Faculty of Electrical Engineering

ADAPTIVE TRAJECTORY GENERATION FOR VISION-BASED ROBOT USING NEGOTIATION PRINCIPLE FOR REHABILITATION APPLICATIONS

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Master of Science in Mechatronic Engineering

2019

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A thesis submitted
in fulfillment of the requirements for the Master of Science in
Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled “Adaptive Trajectory Generation for Vision-Based Robot using Negotiation Principle for Rehabilitation Applications” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……..……

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechatronic Engineering.

Signature : ……...

Supervisor Name : ……..

Date : ……..

DEDICATION

To my beloved father and mother

ABSTRACT

Adaptive behaviour in a robotic system is highly desired in an application that requires a robot to negotiate and adapt its role to the overall goal. For example, in an autonomous hand rehabilitation application, the robot must concern on the safety and comfort of a patient when guiding the rehab exercise and the robot must also be able to motivate patient to gradually improve his motion to achieve recovery. Therefore, this research focuses in solving the problem by adjusting the robot's trajectory automatically to suit changing patient's requirement while considering the planned trajectory. To solve the problem, it is hypothesized that persuasion tactic based on negotiation principle approach can solve the conflict in motion coordination and lead the patient towards the initial planned trajectory. The objectives for this research are to design and develop an adaptive trajectory algorithm with a persuasion tactic based on negotiation principles and to validate the proposed algorithm in terms of automated negotiation point of view. A persuasion tactic is proposed to represent the action of persuasion. Three types of experiments were conducted to validate the proposed method. The first experiment is to study the effect of using negotiation principle without persuasion tactic on the trajectory of a robot. The second experiment is to investigate the effect of using negotiation principle with persuasion tactic on the trajectory of a robot (single input). The third experiment is to examine the effect of using negotiation principle with persuasion tactic on the trajectory of a robot (multi-input). The result of the experiment is analyzed based on a negotiation perspective in terms of negotiated trajectory, the success rate of negotiation, utility, and equality. The result shows that the success rate of negotiation with persuasion tactic is higher than without persuasion tactic which is 91.1%. The result also shows that the utility of the robot is higher than human which are 0.63 (single input) and 0.52 (multi-input). In conclusion, the presented persuasion tactic based on negotiation principle to coordinate motion between robot and human serves as a method that fills the gap in the robotic system which does not consider its initial planned trajectory and totally follows the human requirement.

ABSTRAK

Tingkah laku penyesuaian dalam sistem robotik sangat dikehendaki dalam aplikasi yang memerlukan robot untuk berunding dan menyesuaikan peranannya untuk mencapai matlamat keseluruhan. Contohnya, dalam aplikasi rehabilitasi tangan secara automatik, robot mengutamakan keselamatan dan keselesaan pesakit serta mengekalkan motivasi pesakit. Oleh itu, penyelidikan ini fokus dalam menyelesaikan masalah dalam menyesuaikan trajektori robot secara automatik untuk memenuhi keperluan pesakit-pesakit yang berubah serta mempertimbangkan trajektori yang dirancang. Dihipotesiskan bahawa tindakan pujukan berdasarkan pendekatan prinsip perundingan boleh menyelesaikan konflik dalam koordinasi gerakan serta dapat memimpin manusia ke arah trajektori awal. Objektif kajian ini adalah untuk membangunkan algoritma trajektori penyesuaian dengan taktik pujukan berdasarkan prinsip rundingan dan untuk mengesahkan algoritma yang dicadangkan dari perspektif rundingan automatik. Kaedah taktik pujukan mewakili tindakan pujukan. Tiga jenis eksperimen telah dijalankan untuk mengesahkan kaedah yang dicadangkan. Eksperimen yang pertama adalah untuk mengkaji kesan menggunakan prinsip perundingan tanpa taktik pujukan pada trajektori robot. Eksperimen yang kedua adalah untuk mengkaji kesan menggunakan prinsip perundingan dengan taktik pujukan pada trajektori robot (input tunggal). Eksperimen yang ketiga adalah untuk mengkaji kesan menggunakan prinsip perundingan dengan taktik pujukan pada trajektori robot (input pelbagai).Hasil eksperimen dianalisis berdasarkan perspektif perundingan dari segi trajektori dirundingkan, kadar kejayaan rundingan, utiliti, dan kesamaan. Hasil menunjukkan bahawa kadar kejayaan rundingan dengan taktik pujukan lebih tinggi daripada tanpa taktik pujukan iaitu 91.1%. Hasil juga menunjukkan bahawa utiliti robot adalah lebih tinggi daripada manusia iaitu 0.63 (input tunggal) dan 0.52(pelbagai input). Kesimpulannya, taktik pujukan yang dicadangkan berdasarkan prinsip perundingan untuk menyelaraskan pergerakan antara robot dan manusia berfungsi sebagai satu kaedah yang mengisi jurang dalam sistem robotik yang tidak mengambil kira trajektori awal yang dirancang dan hanya mengikut keperluan manusia.

ACKNOWLEDGEMENTS

Grateful to Almighty Allah for His blessings, I had successfully completed my master thesis to fulfill my study for Master of Science in Mechatronics Engineering. It would not have been possible to complete this research without support and help of many individuals. I would like to extend my sincere thanks to all of them.

A special gratitude to my kind-hearted supervisor, Assoc. Prof. Ts. Dr. Muhammad Fahmi bin Miskon. I owe him a lot of gratitude for giving the freedom of thought and motivation which built confidence in completing my research. It was a great pleasure for me to conduct this thesis under his supervision. Despite of his busy schedule as the Director of PPPA UTeM, he was always available to discuss the progress of my research work, review the progress of my thesis, shared his valuable suggestions and made corrections. I really thank him for providing me valuable advice to help me overcome difficulties related to my academic as well as personal life and professional life in future. Thank you Sir for all this.

I must express my gratitude to my co-supervisor Assoc. Prof. Dr. Ahmad Zaki bin Shukor for suggestions made by him for this thesis. I would also like to thank the experts who were involved in the discussions for this research. A special thanks goes to my postgraduate friends, Quah, Sarmila, Aina, Aine, and Nazori who helped me to conduct the experiments and gave suggestions regarding my research.

I am most grateful to my father, Rasid Hamid and my mom, Rohani Awang. They have always loved me and supported each of my choices. I'm also thankful for great joys and happiness brought to me by my siblings (Feddy, Fizri, Iman and Wawa), my fiancé Amirul and not to forget Dhiya and Zahran.

Lastly, thanks to Universiti Teknikal Malaysia Melaka (UTeM) for UTeM Zamalah Scheme. I am grateful that this institution really wanted to see its students to be skillful and knowledgeable.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ζ	–	Similarity measure
a_t	–	Actual trajectory
A_n	–	Robot as the negotiator
A_p	–	Human as the partner
C_n	–	Conflicting issue
e_t	–	Error
g_t	–	Desired trajectory
G_n	–	Individual desired value
I_t	–	Initial trajectory
K_n	–	Negotiator gain
Ln	–	Individual limitation
max_r^p	–	Maximum partner radius
min_r^p	–	Minimum partner radius
max_r^n	–	Maximum robot radius
min_r^n	–	Minimum robot radius
n_{t+1}	–	Negotiated trajectory
n_t	–	Previous negotiated trajectory
N	–	Negotiation system
r	–	Radius
TG	–	Trajectory Generation
$U_p(r)$	–	Utility of partner
$U_n(r)$	–	Utility of robot
x	–	Proportional negotiation value
RM	–	Ringgit Malaysia

LIST OF PUBLICATIONS

Rasid, F. A., Miskon, M. F., Shukor, A. Z., and Jamaluddin, M. H. 2018. Investigation of Self-Adaptive Trajectory Generation Based on Negotiation Principle. *International Journal of Mechanical and Mechatronics Engineering IJMME-IJENS*, 18(05), pp.130–140.

Rasid, F. A., Miskon, M. F., Jamaluddin, M. H., Bazli, M., and Shen, Q. J. 2018. The Investigation of Circular Path Generation and Hand Motion Tracking Problem Using Vision Based Robot. *International Journal of Mechanical amd Mechatronics Engineering IJMME-IJENS*, 18(02), pp.121–129.

CHAPTER 1

INTRODUCTION

1.1 Background and motivation

Nowadays, the presence of adaptive system in human-robot interaction (HRI) that changes behaviour over time makes a robot no longer seen as a tool. Since human are a part of the robot's environment, the robot must be able to adapt its behaviour to the human's unpredictable reaction (Pérula martínez, Castro gonzález, Malfaz, and Salichs, 2018). The increasing capabilities and adaptive behaviour make a robot as an efficient working partner in industry to perform a collaborative task with human (Calinon and Evrard, 2009; Maeda, Maloo, Ewerton, Lioutikov, and Peters, 2016; Roy and Edan, 2018) and a therapist that assist the rehabilitation exercise for a post-stroke patient (Patton and Mussa Ivaldi, 2004; Squeri, Masia, Giannoni, Sandini, and Morasso, 2013). Most of the works which focus on physical HRI require a continuous or at least a prolonged period between the robot and human partner either both employ similar or complementary roles to achieve one common goal (Sanguineti and Burdet, 2014). This also makes the robot to act as a pure follower instead of a leader that lead the human partner towards the goal of the given task.

The design of adaptive behaviour is more complex in a non-contact physical HRI application. In HRI, when robot and human work in a collaborative task that requires communication, each robot and partner have their own interests, desires, motivation, and goals that are quite different from each other (Sanguineti and Burdet, 2014). At some point, each robot and human have to persuade or being persuaded, exchange something to

come to an agreement. The art of understanding the exchange partner requirement to avoid conflicts and misunderstanding is called negotiation (Adela, 2002). Therefore, negotiation mechanism is necessary to make a robot adapt to the partner's requirement while considering its own desired value.

The research in adaptive robot behaviour for non-contact physical HRI has been addressed in a controlled negotiation environment (Lopez, Hasegawa, and Imai, 2017). For example, in a conversational robot, the robot requires negotiation skill to resolve the conflict occurred during the interaction with a human. The robot needs to understand human behaviour and adapts its role in a negotiation environment (Lopez et al., 2017). The adaptive behaviour for non-contact physical HRI also will be more complex in a rehabilitation application. In rehabilitation exercise, negotiation is required to make the robot to not only consider the safety and comfort of the patient, but it also needs to consider the patient's motivation. Inspired by hand rehabilitation therapy in Figure 1.1, a physiotherapist guides the hand exercise for upper limb recovery for a post-stroke patient.

Figure 1.1:Physical stroke therapy for upper limb (Das, 2009)

In the scenario, the patient could decrease his range of motion over time due to age or injury factor that may limit the ability of the patient to achieve higher levels of movement ability. Imagine this exercise becomes autonomous, a robot arm replaces the therapist to guide the patient doing hand rehab motion, need to change its trajectory profile to suit the patient's range of motion and lead the patient to improve his ability. In this case, initially both parties have the same goal which is to achieve the planned trajectory. The robot must guide the hand motion exercise with the planned trajectory and the patient needs to follow the robot. However, due to joints limitation, the patient is unable to follow the correct motion path. This situation causes conflict where the robot and human have their own desired motion. In this sense, the robot is required to guide the patient to keep doing the exercise by adapting its trajectory based on the patient's requirement while considering the planned trajectory. The purpose of this action is to prevent demotivation and persuade the patient to improve his hand motion performance. If this action can be done by the robot, the outcome will be beneficial for both parties. In the end, the robot able to carry its function to guide the partner to achieve the initially planned trajectory and the patient is able to complete his rehabilitation therapy.

1.2 Problem statement

In this research, particular to the autonomous rehabilitation applications, the problem is in adjusting the robot's trajectory automatically to suit changing patient's requirement while considering the planned trajectory.

In response to the problem, this research proposed an adaptive trajectory generation algorithm using persuasion tactic based on negotiation principle to make the robot have the capability to negotiates and adapts its role the overall goal. The implementation of adaptive

behaviour in generating trajectory shows that considerable coordination and negotiation work takes place both between robot and human who are involved in a joint activity when the robot starts to move. Persuasion tactic will make the robot capable in persuading the patient to act in a particular way which can improves his motion and achieve the planned trajectory.

Based on the proposed method, there is a challenge in performing the method and hence the research question is, 'How does the robot resolve the conflict between the changing human's requirements with the initial plan, merely based on the observation from the changing human's requirements?'. In answering the research question, a hypothesis has been made.

H1: Persuasion tactic based on negotiation principle approach can solve the conflict in motion coordination between robot and human through adaptation with human requirement as well as able to make a robot lead the human partner moves towards the planned trajectory.

The proposed method is based on the automated negotiation system among autonomous agents which can be a robot or a computer. In automated negotiation system, agent need to take a particular course of action, modify a planned course of action or come to an agreement includes persuade the partner to act in a particular way (Peyman Faratin, Sierra, and Jennings, 1998). This system allows the robot to know the total satisfaction toward the partner's response in negotiation through utility and evaluate fairness of the negotiation outcomes in terms of equality (Cheng, Chan, and Lin, 2006; Peyman Faratin et al., 1998). The automated negotiation system is also adopted from human behaviour from human-human interaction. It is stated that a robot can becomes more persuasive in their roles in HRI, if it is adopting the human behaviour (Cruz-maya and Tapus, 2018).

1.3 Objectives of research

The overall aim of this research is to investigate the implementation of negotiation principles in an adaptive trajectory generation system in responding to changing patient's requirement while addressing conflicts between the unfamiliar environment requirements and its original objectives as well as its limitations. In short, the objectives of the research are:

1. To design and develop an adaptive trajectory algorithm with a persuasion tactic based on negotiation principles.
2. To validate the proposed algorithm in terms of automated negotiation system point of view which are utility and equality.

1.4 Scope of research

The scope of this research focused on:

i. The system works based on feedback from a visual observation that is attached 5DOF Kuka youBot.

ii. The experiment is conducted only to validate the proposed algorithm which is able to produce new trajectory using persuasion tactic based on negotiation. Therefore, a healthy person is enrolled as the subject instead of the real patient.

iii. There are only five subjects that are enrolled to validate the proposed method.

iv. The robot does not assist the patient to move his hands, but it only guides the motion in predetermined circular path. It is similar to active assistive exercise where the patient does his exercises on his own.

v. The negotiation cycle is conducted until 10^{th} cycles only.

vi. The analysis is done based on automated negotiation system perspective in terms of the success rate of negotiation, utility and equality of the negotiation outcomes.

vii. There is no analysis on the accuracy of robot negotiated trajectory and partner's actual trajectory because the partner's motion is not controlled by this system. Utility and equality represent the accuracy measure in terms of automated negotiation system.

viii. The experiment focused on circular motion and elliptical motion only.

ix. Nonverbal applications where there is no conversation between robot and human.

1.5 Summary

In summary, this chapter explains the background and motivation of this research. The research problem is explained and the research hypothesis is stated. The objectives and scopes of the research are also stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to negotiation in an autonomous system

Negotiation is an important form of communication in human social interaction (Lopes, Wooldridge, and Novais, 2008). The study of negotiation is blossom to the area of computer science (K. P. Sycara, 1990; Lopes et al., 2008; K. Sycara and Dai, 2010). In computer science, particularly in autonomous system, negotiation is defined as a discussion among conflicting parties with the aim of reaching agreement about a divergence of interest (Provis, 2004; Lopes et al., 2008; Kumar, 2015). Hence, the core of negotiation is how good the adaptability for changing circumstances (Ren, Zhang, and Sim, 2009) and how to acquire more information and use it appropriately to reach consens`us through concession in negotiation (Zeng and Sycara, 1997; Gwak and Sim, 2011; Williams, Robu, Gerding, and Jennings, 2011). The definition of negotiation system, *N* for multiple agents, *A* is has been defined by (Hallam, 1995) through formula:

$$N = \{A_1, A_2 \ldots A_N\} \quad (2.1)$$

$$A_i = \{ C_n, L_n, G_n\} \quad (2.2)$$

$$L_n = \{\text{max value, min value}\} \quad (2.3)$$

Where:

C_n – Knowledge about conflicting issue

L_n – Knowledge about individual limitation value

G_n – Knowledge about the individual desired value.

Reaching an agreement via negotiation requires each of the parties to abandon partly or completely certain goals. It can be reached through narrowing the difference in the demands of the parties over a particular issue. In an automated negotiation system, the issue could be price, volume, duration, quality and etc.. Meanwhile in the robotic system, the issue could be trajectory, kinematics, distance, velocity and etc..

According to (K. Sycara and Dai, 2010), in the social science field, the aim of investigating negotiation is to understand the factors involved in negotiation among people whereas in the computer science field the aim of investigating negotiation is to provide analytical formalizations to discover decision making processes that lead to optimal negotiation outcomes. Regardless of the field of the study, the framework of negotiation must include the principle of negotiation which is referred as a set of strategies (Kumar, 2015). In this research, the principle of negotiation is the study in the field of psychology. This is because, according to (Kumar, 2015), principled negotiation in psychological study allows each party to focus on deciding issues on their merits rather than adopting steadfast positions. In a robotic system, steadfast position is unnecessary, and it is more applicable for real life economics and business interaction. Therefore, it is necessary to comprehend that negotiation principle develops an autonomous robotic system which can improve the adaptive behaviour. The negotiation principle is discussed in the next subsection.

2.1.1 Negotiation principles

Even though there is no fixed rule in negotiation, there is a list of negotiation principles that are highlighted in the psychological field which will lead a negotiator to achieve a successful negotiation outcome. It is necessary to study the principle of negotiation in the psychological field. Negotiation principle refers to strategies and