HUMANOID FULL-BODY MOTION GENERATION BASED ON HUMAN GAIT USING EVOLUTIONARY PARETO MULTI-OBJECTIVE OPTIMIZATION

By

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Designing and realizing artificial systems in human image have always been a fascinating idea for researchers. Humanoid robots with human-like expression are capable of executing tasks in complex environments within the living space of humans. The first and the most important motion for humanoid robot is the walking in a complicated and dynamically balanced manner which differentiates it from other robots. The primary motivation behind this work is to propose a more realistic full-body motion generation method based on learning and optimization in order to translate the recorded human motion to a dynamically feasible motion for a bipedal humanoid robot. Following the objective of this work, high quality captured human motions are used to show the trajectory sequence of robot joints movements. Evolutionary pareto multi-objective optimization method is used in this work in order to optimize an artificial neural network weights which is responsible of applying appropriate modifications on the reference motion lower-body based on the robot real-time sensory feedbacks. Evolutionary pareto multi-objective optimization method is applied to find an optimized artificial neural network based solution for translating the recorded rough walking motion to a dynamically

balanced one with maximum similarity to the human way of walking. Because of the numerous advantages of computer simulation, the simulated Sony QRIO humanoid in USARSim simulator is utilized in this work as a proper platform for mimicking human motions. According to the communication protocols in USARSim and by importing multithreading from Java to Matlab, a powerful Mobile Robots Communication and Control Framework (MCCF) is developed. It offers faster and easier communication process with the USARSim server within Matlab code. It takes the advantages of other analysis and control methods that have been provided in Matlab tool-boxes. Finally, a full-body motion generation method was introduced which is able to translate the original human motion data to a dynamically stable motion for a specific robot.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

HUMANOID PENUH-BADAN USUL GENERASI MENGGUNAKAN GAIT MANUSIA BERDASARKAN EVOLUSI PARETO MULTI-OBJEKTIF PENGOPTIMUMAN

Oleh

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Mereka bentuk dan merealisasikan sistem kecerdikan buatan berdasarkan imej manusia telah sentiasa menjadi satu idea yang menarik bagi para penyelidik. Robot humanoid yang mempunyai ekspresi seperti manusia mampu melaksanakan tugas-tugas dalam persekitaran yang kompleks dalam ruang kehidupan manusia. Ciri-ciri gerakan manusia yang paling penting adalah kemampuan berjalan dengan cara yang seimbang serta rumit dan dinamik dan ini membezakannya dengan robot-robot yang lain. Motivasi utama di sebalik kerja-kerja ini adalah untuk mencadangkan penjanaan yang lebih realistik untuh gerakan penuh badan berdasarkan pembelajaran dan pengoptimuman untuk menterjemahkan gerakan manusia yang dirakam kepada gerakan dinamik yang sesuai bagi robot humanoid yang berkaki dua. Berikutan objektif kerja ini, pergerakan manusia berkualiti tinggi digunakan untuk menunjukkan urutan trajektori pergerakan sendi robot. Kaedah pengoptimuman evolusi Pareto digunakan dalam kerja-kerja ini untuk mengoptimumkan berat rangkaian neural tiruan yang bertanggungjawab membuat perubahan yang sesuai dengan merujuk kepada badan yang lebih rendah maklumbalas deria robot

menggunakan masa sebenar. Kaedah pengoptimuman evolusi Pareto pelbagai objektif digunakan untuk mencari penyelesaian rangkaian berasaskan neural tiruan yang optimum untuk menterjemahkan gerakan berjalan secara kasar yang dirakam kepada sesuatu yang dinamik seimbang dengan persamaan maksimum dengan perjalanan manusia. Oleh kerana simulasi komputer mempunyai banyak kelebihan, simulasi Sony QRIO humanoid di USARSim simulator yang digunakan dalam kerja ini sebagai platform yang sesuai untuk meniru pergerakan manusia. Berdasarkan protokol komunikasi USARSim dan dengan menggunakan thread berbilang dari Java ke Matlab, Mobile Robots Communication and Control Framework (MCCF) telah dibangunkan. Ia menawarkan kaedah komunikasi yang lebih cepat dan mudah dengan pelayan antara USARSim dan kod Matlab. Ia juga mengambil kelebihan analisis dan kaedah kawalan lain yang telah diperuntukkan dalam Matlab. Akhir sekali, kaedah generakan penuh-badan telah diperkenalkan yang mampu untuk menterjemahkan data gerakan asal manusia kepada gerakan yang dinamik dan stabil untuk sesebuah robot.

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I certify that a Thesis Examination Committee has met on 14 August 2012 to conduct the final examination of Saeid Mokaram Ghotoorlar on his thesis entitled "**Humanoid Full-Body Motion Generation Based On Human Gait Using Evolutionary Pareto Multi-Objective Optimization**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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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 is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

SAEID MOKARAM GHOTOORLAR

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
AMC	Acclaim Motion Capture
ASF	Acclaim Skeleton File
COG	Center of Gravity
COM	Center of Mass
DO	Duration Objective
DOF	Degree of Freedom
EA	Evolutionary Algorithm
GA	Genetic Algorithm
GUI	Graphical User Interface
MCCF	Mobile robots Communication and Control Framework
MO	Modification Objective
MoCap	Motion Capture
MOO	Multi Objective Optimization
RL	Reinforcement Learning
SOO	Single Objective Optimization
USARSim	Urban Search And Rescue Simulation
UU	Unreal Unit
ZMP	Zero-moment point

LIST OF SYMBOLS

•	The Articulations
$\otimes$	The Skeleton links
O_i	Joint Center
θ_x	Joint Rotation Angle in x Axis
σ	Standard Deviation

CHAPTER1

INTRODUCTION

1.1 Overview

The fascinating idea of designing and realizing artificial systems in human image is almost as old as humanity. Some formal studies on artificial machines were found in Leonardo da Vinci's drawings [1, 2] (Figure 1.1). Obviously, the desire of making humanoid robots increased more rapidly in the 18^{th} century. Reproducing human movements in some specific tasks like writing or playing music was possible by creation of mechanical systems. The Steam Man (moved by steam-engine) was built by John Brainerd and the Electric Man was built by Frank Reade Junior in the 19^{th} century [1, 2].

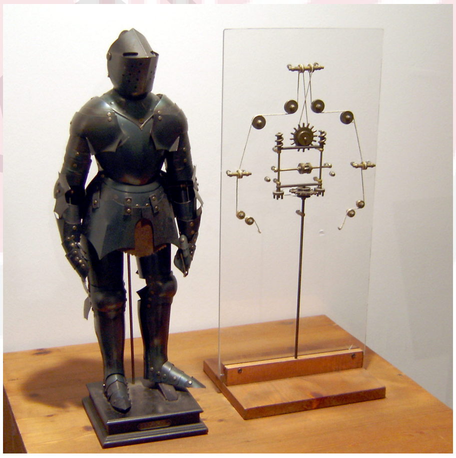

Figure 1.1. Leonardo da Vinci's Humanoid

After a long eclipse in this area, the studies were revived in the 20^{th} century by scientists instead of the brilliant engineers or artists of the previous centuries. Most of the first studies on bipedal robots were carried out in Japan by introducing different bipedal robots like a whole family of Waseda Legged (WL) robots in the robotic team of Waseda University [3]. Companies developed bipedal and humanoid robots very early. Honda, in particular, built a whole range of bipedal robots from E0 to E6 and then humanoid robots from P1 to P3 and finally, the most complete humanoid, ASIMO [4] with a height of 1.4 m and 26 degree of freedom (DOF) which is moved by 26 electric motors. Also in the US, different studies were carried out at Massachusetts Institute of Technology (MIT) in the 1980s [5, 6, 7] on jumping robots which are first in performing walking and running movements in a dynamic and stable gait. The bipedal robots called Biped Planar, Spring Flamingo, Spring Turkey, Uniroo and 3D Biped were introduced with a variety of remarkable dynamic moving gaits performances.

Currently, research in the field of humanoid robotics are diverging into various categories. However, the main idea for humanoid robotics is to enable them to execute tasks in complex environments within the living space of humans. Several humanoid robot platforms like WABIAN [8], ASIMO [4], QRIO [9] and HRP [10] were developed and equipped with high performance actuators, sensors for environmental awareness, and powerful computers. However, they still cannot handle many basic chores that humans do. Humanoids are difficult systems to model and control, therefore, various research approaches were proposed and tested different humanoid robot control strategies including zero moment point (ZMP), self-collision detection and walking pattern generation.

Nowadays, robots are making considerable impact on many aspects of modern life, from industrial manufacturing to healthcare, transportation, and exploration of deep space and sea. The dream to create machines that are skilled and intelligent has been part of humanity from the beginning of time and tomorrow robots will be as pervasive and personal as today's personal computers. Following this idea, in the past years there have been continuous efforts to foster robotics at the earliest stages of education [1].

1.2 Problem Statement

Nowadays, research on humanoid robot is one of the most exciting topics in robotics field because, humanoid robots potentially can achieve what humans are able to perform in the environment which is designed for humans by taking advantage of their physical characteristics [1]. Humanoids come in a variety of shapes and sizes, from a complete human-size legged robot to an isolated robotic heads with human-like expressions. In contrast to the primary works which mainly focused on individual aspects of the humanoid robotics like walking, currently many studies are equipping humanoid robots with full-body motion generation concepts to make and control full humanoid robots.

The problem associated with the humanoid full-body motion generation is separated into the design of a reference motion trajectory and the design of a stabilized controller. Basically, the reference motion trajectory represents a sequential trace of joint positions at each sampling time. Unlike the standard industrial manipulators, a humanoid usually has more than 18 DOFs. Consequently, for a given pose of the robot's hand, there are many postures. Depending on the different objective, there are different strategies for generating humanoid robots' reference motion. A number of methods are exist for humanoid robot reference motion generation such as motion capture system, graphical user interface (GUI) method, teleoperation interface and automatic motion planning. Human motion and motion capture systems are the most interesting approach for generating the reference motion for humanoid robots because these robots are inspired and designed based on human body and replicate most of the important human body structures and articulations. The full body motion planning is a challenging high dimensional problem and captured human motions can show sequences of joint movements and can reduce the dimension of this problem.

Since even the most advanced available humanoid robots are not replicating the exact human body structure, it is not possible to have a dynamic balancing motion by applying captured human motion directly on a humanoid robot. Captured human motion needs to be translated and adapted for specific robot to have a dynamically-stable motion. Different techniques for converting rough reference motions to stable motions have been proposed such as the Dynamics Filter [11] and the Auto Balancer [12]. These methods are able to translate the rough captured human motions and other trajectories which were obtained from other reference motion generation methods to a stable motion for a given robot using classical control methods like Zero-Moment Point (ZMP) [13] and inverted pendulum. However, the robot movement using ZMP differ from human locomotion in significant ways [1, 2] and because these methods modify the original reference trajectory based on the ZMP concept without any optimization, the modified motion of the robot can be far from the original reference trajectory and the human-like way of performing a task. Large dimensions of the humanoid locomotion problem space make it difficult to utilize classical control approaches and optimization. On the other hand, learning and nature inspired techniques like Reinforcement Learning (RL), Artificial Neural Networks (ANN) or Genetic Algorithms (GA) are more suited to learn and optimize the key parameters of stable walking task without making an exact complete model of the environment and the robot itself [14]. In contrast to the classical approaches which have been utilized in Dynamics Filter and Auto Balancer for computing an accurate dynamics of robot structure, learning and nature inspired techniques can be apply with an abstract information or sensory feedback from the robots sensors.

GA is one of the most commonly used methods in unsupervised learning tasks like humanoid robot walking. One of the advantages of GA is that it requires much lower amount of memory in compare with other methods like RL and also it can be used in real and non-markovian problems like humanoid robot motion control [14]. Its main drawback is the long process of evolution; therefore, one issue in this work is to reduce the problem space. The process of translation and adaptation of the captured human motion for a specific robot mainly refers to applying appropriate modification on the reference motion trajectory in order to have a dynamic balancing motion. In some works like Dynamics Filter and Auto Balancer these modifications were applied to all of the robot joints in a way to shift the robots' COG to an appropriate position and control the robot. On the other hand, another approach is to limit these modifications to some specific joints for example like some other previous works that control the robot balance by only controlling the foot placement position or the robot support point in order to simplify the controlling process [15, 16, 17].

The primary motivation behind this work is to give attention to the realistic motion generation by minimizing the amount of modifications on the reference motion and maximizing the walking duration of the robot at the same time by considering them as a MOP. Pareto MOO GA is a proper method for this kind of tasks because it is known as an intelligent technique which follows the population-based approach and individual dominance for optimizing multiple objectives simultaneously without having prior knowledge about the importance and limitation of each objective[18].

Few of the works on humanoid robots have been implemented entirely on physical robots because of some limitations. For example using the EA or RL in robotic will face to different major problems: 1.Evolutionary take a long time, especially if it is carried out on a single robot. 2.The physical robot can be damaged because populations always contain a certain number of poorly performing individuals by effect of random mutations. 3.Restoring the environment to initial conditions between trails of different individuals or populations may not always be feasible without human intervention. 4.Evolution of morphologies and evolution of robots that can grow during their lifetime is almost impossible with today's technology without some level of human intervention. For those reasons, researchers often resort to evolution in simulation and transfer the evolved controllers to the physical robot [14, 19].

1.3 Objectives

The humanoid robots are made with the idea of performing tasks in a human-like way. This project also follows the same idea and concentrates on utilizing original human motion as reference to have realistic motion.

The aim of this work is to propose a method for translating a captured human gait as reference walking motion for a simulated QRIO humanoid robot. This method which concentrates on modifying the lower-body of the reference motion, uses Pareto MOO GA technique in order to maximize the walking duration of the robot and minimize the modifications at the same time. Achieving this goal requires several prerequisites as follows:

- Obtaining a reference motion for the humanoid robot walking from a validated human motion capture database.
- Designing and implementing a realistic motion translation method using ANN with Pareto GA for QRIO humanoid robot in order to adapt the reference motion for the robot in a way that it can complete the walking task without falling.
- Evaluating the performance of the proposed method.

1.4 Thesis Overview

This work follows the idea of proposing a method for translating captured human gait for a simulated QRIO humanoid robot using ANN with Pareto GA. An ANN structure was utilized in order to calculate and apply appropriate modifications on six DOFs of the robots lower-body joint motion in order to achieve a dynamically stable walking motion. These modifications are calculated based on the robots sensory feedbacks. The ANN weights are adjusted using a GA optimization method which known as Pareto MOO.

First of all, the motivations of this thesis and the challenges of humanoid robot motion generation, as well as the objectives will be explained. Chapter 2 reviews related literatures to the bipedal humanoid robots and their full-body motions trajectory generation. Chapter 3 describes the methodology of this work. First, MoCap will be introduced as a complete high quality human motion database. Then, the implementation of MCCF as an open source multi-robot communication and control interfaces for USARSim within Matlab will be explained. Finally, implementation of the proposed learning and optimization method for humanoid full body motion generation will be explained. In chapter 4 this work will be evaluated by presenting and discussing the yielded results. Finally, a conclusion will be presented in Chapter 5 with an explanation of possible related future works.

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