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A NOVEL PATH PREDICTION STRATEGY FOR TRACKING INTELLIGENT TRAVELERS

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By

OMID REZA ESMAEILI MOTLAGH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

October 2009

To my Parents

For their Love and Support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia
in fulfilment of the requirement for the degree of Doctor of Philosophy

**A NOVEL PATH PREDICTION STRATEGY
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October 2009

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There are various technologies for positioning and tracking of intelligent travelers such as wireless local area networks (WLAN). However, the loss of actual positioning data is a common problem due to unexpected disconnection between tracking references and the traveler. Disconnection of the mobile terminal (MT) from the access points (AP) in WLAN-based systems is the example case of the problem. While enhancement of the physical system itself can reduce the risk of disconnections, complementary algorithms provide even more robustness in localization and tracking of the traveler.

This research aims to develop a novel path prediction system which could keep track of the traveler during temporary shortage of actual positioning data. The system takes the advantage of the past trajectory information to compensate for the missing information during disconnections. A novel decision support system (DSS) is devised with the ability of learning decisional as well as kinematical behaviors of intelligent travelers.

The system is then used in path prediction mode for reconstructing the missing parts of the trajectory when actual positioning data is unavailable.

An ActivMedia Pioneer robot navigating under fuzzy artificial potential fields (APF) and blind-folded human subjects are the two types of intelligent travelers. The reactive motion of robots and path planning strategies of the blinds are similar in that both of them locally acquire knowledge and explore the space based on route-like spatial cognition. It is proposed and shown that route-like intelligent motion is based on a combination of decisional and kinematical factors. The system is designed in such a way to integrate these two types of motion factors using causal inference mechanism of the fuzzy cognitive map (FCM). The FCM nodes are a novel selection of kinematical factors. Genetic algorithm (GA) is then used to train the FCM to be able to replicate the decisional behaviors of the intelligent traveler.

Experimental works show the capabilities of the developed DSS in human path prediction using both simulated and actual WLAN-based positioning dataset. Locational error is set to be limited to 1 m which is suitable for wireless tracking of human subjects with up to 10% improvement compared to the most related works. Both simulation and actual experiments were also carried out on the Pioneer platform. The accuracy in prediction of robot trajectory was obtained about 83% with considerable improvement compared to the recent methods. Apart from the positioning algorithm of this dissertation, there are several applications of this DSS to other areas including assistive technology for the blind and human-robot interaction.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SATU STRATEGI INOVATIF UNTUK MERAMALKAN PERJALANAN SUBJEK YANG PINTAR

Oleh

OMID REZA ESMAEILI MOTLAGH

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Rangkaian kawasan setempat tanpa wayar atau *wireless local area networks* digunakan untuk mengenal pasti peletakan dan kedudukan terminal bergerak (MT) dengan menggunakan parameter gelombang elektromagnetik yang pelbagai. Namun, terdapat masalah yang timbul dalam sistem ini iaitu kekerapan MT terputus daripada sudut akses atau *access points* (AP). Penambahbaikan sistem fizikal tersebut dapat merendahkan risiko MT terputus, manakala algoritma dan perisian dalam sistem membolehkan kedudukan dan pergerakan MT dikenal pasti dengan lebih utuh.

Kajian ini bertujuan membina satu sistem ramalan pergerakan yang baru yang mampu mengenal pasti kedudukan MT apabila jaringan tanpa wayar terputus. Sistem yang baru ini memperoleh maklumat trajektori MT yang lepas untuk menggantikan maklumat yang hilang semasa jaringan MT-AP terputus. Sistem sokongan keputusan yang baru (DSS) telah diperbaharui dengan kebolehan membuat keputusan secara bijak serta

perilaku kinematikal subjek pintar yang berperanan sebagai MT. Sistem ini kemudiannya digunakan untuk meramal perjalanan bagi membina semula bahagian trajektori MT yang hilang semasa jaringan terputus.

Robot *ActivMedia Pioneer* yang mengemudi di bawah bidang berpotensi buatan kabur (APF) dan subjek manusia yang ditutup mata merupakan dua jenis subjek pintar yang berperanan sebagai MT. Sementara proses pembuatan keputusan manusia berlaku dalam otak, bagi robot mobil proses ini berlaku pada algoritma berasaskan pergerakan. Pergerakan reaktif robot mobil dan strategi perancangan perjalanan manusia buta adalah serupa dari segi perolehan pengetahuan secara tempatan dan menjelajahi ruang berdasarkan kognisi ruang yang seperti jalan. Jenis pergerakan ini telah ditunjukkan bahawa ia berdasarkan gabungan pemikiran rasional dan faktor kinematikal.

DSS ini telah direka sebegitu rupa untuk mengintegrasikan faktor kinematikal dan pemikiran rasional dengan menggunakan mekanisma inferens penyebab bagi peta kognitif kabur (FCM). Nod-nod FCM merupakan pilihan konsep-konsep pergerakan baru. Algoritma genetik (GA) digunakan untuk melatih FCM agar boleh mereplikakan perilaku pembuatan keputusan MT. Dengan itu, FCM yang terlatih mampu meramal trajektori MT apabila jaringan terputus.

Penyelidikan membuktikan keutuhan DSS dalam meramalkan perjalanan manusia menggunakan set data WLAN secara simulasi dan sebenar. Kesilapan lokasi telah dihadkan kepada 1 m, yang sesuai untuk mengenal pasti kedudukan subjek manusia dengan pembaikan sehingga 10% berbanding dengan kebanyakan strategi yang sedia ada. Hasil penyelidikan telah dijadikan sebagai projek perintis. Ketepatan sistem dalam meramal perjalanan robot adalah dalam lingkungan 83% dengan kadar pembaikan yang lebih baik berbanding dengan pendekatan yang lain. Selain peletakan algoritma dalam kajian ini, terdapat beberapa aplikasi DSS dalam bidang-bidang yang lain termasuk teknologi bantuan untuk orang buta dan interaksi antara manusia dengan robot.

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I certify that an Examination Committee met on 29 October 2009 to conduct the final examination of Omid Reza Esmaeili Motlagh on his Doctor of Philosophy thesis titled "A Novel Path Prediction Strategy for Tracking Intelligent Travelers" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the student be awarded the degree of Doctor of Philosophy. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date: 14 January 2010

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and in not concurrently, submitted for any other degree at University Putra Malaysia or at any other institution.

OMID REZA ESMAEILI MOTLAGH

Date:

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LIST OF ABBREVIATIONS

AP	Access Point
AHL	Active Hebbian Learning
AOA	Angle of Arrival
AI	Artificial Intelligence
AI-DSS	Artificial Intelligence-Decision Support System
APF	Artificial Potential Fields
AGV	Automated Guided Vehicle
BHL	Blind Human Locomotion
BBD	Brain-based Device
CBR	Case-Based Reasoning
DR	Dead Reckoning
DSS	Decision Support System
EEG	Electro-Encephalography
EKF	Extended Kalman Filter
FHSS	Frequency Hopping Spread Spectrum
FCM	Fuzzy Cognitive Map
FLC	Fuzzy Logic Control
GA	Genetic Algorithm
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Host Control Interface
IMU	Inertial Measurement Unit
IR	Infrared
KF	Kalman Filter
KBS	Knowledge-based System
LQ	Link Quality
LBS	Location-based Service
MAB	Malaysian Association for the Blinds
MT	Mobile Terminal

NN	Neural Network
NLP	No Light Perception
PDA	Personal Digital Assistant
PSO	Particle Swarm Optimization
RF	Radio Frequency
RFID	Radio Frequency Identification Devices
RSSI	Received Signal Strength Indication
RPY	Roll-Pitch-Yaw
RMS	Root Mean Square
SNR	Signal to Noise Ratio
SW	Straight Walk
SWSR	Straight Walk and then Straight Return
TOA	Time of Arrival
UDP	Undetectable Direct Path
WF	Wall Following
WLAN	Wireless Local Area Network
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background

There are various techniques for tracking intelligent travelers, i.e., subjects whose motion involve deliberative as well as reactive behaviors. Motion tracking has wide range of applications in security, surveillance, etc. However, due to partial or total loss of actual positioning information, motion prediction techniques have to be employed using simulation tools to predict the future motion. There are many algorithms developed for motion prediction of intelligent and non-intelligent travelers (Bennewitz et al., 2002; Bruce and Gordon, 2004; Iglesias and Luengo 2007; Vasquez and Fraichard, 2004; 2005; Ciurana et al., 2007; 2007b).

As the first approach, there are different kinematical models of path prediction for moving objects such as dead reckoning (DR) (Randell et al., 2005; Warren and Fajen, 2004). But when it comes to intelligent subjects e.g., human or any biological mechanism, there is no mathematical solution to take the challenge of motion prediction that is due to inherent uncertainties and variability of such systems. Kalman filter

(Kalman, 1960) and other recursive filters, as well as Markov localization (Fox, 1998) have been widely used to minimize DR errors. However, they require continuous supply of actual data for update stage of the filter or update of the transition matrix.

In these situations, another approach is to resort to statistical models (Vasquez and Fraichard, 2004). However, the main problem of statistical methods is in the stage of clustering and generation of path patterns (Jain et al., 1999) which requires lots of experimental work with subjects of the same type that is not always possible.

The third approach is to use the knowledge of the past trajectory to predict the future motion based on kinematical (Ciurana et al., 2007a; 2007b), statistical (Vasquez et al., 2005), or artificial intelligence models (Luengo and Iglesias, 2004). The future trajectory of an intelligent subject can be estimated by learning its motion behaviors from the past trajectory. However, in the related works, identification of the motion factors involved in generation of the past trajectory has been based on either kinematical characteristics, or decision making behaviors.

Wireless local area network (WLAN) systems are used for indoor tracking of human and other intelligent travelers e.g., mobile robots, automated guided vehicles (AGV), which are equipped with wireless mobile terminals (MT). Traditionally, the wayfinding behaviors of these travelers have been investigated from a single point of view. The traveler has been either treated as a moving object based on kinematical analysis of motion factors, or as a truly intelligent subject based on decisional factors of motion.