Chapter 76
Real-Time Fuzzy Logic-Based Hybrid Robot Path-Planning Strategies for a Dynamic Environment

Napoleon H. Reyes
Massey University, New Zealand

Teo Susnjak
Massey University, New Zealand

Andre L.C. Barczak
Massey University, New Zealand

Peter Sinčák
Technical University of Košice, Slovakia

Ján Vaščák
Technical University of Košice, Slovakia

ABSTRACT

This chapter sets out to explore the intricacies behind developing a hybrid system for real-time autonomous robot navigation, with target pursuit and obstacle avoidance behaviour, in a dynamic environment. Three complete systems are described, namely, a cascade of four fuzzy systems, a hybrid fuzzy A system, and a hybrid fuzzy A* with a Voronoi diagram. A highly reconfigurable integration architecture is presented, allowing for the harmonious interplay between the different component algorithms, with the option of engaging or disengaging from the system. The utilization of both global and local information about the environment is examined, as well as an additional optimal global path-planning layer. Moreover, how a fuzzy system design approach could take advantage of the presence of symmetry in the input space, cutting down the number of rules and membership functions, without sacrificing control precision is illustrated. The efficiency of all the algorithms is demonstrated by employing them in a simulation of a real-world system: the robot soccer game. Results indicate that the hybrid system can generate smooth, near-shortest paths, as well as near-shortest-safest paths, when all component algorithms are activated. A systematic approach to calibrating the system is also provided.*

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INTRODUCTION

The unrelenting demands of real-world systems for computing speed, high-precision, and adaptability have always pushed intelligent systems to their limits. Within the confines of the problem of robot navigation in a dynamic and competitive environment many design issues arise (Kim, 2012). Firstly, real-time execution must be accomplished. A system that employs computer vision for perceiving the environment (Chang & Chen, 2005; Chang & Chen, 2000; Reyes & Dadios, 2004) will have to respond approximately every 33-50msec., depending on the frame rate of the camera and object tracking algorithms. Secondly, optimal path-planning might be required. A deterministic algorithm with a guarantee of optimality (Garrido, Moreno, Blanco, & Jurewicz, 2011) would usually require a global map of the environment to succeed. Otherwise, this map will have to be built on the fly, requiring substantial memory space and running time. On the other hand, if optimal path planning is not a must, reactionary algorithms (Jayasiri, Mann, & Gosine, 2011) can respond quickly with smooth navigation, without the need for a global map. Their performance, however, is easily curtailed when barricades form a U-shape, and gets them trapped. Last but not least, system calibration is also another major issue. Considering the number of parameters that can be fiddled with, and the number of possible permutations involved, a conglomeration of algorithms tied up together can be burdensome to fine-tune, in order to produce the desired robot behaviour. A calibration map is later presented in one of the subsections of this chapter to demonstrate how this daunting calibration task can be alleviated.

The chapter starts-off with an overview of the problem of real-time robot navigation with target pursuit and obstacle avoidance in a dynamic and competitive environment. Three suitable algorithm solutions are presented in detail, namely the cascade of fuzzy systems, the hybrid fuzzy A* algorithm operating on a fixed grid (Gerdelan & Reyes, 2006b; Gerdelan & Reyes, 2006a; Gerdelan & Reyes, 2009) and the hybrid fuzzy A* utilizing a Voronoi diagram. Each algorithm is discussed with accompanying insights on how it is adapted to the problem domain, followed by a characterisation of its performance and limitations, via a simulation system, in the context of the robot soccer game. In contrast to traditional fuzzy system designs, this chapter presents a solution that capitalizes on the presence of symmetry inherent to the problem, and cuts down the number of fuzzy rules significantly without sacrificing precision and smooth navigation.

The algorithms are discussed in increasing order of complexity. The discussions eventually lead to the fusion of the algorithms into one powerful hybrid fuzzy A* system. An extension of the hybrid system, utilising a Voronoi diagram for increased path safety in hostile environments is also presented. Lastly, essential calibration techniques are provided and this is accompanied by experimental results.

BACKGROUND

Path planning algorithms in the context of robot soccer need to deal with two important problems, among many others: target pursuit and obstacle avoidance. In this context, the environment is well-known (e.g., the limits of the field), and any changes in the inputs are also well constrained. The targets can be the ball, or the goal, or a point within the field where the robot has to be strategically positioned. Changes are updated by the camera on top of the field, and a relatively simple computer vision algorithm keeps track of the positions (including angles) of the ball and the robots. The challenge is to find an optimal (or at least near-optimal one that does not get the robot stuck in corners and partial enclosures) path to arrive as fast as possible on the target coordinates, while