

# Chapter XI

## Walking with EMO: Multi-Objective Robotics for Evolving Two, Four, and Six-Legged Locomotion

**Jason Teo**

*Universiti Malaysia Sabah, Malaysia*

**Lynnie D. Neri**

*Universiti Malaysia Sabah, Malaysia*

**Minh H. Nguyen**

*University of New South Wales, Australia*

**Hussein A. Abbass**

*University of New South Wales, Australia*

### ABSTRACT

*This chapter will demonstrate the various robotics applications that can be achieved using evolutionary multi-objective optimization (EMO) techniques. The main objective of this chapter is to demonstrate practical ways of generating simple legged locomotion for simulated robots with two, four and six legs using EMO. The operational performance as well as complexities of the resulting evolved Pareto solutions that act as controllers for these robots will then be analyzed. Additionally, the operational dynamics of these evolved Pareto controllers in noisy and uncertain environments, limb dynamics and effects of using a different underlying EMO algorithm will also be discussed.*

### INTRODUCTION

Although multi-objective optimization (MO) and evolutionary multi-objective optimization (EMO) techniques have been used successfully in numer-

ous engineering and scientific applications (Coello Coello, van Veldhuizen, & Lamont, 2002; Deb, 2001) there is much less work that applies these techniques to robotics. Being a highly complex endeavor, the automatic generation of robots with

multiple distinct and useful behavioral as well as morphological characteristics can be highly beneficial. One possible way of achieving this is through the use of EMO techniques, which can automatically synthesize robots with multiple distinct characteristics in a single evolutionary run (Teo & Abbass, 2004). For an introduction to EMO techniques, the reader may refer to Chapter 1.

In this chapter, we will attempt to demonstrate the various robotics applications that can be achieved using EMO techniques. The main objective is to demonstrate practical means of generating simple legged locomotion for simulated robots with two, four and six legs using EMO and then presenting the operational performance as well as complexities of the resulting evolved Pareto solutions that act as controllers for these robots. The use of simulated robotics should not be discounted here as it has been recently shown that the use of simulation in evolutionary robotics is particularly beneficial in the training phase of automatic behavior generation in real physical robots (Walker, Garrett, & Wilson, 2003). Furthermore, we will provide additional discussions on the operational dynamics of these evolved Pareto controllers in noisy and uncertain environments, limb dynamics as well as effects of using a different underlying EMO algorithm on the Pareto evolutionary optimization process.

The remainder of this chapter is divided into five main sections, namely, the (1) previous studies on MO and robotics (Section 2), (2) the artificial evolution and virtual simulation setup (Section 3), (3) application of EMO to the automatic generation of legged locomotion in a biped, quadruped and hexapod (Section 4), (4) operational and limb dynamics analysis using the quadruped (Section 5), and (5) comparison of two different EMO algorithms for driving the Pareto evolutionary optimization process for generating locomotion controllers using the quadruped (Section 6). More specifically, the technical contributions are organized as follows:

- Presentation of the EMO algorithm for the automatic evolution of artificial neural network controllers (ANNs) that maximize horizontal locomotion as one objective and minimize controller complexity as another objective is given in Section 4.1;
- Presentation and discussion of results for the evolved Pareto controllers for autonomous locomotion of simulated robots with two, four and six legs is given in Section 4.2;
- Empirical comparison of the evolved complexities for the bipedal, quadrupedal and hexapedal robots using an EMO approach is given in Section 4.2
- Analysis of the operational dynamics under noisy conditions is given in Section 5.1;
- Analysis of the operational dynamics beyond the evolutionary window is given in Section 5.2;
- Analysis of the evolved limb dynamics is given in Section 5.3;
- Empirical comparison of different EMO algorithms for evolving Pareto locomotion controllers is given in Section 6.1.

## **PREVIOUS WORKS ON EVOLUTIONARY ROBOTICS AND MULTI-OBJECTIVE OPTIMIZATION**

Evolutionary robotics is defined to be the synthesis of autonomous robots using artificial evolutionary methods (Nolfi & Floreano, 2000). An early review of this field of research is given by Mataric and Cliff (1996) where the majority of studies focused mainly on the evolution of control structures. A more recent overview highlights the move of evolutionary robotics into evolving both the control and morphology of robots where the interplay between brain and body is considered to be a crucial factor in the successful synthesis of autonomous robots (Nolfi & Floreano, 2002). Another recent review was conducted by Walker et al. (2003) covering both simulated and physical evolutionary robotics. A thorough treatment

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