A MARINE FAULTS TOLERANT CONTROL SYSTEM BASED ON INTELLIGENT MULTI-AGENTS

Tianhao Tang and Gang Yao

Department of Electrical & Control Engineering, Shanghai Maritime University
1550 Pudong Road, Shanghai, 200135, P. R. China
thtang_smu@yahoo.com, shakesteel@hotmail.com

Keywords: Multi-agent system, Faults tolerant control, Communication, Coalition, FIPA Agent Platform.

Abstract: This paper presents a hybrid intelligent multi-agent method for marine faults tolerant control (FTC). A new FTC schema, implemented by different kinds of agent, is discussed as well as the structure and functions of those agents, which have been encapsulated with intelligent algorithms to carry out different aspects in FTC. These agents could, having a purpose of trying to earn payoff as much as possible in a mission, communicate and form a coalition via negotiation when they find cooperation would bring them more benefits. Simulation experiments and its results are shown at last to demonstrate the efficiency of the proposed system.

1 INTRODUCTION

The development of modern marine vehicles is evolving rapidly towards the direction of large scale and complexity, as well as the trend of unmanned intervention, to satisfy the increasing requirements of international marine transportation trade. These features, hereby, call for more and more safer mechanism to guarantee the reliability of ship manoeuvring. For this reason, that applying fault tolerant control (FTC) theory, especially combined with distributed artificial intelligece (DAI), into marine control system attracted much attentions in recent years by researchers and engineers.

FTC could diagnosis component failures in a control system and maintain the system performance at a possibly low but acceptable level. Accordingly, it is possible to improve the system efficiency and to guarantee the operation safety in the control process (Edgar, 2000).

However, the control of marine vehicle, being a typical large scale and complicated system, is a nonlinear, undetermined, time-variable, and open process. The complexity of the FD and FTC system is growing with the increasing complexity of control plants. To keep the FD and FTC system effective, it is essential to encapsulate different tasks and to define strict interfaces between plant components and between components of the monitoring and diagnosis system, although it is quite difficult. To guarantee flexibility -- changing needs in case of an industrial application, the monitoring and FTC system has to be configurable and expandable without the need of modifying any line of code (Luder, 2001). The diagnostic knowledge about an industrial process is available on different parties (process specialists, component manufacturers, etc.). A modern FD and FTC system should be able to integrate the diagnostic knowledge from all available sources, even if different diagnostic mechanisms are applied. To achieve an overall diagnosis of a control process, several diagnostic tasks have to be performed in parallel. This requires new strategies to handle diagnostic conflicts that might occur between different diagnostic results.

Multi-agent system (MAS), about which rapid progress has been made, is an important research branch in DAI parallelized with distributed problem solving (DPS). Possessing modularity, adaptability and other attractive characteristics, MAS drew much attention in recent years and is adopted by many researches in control systems.

This paper presents a hybrid intelligent mutli-agent method for mrine fault tolerant control. The architecture of the MAS, as well as the structure of an agent, and the control diagram are designed in section 2. Then, the algorithms encapsulated in the information processing mudule of agents are briefly mentioned in section 3. In section 4, simulation experiments, applying the proposed method in

marine FTC system, is carried out. And the conclusion of this paper is made in section 5.

2 SYSTEM ARCHITECTURE

2.1 MAS Perspective

The framework of hybrid intelligent multi-agent method, with hierarchical and federal organized intelligent agents that are responsible for different tasks, is presented in figure 1.
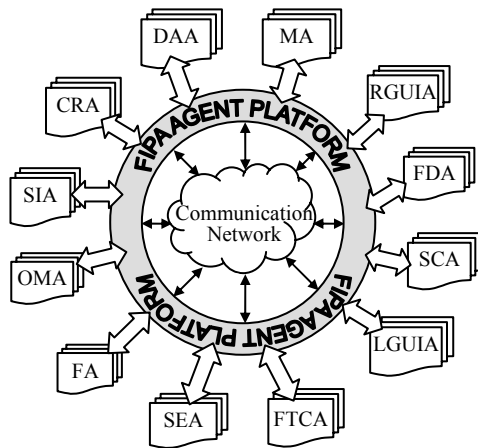
MA-Management Agent; RGUIA/LGUIA-Remote/Local Graphic User Interface Agent; FDA-Fault Diagnosis Agent; SCA-State Control Agent; FTCA-Fault Tolerant Control Agent; SEA-State Estimate Agent; FA-Facilitate Agent; OMA–Ontology Mediate Agent; SIA-System Identification Agent; CRA-Conflict Resolution Agent; DAA-Database Access Agent

Figure 1: Architecture of MAS organization.

As shown in the figure, many agents with different capabilities are connected together by accessing FIPA Agent Platform and through communication networks to form a MAS. In this system, each individual has a special function that can work autonomously and independently. Although being fully autonomous, like human beings, on the other hand, agents in the figure trend to seek cooperation to fulfil more difficult task if they believe that better payoff will gain by form a coalition or the job assigned to some agents is impossible to achieve with their own capability. To facilitate a coalition, *superadditive environment* (Nicholas, 2007) is assumed in this paper.

At agent level, all agents in proposed system have the same hybrid architecture, where the agents are capable of reactive and deliberative behaviours. The proposed agent architecture is based on horizontal layering where all layers are connected to the perception and actuation of the agents with the environment. In the reactive layer, an agent could deal with urgent situations according to the rule in its rules library while it will do some inference, in normal case, in its information processing module (IPM), which has been encapsulated with intelligent algorithms and upon which different type of agents are determined, according to the current mental state, knowledge and goal in deliberation layer.

Details about the MAS and agent architecture could refer to (Yao, 2007).

In figure 1, twelve species of agent, which are determined by different algorithms in an agent's IPM, are involved: MAs are mainly used in FIPA Platform to manage the life cycle of agents; FAs provide yellow page services; DAAs are responsible for interoperation with database; RGUIAs and LGUIAs are graphic user interface extendedly and locally respectively; FDAs are in charge of diagnosis faults for the whole system; FTCAs are going to do fault tolerant control in case that the system actuator lost efficiency. SEAs are supposed to replace failed sensors by estimating state signals and feedback them to keep the system stable; SIAs collaborate with the FTCA to do fault tolerant control; SCAs answer for switching feedback signals from failed sensors to SEAs; OMAs maintain term mapping tables between different domain ontologies; CRAs resolve conflicts in diagnosis results reported by different FDA. When faults exist in a control system or a user instruction is issued, all the above species of agent will act autonomously and could communicate to form coalitions to fulfil the task with lease cost.

2.2 Control System Perspective

The architecture of MAS was discussed in last section. In order to illuminate how those agents implement fault tolerant control in a control system, this section describes MAS based FTC system architecture in a state feedback control system perspective, as shown in figure 2.

In the figure, r is system reference; u is the output of an adaptive fuzzy neural network (AFNN) based FTCA, which acts as system controller; OV is omen variables collected by fault diagnosis agents; $\tilde{x}$ is the difference between x (the detected value from system sensor) and $\hat{x}$ (the output value of an output recurrent neural network (ORNN) based SEA), which is use by IPM of SEA to train the state

estimation neural network on line; SCAs are used to cut off failed sensors.

AFNN-Adaptive Fuzzy Neural Network
ORNN-Output Recurrent Neural Network
LIF- Layered Information Fusion

Figure 2: Architecture of MAS based FTC system.

In this FTC system there are three distinct parts that differ from traditional control systems: fault diagnosis agents to diagnose system failure, state estimation agents to estimate state approximately when the sensor failed, and system self-adaptive controller, realized by FTCA, for FTC under actuator faults:

(1) In the LIF based FDA, two kinds of faults, actuator faults and sensor faults will be diagnosed. If actuator faults happened, FTCA will take some responding actions according to the fault state. While the sensor faults have been found, the SEA will play a part in the sensors.

(2) A SEA based on an output recurrent neural network is proposed to provide the system states estimation to replace the fault sensors. Usually, SCA controls the switch to be on the position 2. In this case, the system state feedback signals will be from sensors. If the sensor faults occur, SCA will switch to the position 1. In this case, the signals from SEAs will be used as the system feedback.

(3) The FTCA, system controller, will give different control strategy according to the system state and fault cases to keep the system performance. For example, when a fault from the actuator was detected, the FTCA based on AFNN could adjust the control signal to overcome the influence of the fault according to the system response on line.

3 INTELLIGENT ALGORITHMS OF AGENTS

As mentioned above, algorithms encapsulated in an agent's IPM determines its functions. In the IPM of a FDA, multi-layer information fusion technology is adopted for fault diagnosis, which separated fault

diagnosis into two parts: local diagnosis fusion implemented by multi-sensors fuzzy inference and global diagnosis fusion implemented by a three-layer fuzzy neural network. In SEA, a new output recurrent neural network is designed to construct the system state estimator. For FTCA, a self-adaptive fuzzy neural network is proposed as its information process method. Detail about these solutions could refer to (Yao, 2006)

4 SIMULATION EXPERIMENTS

4.1 Experiment Platform

In this simulation, the MAS framework is coded in JADE platform, a software development framework for agent application developed by TILAB. The algorithms mentioned in section 3 are coded in Matlab 6.5.

To implement calling Matlab methods from JADE, JMatLink, a small toolkit to connect Java with Matlab, is used to call for the functions in an m-file.

The main user interface of MAS compiled in JADE is shown in figure 3.

4.2 Working Flow of MAS

A prominent advantage of MAS is that agents could discover an optimized way to fulfil tasks by negotiation, coordination and cooperation via sending messages. Accordingly, the communication and cooperation between agents are the most two important research topics regarding MAS.

The communication among agents, as well as their knowledge and mental state, is based upon domain ontology. But different ontologies regarding one domain may exist sometimes in a system. These ontologies contain different terms, which engender great obstacles for agent communication, to express same or similar concepts. Dealing with this problem, a method called term substitution based on intelligent ontology mapping is proposed and implemented by ontology mediation agent (OMA).

OMA maintain glossary mapping tables between domain ontologies. When an agent receives an ACL message containing a few baffling words, the agent forwards this message to OMA for interpretation. If OMA could find terms in an ontology upon which this agent based corresponding to those baffling ones, it will substitute them and send the message back. And then, the agent will understand the message meaning.
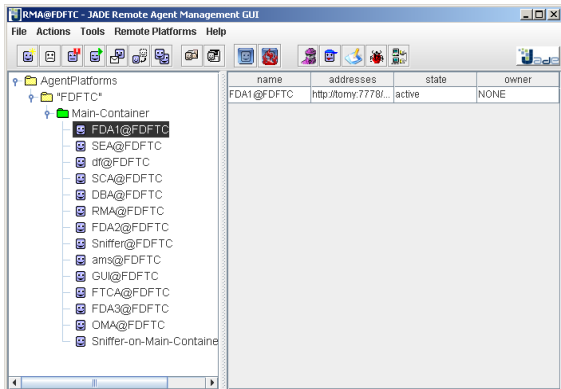
Figure 3: MAS interface in JADE.

Cooperation will bring agents more efficiency and benefits, while coalition is an important solution to implement it. As mentioned in section 2.1, superadditive environment is assumed to facilitate the coalition formation. Under this circumstance, agents in MAS are inclined to form a grand coalition, because they believe that they will earn payoff in this coalition at least as much as those they will get if they work alone. New task and payoff allocation algorithms are also put forward. Details about these solutions regarding with the agent communication and coalition will be specified in future papers. And some research results about these solutions have been applied in agents work flow in this simulation experiment, as illustrated in figure 4.

4.3 Marine FTC System Framework

The method proposed above had been used in marine automatic steering system for actuator fault tolerant control. The structure of ship FTC system is shown in figure 5.

In order to represent the rudder faults, a coefficient called as loss of efficient (*LOE*) is introduced to simulate the faults. When the rudder is normal, define *LOE*=0. And define *LOE*=1 if the rudder is whole failure. So the coefficient *LOE* expresses the fault degree of the rudder. In the simulation system, the faults of the rudder servo system could be set by fault factor L, which is defined as L=1-*LOE*.
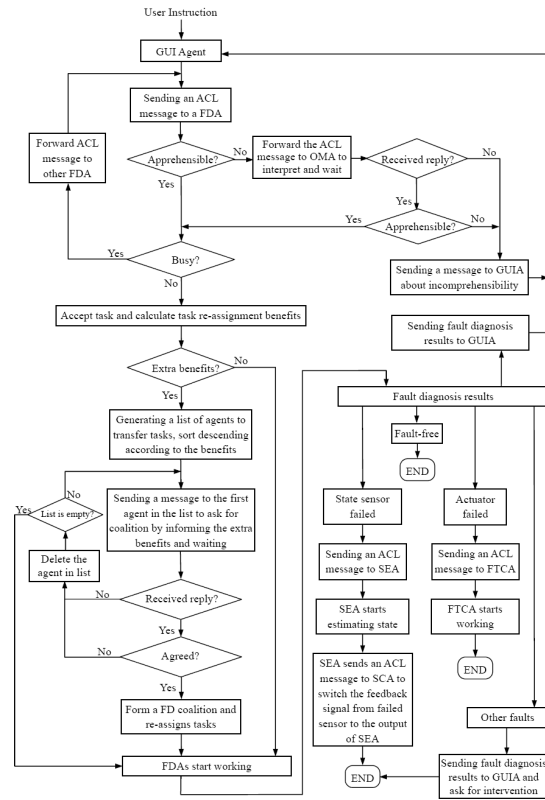
Figure 4: Flow chart of MAS based FTC process.
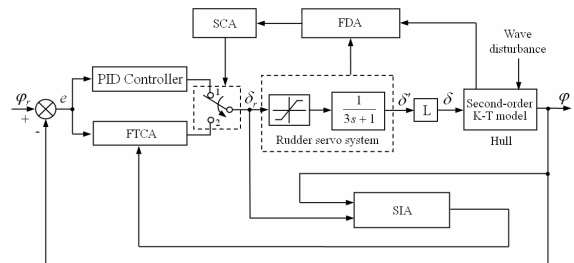
Figure 5: Marine FTC System.

Marine vehicles will definitely be disturbed by ocean wave which is the uppermost factor to cause ship rolling. Usually, wave motions on a ship can be analytically computed using strip theory. The ocean wave spectrum model adopted in the simulation is shown in figure 6.

4.4 Simulation Results

During the simulation, Sniffer, a monitoring tool in JADE, is used to sniffer the communication of agents. The monitoring result is shown in figure 7.
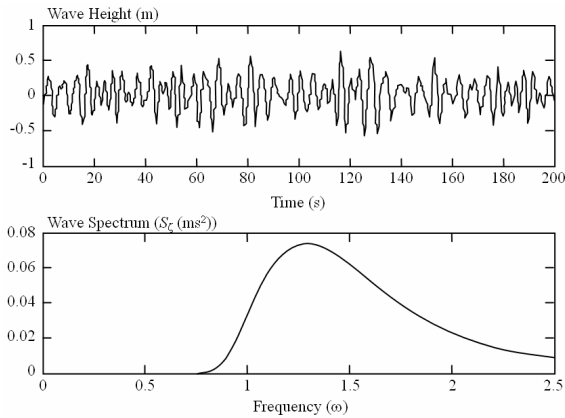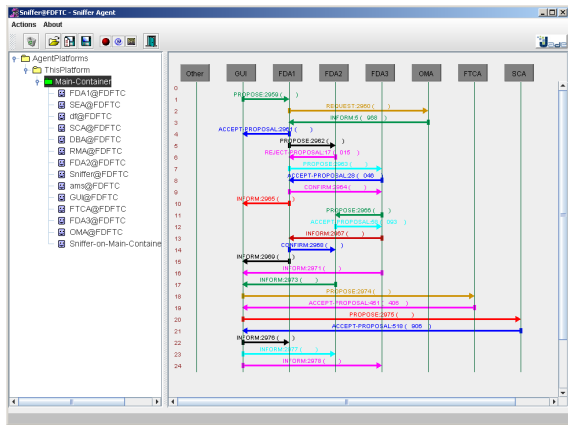
Figure 6: Ocean wave spectrum.

Figure 7: The communication of cooperated agents.

Some rudder faults with different degrees are used to test the performance of the proposed system. In these cases, the effect of FTC is simulated with and without wave disturbances.

To judge how well the FTC method performs, a PID controller is used to perform the same tasks under the same conditions. Some simulation results are shown in figure 8 ~ figure 11.

In order to make a detailed comparison between the two kinds of controllers with rudder faults, the rise times of the ship steering system are recorded to evaluate the performances, where the rise time is defined as the time taken for the ship to rise from five to ninety five percent of the demanded yaw angle. The rise times of the two controllers in different fault conditions without and with disturbances have been compiled in Table 1 and Table 2 shown below.
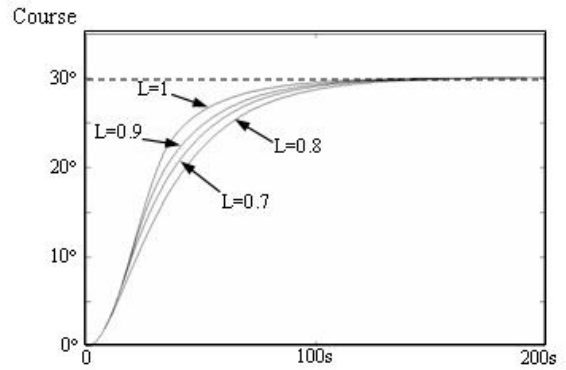
Figure 8: Ship courses with PID controller (without disturbance).
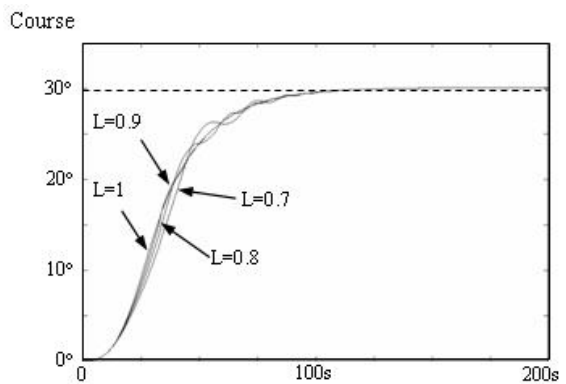

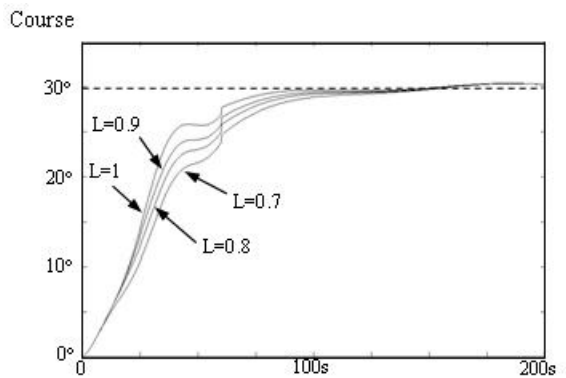Figure 9: Ship courses with FTCA (without disturbance).

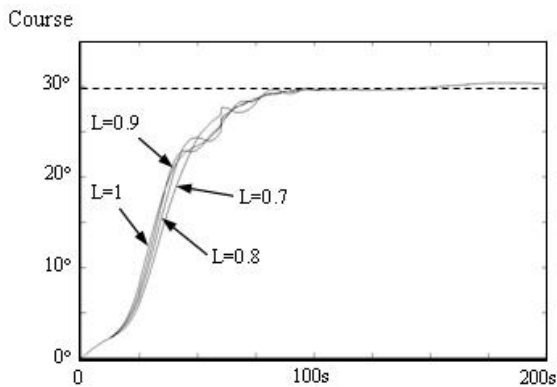Figure 10: Ship courses with PID controller (with disturbance).

361

Figure 11: Ship courses with FTCA (with disturbance).

Table 1: Rise Times without Disturbances (s).

	$LOE = 0$	$LOE = 10\%$	$LOE = 20\%$	$LOE = 30\%$
PID	70	81	87.5	96.5
FTCA	70	70	70.5	71

Table 2: Rise Times with Disturbances (s).

	$LOE = 0$	$LOE = 10\%$	$LOE = 20\%$	$LOE = 30\%$
PID	75	84	90	98.5
FTCA	75	75.5	77	79.5

From the figure 7, it could be seen that different types of agents in MAS followed the working flow shown in figure 4 to work cooperatively. When a FDA found there exists baffling terms in an ACL message, it will ask for help to OMAs automatically. If an agent finds that extra value will be gained if tasks are re-assigned, it will send proposing message to others about coalition by informing this value. When the coalition is formed, tasks will be done and coalition value will be divided according to each agent's contribution.

From the showings of figure 8, figure 10 and two tables, it is easy to find that the PID control system doesn't have the fault tolerant capability; when the rudder servo system lost some efficiency, the system performance is greatly reduced with increased rise time and stable time.

Figure 9, figure 11 and also those two tables show that in the MAS based marine fault tolerant control system, the system's performance can be distinctively improved in the condition of actuator failure; it is nearly close to the normal performance. The rising time and stable time are not influenced much. The target of actuator fault tolerant control is fulfilled.

From the simulation experiment above, it is easy to find that the MAS based marine fault tolerant control system can adapt to different failure modes when the rudder servo system is partially failed. It successfully realized fault tolerant control for actuator failure by the multi-agents organization shown in figure 1. The agents could communicate to seek coalition autonomously. Adopting this MAS based method will need no object's mathematic model and could realize cooperation between heterogeneous intelligent algorithms.

5 CONCLUSIONS

This paper describes a concept of building a hybrid intelligent fault tolerant control system for marine vehicles based on the application of MAS, and also proposed a new fault tolerant control schema integrates several algorithms implemented within the MAS method, which allows the flexibility, the extendibility, and a cost-effective development of the system. Details about the overall architecture, algorithm encapsulated in IPM, and coding tools are discussed. And at last, some simulation experiment results are given to demonstrate the efficiency of the presented system.

ACKNOWLEDGEMENTS

REFERENCES

Edgar, T. F., Dixon, D. A, 2000, Computational needs of the chemical industry, University of Texas Press.

Luder, A., et al., 2001, Industrial requirement and overall specification. Prepared within the PABADIS IST research project no. IST-1999-60016. Available at www.pabadis.org.

Nicholas R. Jennings, 2007, Forming fuzzy coalitions in cooperative superadditive games, IEEE International Conference on e-Business Engineering (ICEBE'07) pp 221-228.

Yao Gang, Tianhao Tang, 2007, A hybrid intelligent multi-agent method for monitoring and faults diagnosis, 4th International Conference on Informatics in Control, Automation and Robotics, France.

Guy Lebret, Gang, Yao, 2006, A gain-scheduling and intelligence fusion method for fault-tolerant control, 6th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes, Beijing, China.