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Simulation of a collision and obstacle avoidance algorithm for cooperative industrial autonomous vehicles

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Summary: Industry 4.0 leads to a strong digitalization of industrial processes, but also a significant increase in communication and cooperation between the machines that make it up. This is the case with intelligent autonomous vehicles (IAVs) and other cooperative mobile robots which are multiplying in factories, often in the form of fleets of vehicles, and whose intelligence and autonomy are increasing. The implantation and deployment of IAVs fleets raises several challenges: acceptability by employees, vehicle location, traffic fluidity, vehicle perception of changing environments. Simulation offers a good framework for studying solutions for these different challenges. Thus, we propose in this paper the extension of a collision detection algorithm to deal with the obstacle avoidance issue. The conclusive simulation will allow us to experiment in real conditions.

Keywords: Simulation, autonomous vehicles, cooperative collision avoidance

1. Introduction

One of the challenges of Industry 4.0, is to determine and optimize the flow of data, products and materials in manufacturing companies. To realize these challenges, many solutions have been defined [1] such as the utilization of automated guided vehicles (AGVs), intelligent autonomous vehicles (IAVs) and other cooperative autonomous robots. The implantation and deployment of intelligent autonomous vehicle fleets raises several challenges: acceptability by employees, vehicle location, traffic fluidity, vehicle perception of changing environments (dynamic). In this context, autonomy is reduced to predetermined trajectories.

To improve the autonomy of a fleet, one way it to develop a collective intelligence to make the behaviors of vehicles adaptative. We will focus on a class of problems faced by IAVs related to collision and obstacle avoidance. This occurs when two vehicles need to cross an intersection at the same time, known as a *deadlock situation*. But also, when obstacles are present in the aisles and need to be avoided by the vehicles safely.

In this paper, we will propose an enhancement to the collision avoidance algorithm experimented in the study [2], in order to handle the problem of obstacle avoidance.

2. State of the Art

For the consumer sector, autonomy of vehicles is well determined with 6 levels of autonomy [3]. However, no such scale exists in the industrial context. Our objective is to improve the IAV autonomy integrated in a fleet based on collective intelligent strategies. Among the problems to be solved to make

IAVs more autonomous, we can particularly note the location and positioning of vehicles [4], as well as the avoidance of other vehicles or obstacles [5]. This last problem can be solved by the cooperation between IAVs [2, 6].

The capacity to exchange information between the different IAVs of a fleet should improve this autonomy [7, 8]. The study [2] proposed a cooperation strategy based on the exchange of messages to determine the priority to pass an intersection between IAVs. The solution requires the vehicle to know its own position, and to be able to communicate with the other vehicles.

The collision avoidance algorithm presented in [2] allows IAVs to communicate and cooperate using different types of messages.

The communication between IAVs is done with 3 different types of messages:

- Hello_msg: message to indicate its presence with its position
- Coop_msg: message before an intersection area to determine priority.
- Ack_msg: message to confirm receipt of a Coop_msg.

The European Institute of Telecommunications Standards (ETSI) has published a standard for this kind of cooperative awareness messages (CAM) (ETSI EN 302 637-2 standard [9,10]) and decentralized environmental notification message (DENM) (ETSI EN 302 637-3 standard [11]). These specifications and messages are approved and constitute building blocks for the safety of future intelligent transport systems (ITS) [12]. The purpose of CAM messages is similar to Hello_msg in [2]. They make it possible to locate vehicles in real time relative to each other. DENM messages are alert messages. They are issued at the time of an unexpected event in order to cooperate, warn and disseminate information in the geographical

area concerned. They are important messages that would complete the range of possible messages to be exchanged to cooperate and avoid collisions for the IAVs in the Bahnes et al. algorithm [2].

3. Algorithm improvement

The collision avoidance algorithm of [2] makes it possible to deal with the priority of different vehicles when approaching an intersection. However, it does not deal with the problems of detection, communication and avoidance of fixed or moving obstacles (e.g. human operators).

We extend the algorithm of Bahnes et al. to handle the presence of fixed or moving obstacles in **Fig. 1**.

Then, we simulate the algorithm staying within the framework of the three scenarios proposed by [2]. These simulations rely on an agent-based model where IAVs are agentified [13, 14]. Indeed, agent-based simulation for IAVs is the most common in the same way as simulations based on discrete events or robotics software [15].

IAV agents have the ability to exchange messages and are equipped with radar. This allows them to detect vehicles in front of them. For instance, given an IAV agent α_i , if an other IAV agent α_j in front of it is stopped or travelling at a slower speed, the IAV agent α_i can detect it with its radar and stop accordingly to avoid hitting it, as in **Fig. 2**.

To improve the collective autonomy of the IAVs it is essential that they have a good capacity for individual autonomy. The individual autonomy of the IAVs strengthens their collective autonomy.

The messages exchanged by the different IAVs remain consistent with the Bahnes's algorithm. We just propose two new message types for the collaborative perception (added to the three messages defined by Bahnes et al.: Hello_Msg, Coop_Msg and Ack_Msg):

- Obstacle_msg: a message sent by an IAV agent to the other IAV agents circulating in the warehouse to indicate the presence of a perceived obstacle.
- Alert_msg: a message sent by an IAV agent to the other IAV agents circulating in the warehouse to indicate an unavoidable obstacle.

4. Simulation Results

The traffic plan presented in **Fig. 3**. shows the different scenarios that we consider as a benchmark plan to compare results. Ten IAVs are distributed over 3 circuits: the red IAVs on the first circuit, the blue ones on the second and the yellow ones on the third.

It involves different intersections, where vehicles can arrive from different sides like in a warehouse (4 intersections are shown in **Fig. 3**.). Thus, it provides the different characteristics of an industrial environment and allows us to realize simulated experimental tests in line with realistic scenarios.

We notice in the simulation that the avoidance is well respected and the obstacles are perceived by the IAVs. Therefore, the simulation validates the extended Bahnes's algorithm with collision avoidance and fixed or dynamic obstacle detection processing.

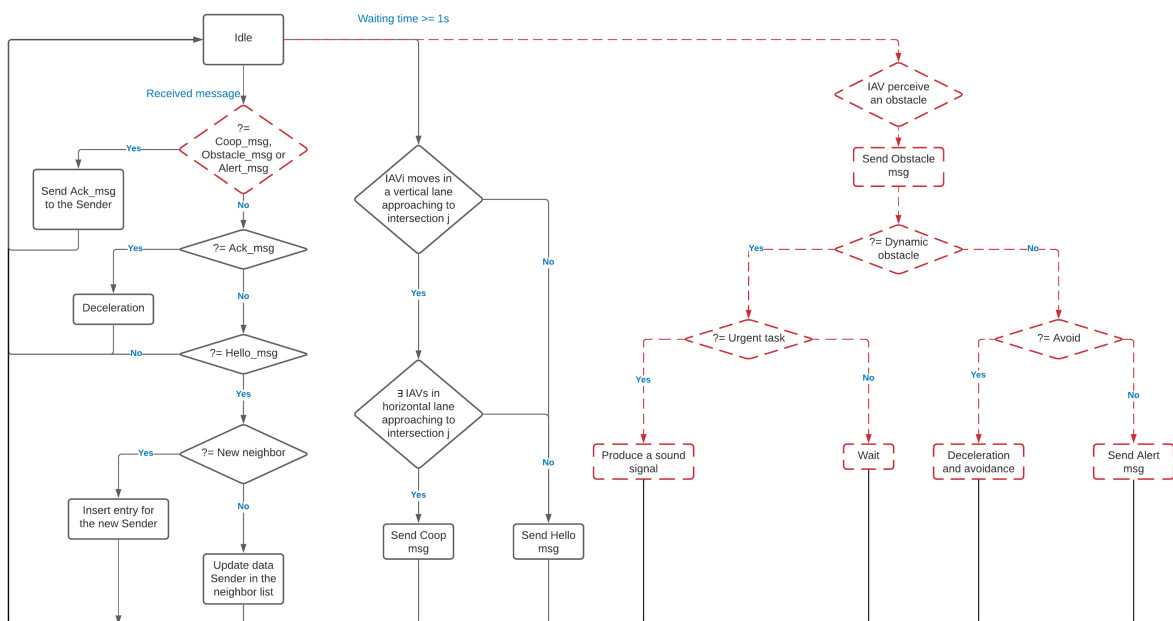


Fig. 1. Improvement of Bahnes's algorithm to treat the problem of collision and obstacles

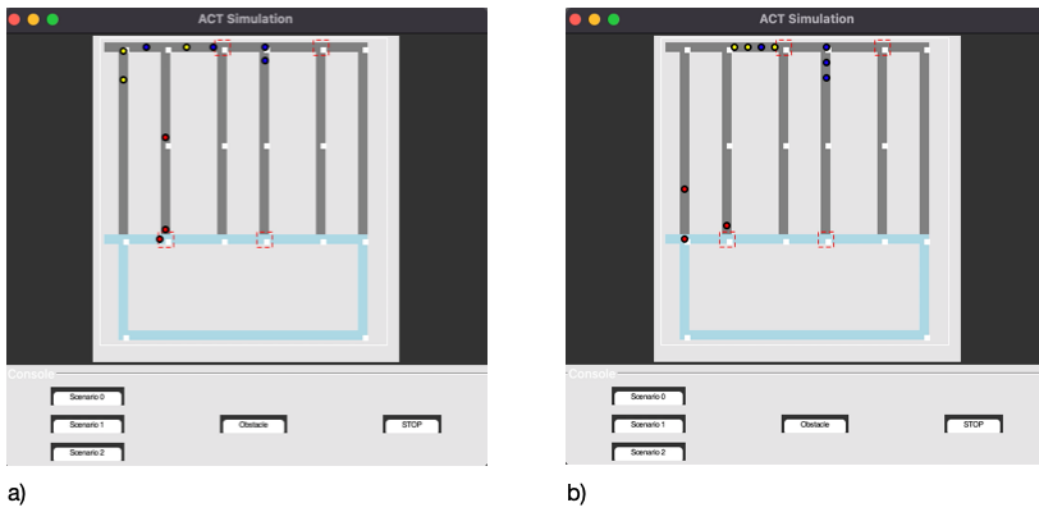


Fig. 2. Simulation of radar use:
 a) at the top of the picture: one blue and three yellow IAVs arrive near the intersection
 b) while waiting for the yellow IAV to pass the intersection, the radar of the blue IAV and the two other yellow IAV allow them to stop and keep their distance to avoid colliding

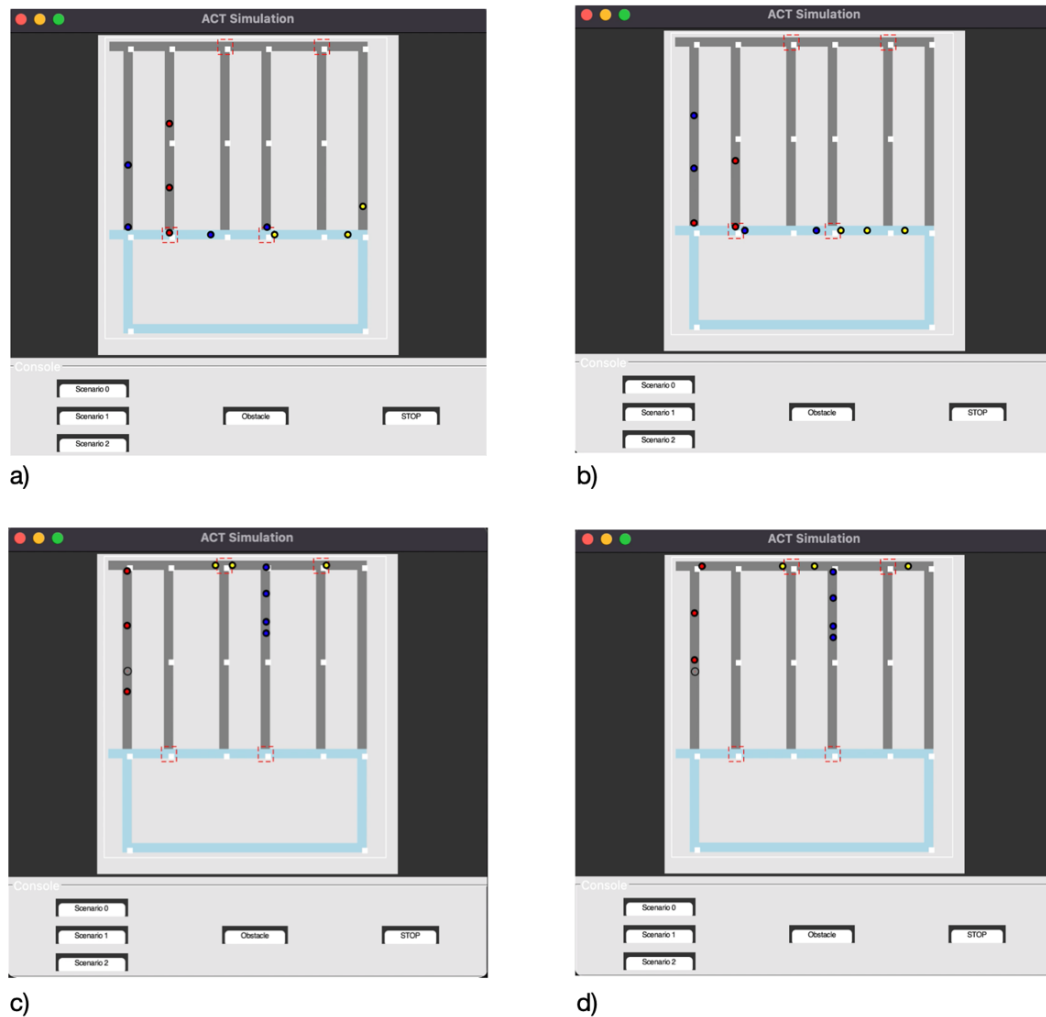


Fig. 3. Simulation of the scenarios:
 a) in the center of the picture: a blue and yellow IAV arrive at an intersection
 b) the yellow IAV passed the intersection after communicating with other IAVs
 c) on the left side of the picture: a red IAV perceives a fixed obstacle in front of him
 d) a red IAV avoided the obstacle

5. Conclusions and Perspectives

In an Industry 4.0 context, many actors cross paths in different areas of a warehouse: vehicles, operators, obstacles (objects that fall or are left in aisles may appear).

The algorithm in [2] proposed a message-based communication protocol between vehicles to prioritise passage through an intersection. We extended it in order to have the possibility to handle the detection of these fixed and mobile obstacles (**Fig. 1**).

We have validated the algorithm by a simulation approach with the traffic plan presented in [2].

As an extension of the work and the aim to propose a cooperation protocol for a collaborative collision and obstacle detection, the messages will respect the standards defined by ETSI [9, 11].

In future work, we will work to simulate other levels of autonomy using collective strategies – cooperation between IAVs but also cooperation integrating the infrastructure and the environment of the IAVs. We also plan to do real experimentations with robots.

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