2*. In 1998 IEEE Int. Conf. on Robotics and Automation, vol. 2, (1998) 1315-1320.

[5] B. Tversky, P. Lee, S. Mainwaring. *Why do speakers mix perspectives?* In Spatial Cognition Computing 1, (1999) 399-412.

[6] T. Tenbrink, K. Fischer, and R. Moratz. *Spatial strategies in Human-Robot communication*. In Korrekturabzug Kuenstliche Intelligenz, Heft 4/02, (2002) 19-23.

[7] D. Roy, K.-Y. Hsiao, and N. Mavridis. *Mental imagery for a conversational robot*. In IEEE Transactions on Systems, Man and Cybernetics, vol. 34(3), (2004) 1374-1383.

[8] H. Kobayashi, T. Tsuji, and K. Kikuchi. *Study on face robot platform as a KANSEI medium*. In IEEE Int. Conf. on Industrial Electronic Society, vol. 1, (2006) 481-486.

[9] M. Hashimoto and D. Morooka. *Robotic facial expression using a curved surface display.* In Journal of Robotics and Mechatronics, vol.18, no.4, (2006) 504-510.

[10] S. Hashimoto. *Kansei robotics to open a new epoch of human machine relationship - Machine with a heart-*. In the 15th IEEE Int. Symp. on Robot and Human Interactive Communication (RO-MAN06), (2006).

[11] J.A. Russell, M. Lewicka, and T. Niit. *A cross-cultural study of a circumplex model of affect.* In Journal of Personality and Social Psychology, vol. 57, no. 5, (1989) 848-856.