Advances in Engineering Software 41 (2010) 506–516

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Modeling and simulation of target motion analysis for a submarine using a script-based tactics manager

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ARTICLE INFO

Article history:
Received 22 October 2008
Received in revised form 21 September 2009
Accepted 1 October 2009
Available online 10 November 2009

Keywords:
Tactics manager
Target motion analysis
Script
Submarine
DEVS

ABSTRACT

Various types of simulation are required for underwater vehicles such as submarines or torpedoes. These include engineering-level simulations for predicting the performance and engagement-level simulations for examining the effectiveness of certain tactics. For this reason, a tactics manager that can change the behavior of a simulation model according to tactics defined outside the model is needed. This paper describes a tactics manager that supports a scripting language that can represent various tactics and can help users to easily define external input tactics. Python and Lua, representative scripting languages, are compared and analyzed from the viewpoint of a tactics manager, and a tactics manager using those script languages is implemented. A target motion analysis simulation of the engagement between a submarine and a surface ship is conducted to demonstrate the effectiveness of the tactics manager. We generated a simulation model based on the Discrete Event System Specification formalism and provided it with an interface to the tactics manager.

1. Introduction

Development of a submarine requires a large budget and a long period of time. Accurately predicting the performance of a submarine before its construction reduces both the cost and time required, and enhances productivity. Modeling and simulation (M&S) is a way to minimize the development risk caused by errors in the design and construction processes, and it also helps to optimize the design. M&S is also helpful for predicting the tactical effectiveness based on the various tactics used in underwater vehicle operations.

1.1. Requirement for a tactics manager

In the real world, a submarine operates according to the captain's orders. In a simulation, however, the submarine model is controlled by previously defined decision data or tactical data. The tactics manager supports the model by dynamically determining the pattern of action according to the predefined tactics.

A simulation model without a tactics manager requires that the model be rewritten every time the tactics change because the tactics are statically defined inside the model (Fig. 1). The tactics manager uses plans that are input from outside the model through files, and controls the actions of the model by analyzing those inputs. In other words, including a tactics manager in the model has the benefit of being able to simulate various scenarios without modifying the model when tactics change, by modifying only the tactics definition files (Fig. 2).

1.2. Related works

Modeling and simulation can be classified into three different types: live, virtual and constructive. A live simulation comprises real people, real platform in the real environment. A virtual simulation comprises real people, simulated platform in the simulated environment. A constructive simulation comprises some human operators, computer generated forces and simulated platform in the simulated environment [1]. Modeling and simulation using a computer for the purpose of a system analysis is the constructive simulation. So it needs to be decided to determine the right decision or make some appropriate action for the situation. And those should be simulated in a computer and programmed in the code. There have been some researches in decision making modeling [2–5]. These researches treated the method how the decision making can be implemented and modeled well in simulation. Especially in the military simulation, a decision making modeling is categorized by the human behavior representation (HBR) [6].

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doi:10.1016/j.advengsoft.2009.10.009

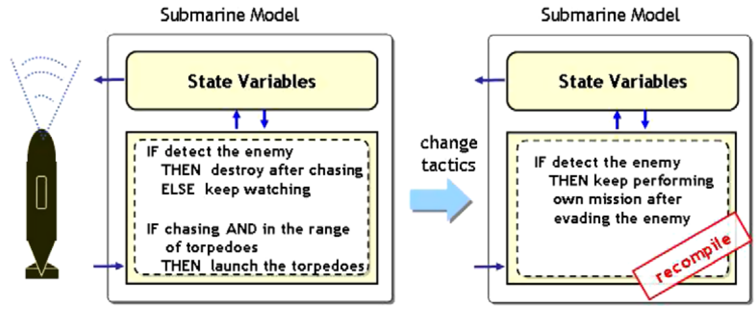

Fig. 1. Current: tactics implemented inside the model.

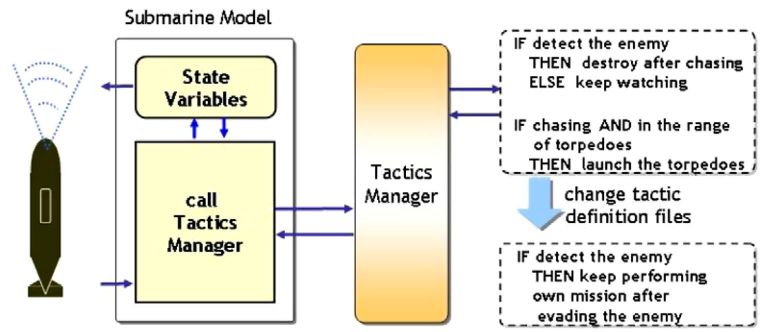

Fig. 2. Future: tactics separate from the model.

In this research, a decision making and a human behavior representation are related to the tactic and its description method. In the multi agent research fields, to make an agent with autonomous behavior, a simulation-based decision making and a rule-based implementation in a manufacturing control scenario has been compared and researched [7]. The main concept of a tactics manager is separating tactics from the simulation model, so that the interface between them and the framework of a tactics manager is the originality of this work. In other words, we suggest and implement a tactics manager not in the aspects of the decision making modeling or representing method but in the aspects of the simulation model architecture.

1.3. Paper structure

We study the definition of the tactics manager in this study. A simulation model is constructed with Discrete Event System Specification (DEVS) formalism [8–10], which is widely used in discrete event simulation. The interface for passing the parameters between the tactics manager and the model is included. Table-based tactics definition methods are used to simplify implementation of the tactics manager. Target motion analysis (TMA) in an engagement between a submarine and a surface ship was simulated to demonstrate the effectiveness of the tactics manager.

The structure of this paper is as follows: Section 2 describes the warfare scenario of an engagement between a submarine and a surface ship that is simulated using the tactics manager. Section 3 presents the concept and the algorithm of the tactics manager, and Section 4 describes the implementation methods for developing the simulation model. Section 5 presents the simulation results and discusses its applications. Conclusions and suggested future work are described in Section 6.

2. Scenario description

The type 209 diesel submarine is designed for coastal protection missions and is noted for its short cruising range and low noise signature. The coastal protection mission requires the submarine to move in fixed patterns in a predefined area to detect an enemy ship passing through that area, and to attack it. The enemy surface ship (e.g., battleship, supply ship, or troop transport ship) crosses the submarine's operational area at high speed. When the submarine detects the enemy surface ship, it starts TMA procedures to estimate the range, bearing, course, and velocity of the target, and simultaneously calculates approaches to the target. The bearing is the direction of the target from the submarine measured from true north (0°). After obtaining the enemy motion parameters using TMA, the distance to the target is examined to see if the target is within maximum torpedo range. The submarine launches torpedoes when the target is at less than half the torpedo's maximum range to increase the probability of a successful strike. If the enemy is too far away, the submarine attempts to move closer to the target before launching torpedoes.

2.1. Target motion analysis and leg methods

TMA includes methods for estimating the kinematic state of the surface or underwater target [11,12]. Obtaining the kinematic state of the target is easy when the active sonar is used. However, active sonar analyzes the reflection of sound waves it emits, and the submarine usually does not want to reveal its presence to the target. Therefore, TMA must operate with only passive sonar that detects the enemy using the noises radiated by the enemy itself. The TMA procedure requires listening while traveling on more than two legs. A leg is a path on which the submarine moves at a constant course and speed [12,13].

When the observer moves from P1 to P3 as shown in Fig. 3, the target moves from b1 to b3. After the first leg, the bearing shown as gray arrows, the bearing rate, shown as dotted arrows, and the distance ratio are known. Both S1 (assumed course 1 of the target), which represents a far target moving at slow speed, and S2 (assumed course 2 of the target), which represents a close target moving at high speed are possible TMA solutions. Since ambiguity exists for TMA solutions on only a single leg, the submarine travels another leg on a different course, for example, moving from P4 to