INTELLIGENT SUPERVISION OF AUTONOMOUS HEAVY VEHICLES: APPLICATION TO MARITIME AREA

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ABSTRACT

There is a strong need to improve the efficiency of existing transport infrastructure of seaport in North West Europe. One of the solutions would be to integrate intelligent transportation systems allowing the transportation of goods in the internal traffic of the seaport. However, the design of intelligent and autonomous vehicles integrates the definition of fault detection and localization algorithms and strategies of control reconfiguration. The ultimate objective of our work is to design a supervision system representing the management of the operating modes and giving the conditions for reconfiguration of an autonomous system, in real time. Then, a co-simulation is done on a platoon of Intelligent and Autonomous Vehicles (IAVs) inside seaport terminal in the framework of the European project InTraDE (Intelligent Transportation for Dynamic Environment).

Keywords: Intelligent transportation system, maritime logistics, supervision, Bond Graph, self-diagnosis, intelligent and autonomous vehicle.

1. INTRODUCTION

Innovation is an important factor for maintaining the development of logistics industry. There is a strong need to improve the efficiency of existing transport infrastructure in North West Europe. The construction and implementation of intelligent transportation systems (DeLaurentis 2005) will be a key factor in this development.

Because the ports are of primary importance for regional and national economies, the introduction of intelligent transportation systems (ITS) in their dynamic environment is an essential necessity to improve their economic competitiveness and efficiency.

The main problem of the development in the ports and terminals of some North West European area depends on the internal traffic management and space optimization inside a confined space. A solution was proposed for a selection of major ports such as Rotterdam, Düsseldorf and Hamburg, to automate the handling of goods using automatic guided vehicles (AGV). This solution has resolved some relative internal traffic issues, although it has highlighted several limitations.

Thus, the vehicles will adapt to the infrastructure rather than the reverse. The proposed solution consists in automating the routing of goods using automated guided vehicles (AGV). This solution was able to manage one way traffic, but it has several internal structural limitations. Thus, the European project InTraDE (http://www.intrade-nwe.eu) contributes in the improvement of internal traffic management, the optimization of space and the development of a clean and safe intelligent transportation system in order to adapt the considered environment. This ITS should be transferable on different sizes of port terminals. This transportation system operates in parallel with Virtual simulation software SCANER Studio allowing robust and online supervision.

The ultimate objective of this work is to design a supervision system representing the management of the operating modes and giving the conditions for several possible reconfigurations by using functional and behavioral models. The intelligent and autonomous vehicles (IAVs) should be able to transport goods from one specific place to another in both normal and degraded functioning by using global reconfiguration strategies which will be detailed in this paper and the simulation of the faulty scenario is done by using SCANNER Studio software which represents the supervision system.

2. SUPERVISION STRATEGY:

The main tasks considered in the supervision strategy are the fault diagnosis and the reconfiguration.

2.1. Fault Diagnosis:

The objective of a self-diagnosis system is to diagnose the states of devices mounted in the vehicle when a fault occurs. To achieve this purpose, we use fault detection and isolation procedures based on functional and behavioral models of the vehicle. After detecting and isolating of a fault, a reconfiguration strategy is applied to a vehicle operating in a platoon (Rajamani, Howell, Chieh, Hedrick, and Tomizuka 2001). A platoon is a set of independent and interconnected IAVs structured in leader-follower (Wang, Pham, Low, and Tan 2006). The IAV, called RobuTainer (Figure 1), is a 4 x 4 decentralized multi inputs multi outputs system (Merzouki, Medjaher, Djeziri, and Ould-Bouamama 2007). It contains a real time monitoring system, makes it possible to detect and isolate the actuator and sensor faults.

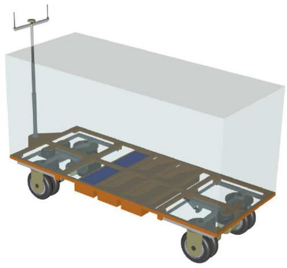

Figure 1: RobuTainer

2.1.1. Functional Model:

So, let us consider at first the case of a supervision system of low level decomposition by taking as illustration the electrical wheel motor for which the main objective is to give mechanical torque to the wheel. The realization of this objective requires many services such as the generation of an electrical power, the conversion of the electrical power to a mechanical one, the transmission of the mechanical energy to the tire and a measurement service required to control the motor in closed loop. These services can be decomposed as shown in Figure 2.

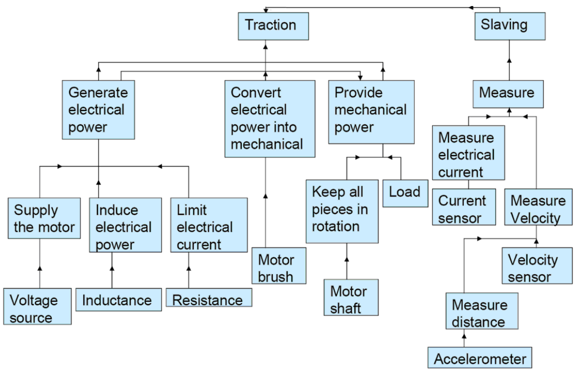

Figure 2: Hierarchical functional decomposition

The elementary components, such as the electrical resistance R, the electrical inductance L and so on, allowing the services realization are also shown by this functional decomposition. The latter is built from the interconnection of different components. The interconnections are taken into account by considering higher level components which aggregate lower level ones. Sensors, actuators, process components are at the (lowest) field-level. They are named elementary components and provide elementary services. The highest level of aggregation corresponds to the overall system and its objectives.

This figure shows that the evaluation of the potential for the system to achieve its objectives rests on the evaluation of the potential for the components of lower-level to provide their associated services. This service availability evaluation requires a physical and behavioral description (Venkatasubramanian, Rengaswamy, Yin, and Kavuri, 2003)

The Bond Graph (Merzouki, Djeziri, and Ould-Bouamama 2009) tool by associating each service with a behavioral equation is a well suited to quantify the availability of services by indicators of faults directly related to a technological component.

2.1.2. Behavioral model:

The description of the behavioral model of the system is done by The Bond Graph which is a graphical representation of the physical effects and their interactions in a physical system (Staroswiecki, and Gehin 2001). It is consistent with the first principle of energy conservation. It is a multidisciplinary approach. In addition, its structural and causal properties can be exploited to generate systematically faults indicators directly associated with the components. To each elementary service, a Bond Graph element can be associated as shown by Table 1.

Table 1: Elementary components of each service of the DC motor

N	Services	BG elements
1	Measure velocity	Df_2
2	Generate electrical power	$R : R_A ; I : L_A ; MS_e$
3	Provide mechanical power	$R : F_m ; I : J_m ; S_e : Ch$
4	Convert electrical power into mechanical	GY
5	Measure acceleration	Df_3
6	Measure current	Df_1
7	Keep all the pieces in rotation	$R : F_m ; I : J_m$
8	Limit the electrical current	$R : R_A$
9	Induce an electrical current	$L : L_A$
10	Maintain	-

The Bond Graph Model is then built (Figure 3). It details the realization of the service of traction given by the motor itself. It can be split into several parts corresponding to services of lower levels. Then, we use a software graph analysis tool FDIpad to generate the residuals from the Bond Graph Model. The residuals allow to build the fault signature matrix which permits to show whose faults are detectable and isolable by analyzing the independent lines of the matrix. The three following residuals are found in our case:

$$R_1 : -I\frac{dDf_2}{dt} - f_e.Df_e + Se_2 + Df_1.R = 0$$

$$R_2 : Se - R.Df_1 - I\frac{dDf_1}{dt} - K_e.Df_2 = 0$$

$$R_3 : Df_2 - Df_3 = 0$$

The fault signature matrix derives directly from the generated residuals. It is given in Table 2.

Table 2: Fault signature matrix of DC motor

BG Els	Components	M_b	I_b	R_2	R_2	R_3	V
Se_2	Load	1	0	0	1	0	V_1
Se	Voltage source	1	0	1	0	0	V_2
Df_1	Current sensor	1	0	1	1	0	V_3
Df_2	Velocity sensor1	1	1	1	1	1	V_4
Df_3	Velocity sensor2	1	1	0	0	1	V_5
R	Resistance	1	0	1	0	0	V_2
L	Inductance	1	0	1	0	0	V_2
GY	Gyrator	1	0	1	1	0	V_3
Fm	Friction	1	0	0	1	0	V_1
Im	Inertia	1	0	0	1	0	V_1
-		0	0	0	0	0	V_6

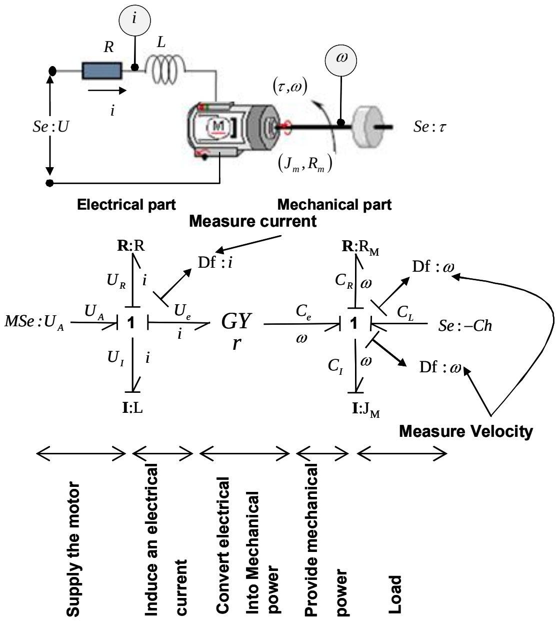

Figure 3: Association between Functional Model and Bond Graph model (Behavioral Model)

The lines V_4, V_5, which are different for the other lines, show that speed sensor failures are detectable and isolable. This fault isolation is provided by the hardware redundancy of the speed sensors. The three lines noted V_1 are identical. This means that the fault cannot be isolated between the part load and the motor shaft. But as these two parts are implied in the realization of the same service: óprovide mechanical powerô, this allows to conclude about the unavailability of this service when the signature corresponding to the line V_1 is observed. Nevertheless, for the signature corresponding to V_3, the unavailability may refer either to the conversion service or on the current measurement service. Without additional information, the fault cannot be isolate. Probabilistic approaches related to the failure rate may help in decision-making.

2.2. Fault Diagnosis:

The management of the operating mode is represented by a finite automaton as seen in Figure 4.

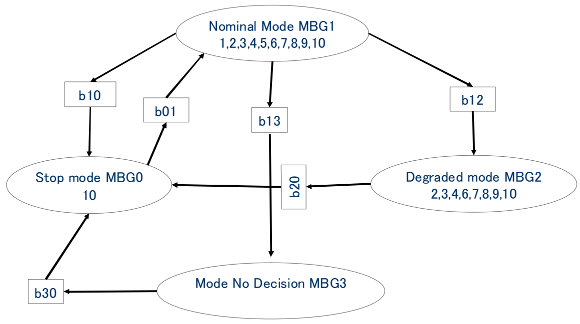

Figure 4: Finite automate describing the management of operating modes

Each operating mode, corresponding to a graph node, is associated with a set of services, and is defined by a single Bond Graph model. The service availability (associated to the Bond Graph elements) and the conditions of passage from one mode to another are analyzed by faults detection and isolation algorithms generated on the basis of the structural and causal properties of the bond graph tool. The reconfiguration is described by different operating mode as shown in the finite automate.

Initially, the system is in nominal mode and remains there while all services are available. If the velocity sensor fails (i.e. signature V_4 is observed) then the system goes into the degraded mode MBG2. If the signature V_1 is observed, the system switches to MBG0 because whatever the failure, the service óprovide mechanical powerô is no longer available. If the signature V_3 is observed, then the system switches to MBG3 where the operator must intervene to evaluate the criticality of the failure. The reconfiguration is activated when a fault is detected and isolated as described before. This leads to a new reconfigured mode of the Platoon. In the case of degraded mode, a reconfiguration strategy should be applied on the platoon as seen in the next section.

3. SIMULATION RESULTS

The simulation is realized on SCANeR studio (http://www.oktal.fr). This latter is a dynamic and real time simulator which will be used to supervise the platoon by bilateral teleoperation.

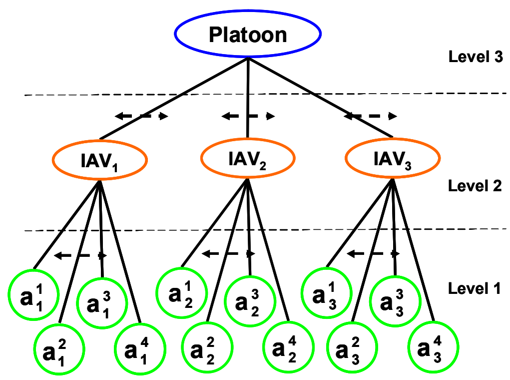

Figure 5: Platoon in normal operating mode

Let us consider that the platoon is in normal operating mode (Figure 5). The maximal detected inter-distance between IAVs is 10 m. To avoid collision, each IAV needs to respect the safety inter-distance of 2 m.

We suppose that at time 13 s, faults occur on the applied voltage efforts and on the current Inputs of the 1st and 3rd actuators for the 2nd IAV. The low monitoring level detects the faults at 15 s, and then isolates the faulty system by using the multi model approach described before at 18.5 s.

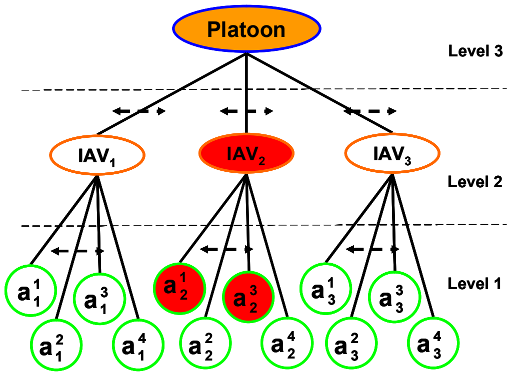

Figure 6: Platoon in degraded operating mode

So, the operating mode of the 2nd IAV becomes failed. Consequently, the platoon operates in degraded mode (Figure 6). The 3rd IAV stops at 14 s to avoid collision with the 2nd one.

We suppose that the considered scenario for the reconfiguration strategy consists of removing the faulty IAV from the main trajectory of the actual platoon.
The reconfiguration (Zhang and Jiang, 2008) of the platoon can be done by generating progressive reconfigurations of the platoon of IAVs as follows:

1. Reconfiguration 1: in this case, the platoon is stopped and the 2nd IAV is put out after a progressive lateral and omnidirectional motion using the steering systems.
2. Reconfiguration 2: in this case, the 3rd IAV is accelerated until it approaches the 1st one in order to reconstruct the new platoon with respect to the inter-distance, using the front laser sensor.
3. Reconfiguration 3: in this case, the new reconfigured platoon is moved to achieve the initial planed mission.

Then, we can summarize the studied scenario by Figure 7.

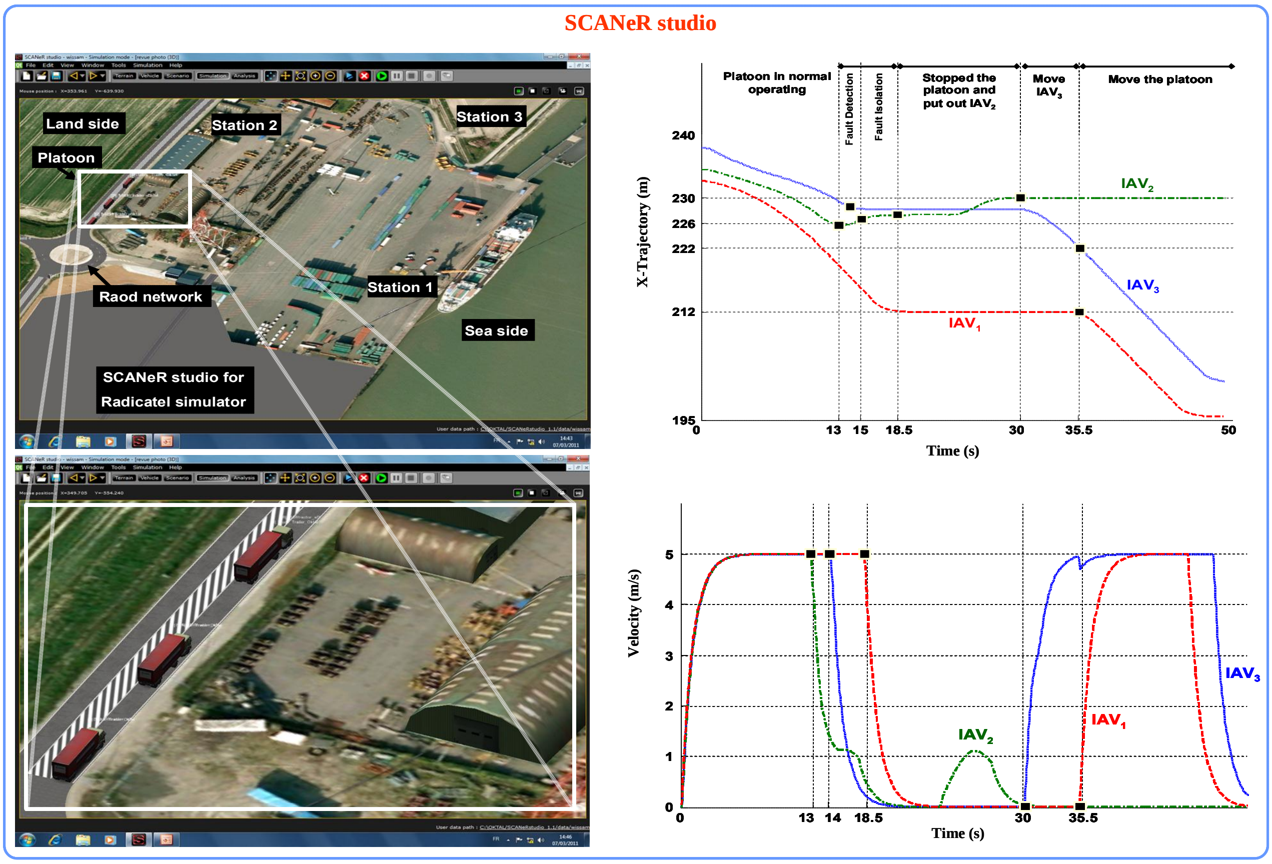

Figure 7: Operating modes and real velocities of the three involved vehicles

4. CONCLUSION

The use of intelligent and autonomous vehicles overcomes the limitation of the seaport infrastructure. The realization of this system needs a supervision system which can be able to diagnosis the different operating modes of the vehicle. However, the supervisor oversees the operating state of an autonomous vehicle through the availability of the functions and services provided by the vehicle components. Thus, the functional analysis provides a systematic tool for finding the different reconfiguration strategies of a system when faults occur by taking into account the availability of the elementary system components. Then when a fault occurs, a management reconfiguration is applied to a platoon. The first simulation on virtual port simulator shows the feasibility of the research work. The second step is going on and concerns an implementation of algorithms in real IAVs developed in this framework.

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