FACE DETECTION USING SKIN COLOR AND EIGENFACE TECHNIQUES FOR HUMAN-ROBOT INTERACTION

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Dedicated to my beloved family

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ABSTRACT

The main objective of the research undertaken here is to develop an automated face detection system to be implemented on a mobile robot for human-robot interaction (HRI) applications. HRI has gained increasing attention in recent years due to escalating numbers of assimilation of robots into human lives. Face detection is a vital aspect to sense human presence in a robotic environment. Despite the fact that research on face detection has long been carried out, development and implementation of face detection on mobile robot remains a great challenge due to the complexity of the robot itself. A HRI model is presented to represent a human-robot relationship in the shared robotic environment. The work focuses in building a natural form one human to one robot HRI based on face detection. The main concern of the work is to develop face detection using multiple features to increase robustness of the system. The face detection comprises of a skin color detection based on various chrominance information of images using multiple color spaces. Later, the skin region is verified using crisp rules face verification. Different rules are applied at different robot behavior that accommodates the HRI. Where applicable, eigenface method is implemented for further verification. Later, the robot makes decision and reacts based on the face detection result using heuristic search on the decision tree. An adaptive weighting technique for the branches in the decision tree is presented to solve problem for various robot behaviors and noise in images. Graphical user interface (GUI) and text-to-voice ability are employed on the robot to support HRI. Through experiments, it appears that the robot can successfully detect human face and react meaningfully towards the face that has been detected.

ABSTRAK

Tujuan utama penyelidikan ini dijalankan adalah untuk menghasilkan satu sistem automasi pengesanan muka manusia yang ditempatkan pada sebuah robot mudah alih untuk aplikasi interaksi antara manusia dengan robot. Interaksi antara manusia dengan robot semakin mendapat perhatian kerana bilangan robot yang diasimilasikan dalam kehidupan manusia meningkat. Pengesanan muka penting untuk mengesan kehadiran manusia dalam persekitaran robotik. Walaupun penyelidikan dalam bidang pengesanan muka telah lama dijalankan, pembangunan and aplikasi pengesan muka pada robot mudah alih sukar disebabkan kompleksiti pada robot tersebut. Satu model diberi sebagai satu gambaran untuk hubungan manusia-robot dalam sebuah lokasi yang dikongsi bersama. Kerja ini fokus pada pembangunan interaksi antara satu manusia dengan satu robot secara semulajadi menggunakan pengesanan muka. Kerja ini menitikberatkan pembangunan pengesan muka mengunakan pelbagai ciri untuk meningkatkan prestasi sistem tersebut. Pengesan muka itu terdiri daripada pengesan kulit manusia melalui variasi maklumat krominasi pada imej menggunakan pelbagai ruang warna. Kemudian, sektor kulit tersebut akan dikenalpasti jika ia adalah muka dengan menggunakan peraturan tetap. Peraturan adalah berbeza untuk tingkah laku robot yang berlainan bagi menampung interaksi manusia dengan robot. Jika berkenaan, cara *eigenface* akan diaplikasikan untuk proses pengenalpastian selanjutnya. Kemudian, robot membuat keputusan dan memberi reaksi berdasarkan pencarian pintar pada pokok keputusan. Satu teknik pemberat secara adaptif untuk cabang pada pokok keputusan diberi untuk menyelesaikan masalah pelbagai tingkahlaku robot dan kebisingan dalam imej. Antaramuka pengguna secara grafik dan kemampuan penukaran ayat kepada suara diaplikasi pada robot untuk menyokong interaksi manusia dengan robot. Melalui eksperimen-eksperimen yang dijalankan, robot tersebut dapat mengesan manusia dengan berjaya dan memberi reaksi yang bermakna kepada muka yang dikesan.

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LIST OF ABBREVIATIONS

A/D	-	Analog-to-digital converter
Ah	-	Ampere per hour
AI	-	Artificial intelligence
API	-	Application program interface
Av_i	-	are the eigenvectors of covariance matrix C
b	-	Blue component in normalized RGB color space
B	-	Blue component in RGB color space
BLDC	-	Brushless direct current
cm	-	Centimeter
col	-	total number of pixels in x-axis of two-dimensional array
C	-	Color vector with non-zero luminance
C	-	Covariance matrix,
C'	-	Radial projection of C in Maxwell
CCD	-	Charge-coupled device
CIE	-	Commission International de I' Èclairage
DARPA	-	Defense Advanced Research Projects Agency
DC	-	Direct current
DIFS	-	Distance to face space
DIO	-	Digital input-output
DLL	-	Dynamic link library
DOF	-	Degree of freedom
e^2	-	Euclidean distance
ETA	-	Electronic travel aids
fps	-	Frames per second
F	-	face
FALSE	-	False face detection
FROI	-	Face region of interest

G	-	Green component in RGB color space
GHz	-	Giga hertz
GUI	-	Graphical user interface
h	-	height of initial SROI
h_{new}	-	New height of segmented SROI
h_{old}	-	Old height of SROI
H	-	Hue component in Modified HSV color space
HCI	-	Human-computer interaction
HMI	-	Human-machine interaction
HRI	-	Human-robot interaction
HSV	-	Color space for specification in terms of hue, saturation and value
I	-	Intensity component in Modified HSV color space
I/O	-	Input-output
IQ	-	Intelligent Quotient
j	-	Location of pixel position in one-dimensional array
LAB	-	Color space with a perceptually uniform coordinates in 3-dimensional color space
LCD	-	Liquid crystal display
min	-	Minimum value of pixels in one image
max	-	Maximum value of pixel in one image
MB	-	Mega byte
MFC	-	Microsoft Foundation Class
MISSED	-	Missed face detection
MRF	-	Markov random field
n	-	1, 2, 3, …, number of pixels
n	-	15 different skin images
n_{Face}	-	Number of face detected by human
n_{False}	-	Number of non-face images detected by computer
n_{Frames}	-	Number of frames process in T
n_{Missed}	-	Number of face not detected by computer
n_{True}	-	Number of face correctly detected by computer
nm	-	Nano meter
N	-	Number of elements in the one dimensional image vector
NF	-	Not face

NS	-	Not skin color
NN	-	Neural network
NSF	-	National Science Foundation
M	-	1, 2, 3, …, number of images
PCA	-	Principal component analysis
PCMCIA	-	Personal Computer Memory Card International Association
Qc	-	Quasi-chroma component in Modified HSV color space
r	-	Red component in normalized RGB color space
R	-	Red component in RGB color space
RAM	-	Random Access Memory
RGB	-	Red, green, blue color space
RIA	-	Robotics Industries Association
s	-	Standard deviation
SDK	-	Software development kit
SROI	-	Skin region of interest
SVM	-	Support vector machine
t	-	Time for robot to change position
t_0	-	Unique positive real number
th	-	Threshold value for Euclidean distance
T	-	Total time utilized to process a series of image frame
TRIPOD	-	Template for Real-time Image Processing Development
TRUE	-	True face detection
u_i	-	Eigenface
U	-	U component in YUV color space
USB	-	Universal serial bus
v	-	Volt
v_i	-	Eigenvectors of $A^T A$
V	-	V component in YUV color space
w	-	Width of initial SROI
$\boldsymbol{w}$	-	Weight
w_{old}	-	Old width of SROI
x	-	X component in CIE's XYZ color space
xyz	-	Color space with a perceptually uniform coordinates in chromaticity plane

x	-	Location in x-axis of two-dimensional array
X	-	Pixel value
$\overline{X}$	-	Mean of all pixel values
y	-	Luminance component in CIE's xyz color space
y	-	Location in y-axis of two-dimensional array
Y	-	Luminance component in YUV color space
YCbCr	-	Color space for a digital color system
YIQ	-	Color space for encoding a composite video signal where Q component has narrower bandwidth of spectrum than I component
YUV	-	Color space for encoding a composite video signal where UV components occupy the same bandwidth of spectrum
z	-	Z component in CIE's XYZ color space
ρ, α, β	-	Positive real values used in RGB to CIE's XYZ color space conversion
μ_i	-	Eigenvalue
Γ	-	Training set of face database
Γ_{new}	-	Input face image
Ψ	-	Average image
Φ	-	Image difference

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CHAPTER 1

INTRODUCTION

Studies in the area of robotics have been growing swiftly for the past decade and their developments are even faster at the turn of this millennium. Previously, researchers within the robotics community have been emphasizing more on technical challenges of achieving mobility, control and intelligence rather than social issues.

Lately, the development of robotics has motivated the feasibility of integrating robots into human daily lives. Therefore, study on human-robot interaction (HRI) is taken to more serious consideration in research within the robotics community. As robots have to interact with humans, it is important to detect humans in the first place. The research presented here focused on developing a natural HRI system based on face detection that integrates a HRI model to clarify the human-robot relation.

Section 1.1 presents introduction to robotics. Next, section 1.2 describes on research background of HRI. The problem background of developing a HRI system is mentioned in section 1.3. By identifying the problem, objectives of the study are highlighted in section 1.4. Meanwhile, the scope of the project is explained in section 1.6. Later, section 1.7 presents the outline of thesis. Last but not least, the summary of Chapter 1 is portrayed in section 1.8.

1.1 Introduction to Robotics

Robots are moving machines created by men. People, when mentioned about robots, will certainly thought of movies such as War of the Worlds, Star Wars, Robocop, Terminator, Matrix and most recently I-Robot. The term “robot” originates from a play staged in London, called "Rossum's Universal Robots" written by the Czech writer, Karel Çapek, in 1921. Robot is derived from a Czech word *robota*, which means a servitude or forced worker (Groover, 1986).

In general definition, a robot can be described as an automated machine, performing functions in human manner, automation and mechanical slave (Webster, 1995). Robotics Industries Association (RIA)’s defined a robot as a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks (Groover, 1986). Arkin (1998) provided another working definition of robots, which is inclusive of mobile robots. According to him, an intelligent robot is a machine able to extract information from its environment and use knowledge about its world to move safely in a meaningful and purposive manner.

Human and robots have a strong correlation ever since the emergence of the very first idea of robotics. All robots fulfill one purpose, which is to serve mankind. Isaac Asimov listed the basic principles of robot and human relationship and how the robot should behave in Three Laws of Robotics (Groover, 1986). The laws stand as an informal universal rule on how robot should conduct itself in a human world.

Throughout the years, robots are changing in shape, size and mobility method. Along with their physical evolution, issues of robot intelligence come into the limelight in order for a robot to behave and act smartly in a real world. Nevertheless, with strong development in artificial intelligence (AI), robots are claimed to have ability to think, learn and evolve by their own (Pfeifer, 1999). According to Hans Moravec (1991), robots will have human perceptual, motor abilities and their own superior reasoning powers after year 2050. Combining intelligence and computational capabilities, will robots may become superior to human one day?

Until today, humans have not observed any robot that causes intentional destruction to mankind. In fact, robots have aided human in many ways. Robots provide support, companionship, entertainment, and etc. Eventually, study in robotics stirs towards human-robot interaction (HRI), as more robots assimilate into human daily life.

1.2 Research Background

Today, HRI has received much attention in robotics. According to Schlotz (2003), HRI started with tele-operation for factory platforms. HRI is a cross disciplinary area, that involves psychology, sociology, cognitive science, communication and robotics. HRI refers to how human and robot interact in a given situation. HRI has been a fraction of robotics research but it is still in its infancy as researchers are more focused on achieving better control and mobility in robots (Murphy and Rogers, 2001).

Service robots are sample of HRI and they are used for specialized task. Service robot can be listed as exploratory robots, maintenance robots, military robots and surgical robots. Those robots perform dangerous tasks or they can venture into unsafe environments. Another type of service robots is more human oriented. They are the office robots, home robots, hospital robots and robot tour-guides. The robots tend to interact more with human and help people in a more personalized and friendly way. The service robots hold responsibility to perform some serious task at a specified time length. Thus, they are sometimes referred as the occupational robots.

Commercialization of mobile robots for general users can be found lately, as the cost of making and marketing robots become more economical. Personal robots are robots that can be purchased for individual usage. One of the personal robots is the Electronic Travel Aids (ETA) for the visually impaired to navigate and avoid obstacles (Borenstein and Ulrich, 1997). Other types of personal robots, which are growing in quantity, are the robot toys. Aside providing service, the robots are able to aid and offer entertainment to human. In other words, robots are able to help human physically and emotionally.

Generally, the modalities for HRI are speech, vision and wireless techniques. Wireless based HRI requires a communication tool in between the robot and human. If a robot is in direct contact with a human, it must have some natural means of communication (Sekmen, 2000). Therefore, speech and vision-based HRI are more widely used for natural HRI development as no equipments or tools are needed in between human and robot during the interaction process.

Speech processing is essential for robot to understand the verbal commands given by a human. However, the robot must be capable to acknowledge the human presence and location in order to interact with the person at the first place. Thus, robot's vision comes into limelight in HRI research.

Basically, a robot needs to 'see' a human in the robotic environment. Through machine vision, knowledge of the environment is acquired and processed by a robot and thus, providing a certain level of intelligence to the robot for HRI. Vision-based techniques used in HRI are gesture recognitions using body gesture and posture. Over the past few years, face processing has also emerged as an important approach for HRI. Face processing methods includes face detection, face localization, face tracking, face recognition and facial expression recognition.

In order to proceed to the mentioned face processing, it is crucial to have good face detection ahead of it. Human face detection is taken as a natural representation and visualization of a human existence in the robot's environment. According to Marsic *et al.* (2000), the face to be "seen" by the computer may be complex but it is desirable to unburden a human to the extend possible. Through face detection, a human does not have to speak or manipulate the robot physically in order for robot to detect human presence. Due to the fact, face detection is an essential ability to have in HRI robots.

1.3 Problem Background

The study begins by reviewing the impact of robots to human life. It is without doubt that greater understanding of the vital link between human and robots is essential when planning to integrate robots into human-centric robotic applications.

The human-centric robotic applications are basically the service robots and personal robots, as those robots have to serve humans. Service robots and personal robots applications are aimed for a novice user. In this context, a novice refers to a potential human user of that robotic application, who has little or no experience of handling robots. For this reason, HRI is also closely related to human-centric design.

Based on literature review, the study highlights some issues in HRI development. They are generalized as the following:

1. Structural relationship of human, robot and the environment
2. Natural human-robot interaction
3. Challenges in robot design

1.3.1 Structural Relationship of Human, Robot and the Environment

Studies on HRI are important as robots become more human-centric. Previously, robot researches basically emphasize on achieving intelligent control and mobility. Besides the robot and its operating environment, human factor is integrated into the robotic system. Human factor refers to human existence and human intervention during HRI operation. Thus, information flow increases. A structural relationship is vital to manage information sharing between human and robot for decision making of both parties in the shared environment. Based on the literature review, established organized structure for describing human-robot relation and interaction could not be clarified.

1.3.2 Natural Human-Robot Interaction (HRI)

Natural relationship of human and robot in HRI is essential to create a level of comfort during the process. Secondly, a robot that can interact naturally will tend to attract human user. An example of a natural interaction is when a person talks to another person face to face. In this case, the human and robot "talks" to each other without any help from external equipment, which is neither part of body of the robot nor the human. In human point of view, the interaction should be as natural as possible to provide attraction and simplicity. As a whole, natural interaction can provide a positive psychological factor for the interaction process.

1.3.3 Challenges in Robot Design

Reaction of the robot during HRI is affected by the challenges faced in robot design. Similar to the challenges in general robotics, the main challenges in building real robots are (Tan, 2002):

Robustness: Robot that operates in real world is succumbed to the uncertainties in the environment, as prior knowledge of the environment may be incomplete or non-existent. Knowledge gained from sensors may be incomplete, inaccurate or irrelevant. The robot itself has limitation due to imperfection of its sensors and actuators. Environment that is dynamic in nature also leads to unpredictable changes. However, the robot must be able to react intelligently even though it is governed by various limitations. Hence, robustness is essential to handle the uncertainties.

Real-time responsiveness: A real-time system must satisfy explicit bounded respond time constraint to avoid failure. A robot has to think and react within a suitable period of time. In order to interact naturally, robot must be able to respond to human in a "comfortable" time frame. However, comfortable time zone for each person is dissimilar as every human expectation is inconsistent. However, the main point is to avoid the robot to be in a state where its reaction is no longer meaningful.

1.4 Research Objectives

In summary, the main objective of the study is to develop an automated face detection on a mobile robot for potential HRI implementation. The sub-objectives in order to accomplish the main objective of the study are:

1. To propose a HRI model to manage information flow;
2. To build a mobile robot that can support a basic HRI based on face detection;
3. To develop a face detection application program that can operate in real-time;
4. To integrate the face detection on the mobile robot and test the responsiveness of the system in the robot's environment.

1.5 Scope of Project

The main purpose of the research is that it emphasizes on developing automated face detection ability on mobile robot in an organized method for possible HRI application by incorporating the proposed HRI model. The robot does not utilize any other sensors to sense human presence. Hence, the robot mainly relies on the face detection for motion and reaction.

The research is divided into three main modules. The initial work is the construction of a HRI model. The second part involves development of a face detection algorithm that is robust enough to function within the robot environment in real-time. Improvement of face detection using skin color and eigenface techniques is performed for the HRI application. The third part is testing of the developed system in real world environment. A heuristic search technique is employed for the robot to handle information, make decision and action based on the face detection result. The responsiveness of the robot includes visualization of the face detection result and robot's written command on a graphical user interface, robot's voice command and its movement in the robotic environment.

1.6 Outline of Thesis

The thesis is organized in seven main chapters. Chapter 2 gives an overview of the background studies on areas that are useful to build a face detection based mobile robots for HRI. Next, detail of the proposed methodology is discussed in Chapter 3. A HRI model is proposed to give a clear view of human robot relation. Meanwhile, the face detection development methodology will be explained in details in Chapter 4. The face detection comprises of initial face detection via skin color detection and face verification via rule based and eigenface. Chapter 5 covers on system integration of the face detection into a real mobile robot and the robot reaction based on the information attained during HRI. Later, experimental results, comparisons and discussions are presented in Chapter 6. Finally, Chapter 7 contains the conclusions of study, which includes the contributions and future developments of the work presented.