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Spanish initiative for fully automated stowage on roll-on/roll-off operations

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Abstract

In the past decades, social development has motivated a notable growth on transportation necessities. In 2020, higher tendencies are expected, so transportation demand will grow about a 20%. Besides, one of the foundations of the UE's Green Policy initiative for freight is the transportation sea-to-ground through the so-called „Short sea shipping" or „Motorways of the sea". Facing this scenario, it is needed the development of technologies and solutions which contribute to raise the profitability, flexibility and efficiency of marine transportation. This will lead to more competitive freight, so investing on such technologies is a guarantee of success. On this basis, within the framework of the Innterconecta 2013 programme, funded by the Spanish Ministry of Economy and Competitiveness through the Centre for Industrial Technological Development (CDTI), the project AUTOPORT is being developed, which objectives are here detailed. The main objective of the project is to develop the technologies needed for a fully automated stowage on roll-on/roll-off ships in order to improve the logistic flow, reduce stowage times and maximize the efficiency of the space occupation in hold. This will be accomplished by both the automation of logistic processes and terminal trucks. Automation of processes aims for obtaining a stowage plan which reduces to the minimum the obstructions between cargo and trucks in the process and also the imbalance of the hold, in order to allow easy and smooth load operations even in rough sea conditions. Automation of terminal trucks consist in the efficient use of localization, path planning

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and control for taking a specifically designated roll trailer and stowing it on the exact hold location pointed by the stowage plan, all without human intervention.

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Keywords: Autonomous vehicle; vehicle automation; Dynamic Routing System; cargo transportation; Ro-Ro Transshipment; Artificial Intelligence

1. Introduction

Transport in all its forms is subjected for years to extraordinary pressure drastically in order to reduce inefficiencies and environmental impact, which is enhanced with the uncertain economic outlook.

Within the new „Green Policy" it has identified transportation as one of the main pollutants, which is why through the new directives are encouraging strategies and actions to reduce the gas emissions from the consumption of the fossil fuels and noise emissions in the transport of goods and people. The transfer of freight from road to other modes of transport such as sea appears as an option with great potential for reducing emissions. Also one of the pillars on which the „Green Policy" is based on transport is the modal shift of goods from land to sea through the so-called „Short Sea Shipping" or motorways of the sea.

Taking into account this scenario, the development of solutions and technologies that help ensure greater profitability, flexibility and efficiency and thus more competitive maritime freight transport is a necessity, and investment in these technologies guarantee success.

In this context, the overall objective of the project is the development and demonstration of new technological concepts and oriented towards full deployment of automated cargo transport port terminals Ro-Ro (Roll on-Roll of).

1.1. Main objectives

- The development of a novel Port Operation Management System (POMS) and tools combining functionalities of Transport and Inventory Management for enterprise communities operating in ports and intermodal freight terminals. Such tools will incorporate real-time operational logistics planning among others.
- The development of a new easy to use and affordable tool for RoRo enterprise communities based on a semantic approach to improve connectivity in order to facilitate the communication between different systems from different companies providing complimentary services and/or information regarding the logistic process.
- The development of Automatic stowage and lashing through novel Automatic Guided Vehicles (AGV) based on terminal tractors for Ro-Ro (Roll-on Roll-off) transshipment tailored to the specific needs.
- The improvement of infrastructures for ports and the related freight terminals through the innovative communications and positioning technologies oriented to support and manage the previously mentioned Automatic Guided Vehicles.
- The development of a new logistic concept and ICT-based control center to be applied by shippers, based on the integration of the AGVs into the POMS for real time planning optimization. The AGVs will be linked to the information flow incurred by logistic operation and thus to the whole supply chain.
- The generation of a new ecosystem of integrated tools to increase the visibility and transparency of information for stakeholders in the RoRo transport value chain due to mobile connectivity and real-time localisation, identification, and tracking of goods and resources, and also based on the availability of all the previous elements.

2. General architecture

The architecture is composed by software and hardware modules and the vehicle automation, which will be explained in another section before. This architecture involves all the different modules of the system, that includes the sensor-view system, the intelligence and control of the vehicle and the automation of the vehicle itself.

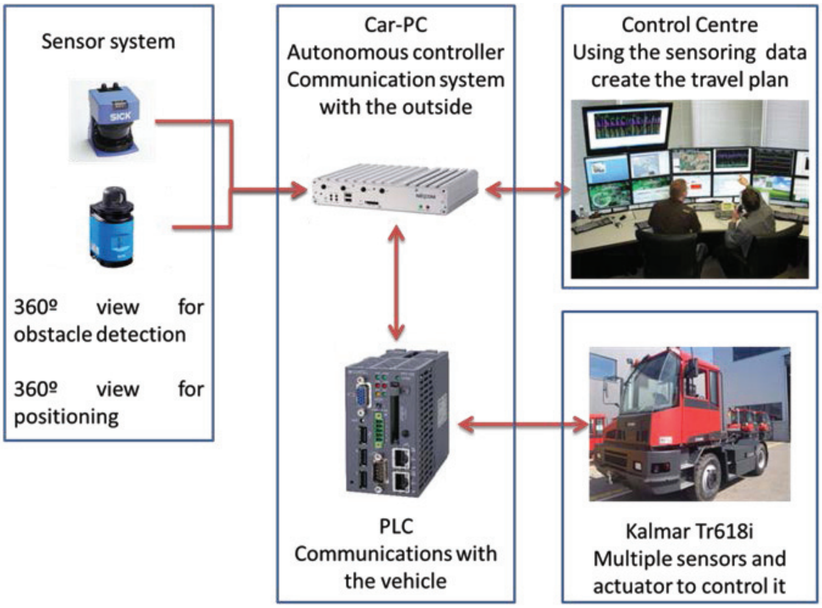


Fig 1. General architecture overview.

3. AUTOPORT project

3.1. Vehicle automation

In order to automate the vehicle has been made the required installation and programming of all the necessary equipment for the vehicle TR618IB Kalmar L2C21 with the goal of perform all the operations as it's possible as a driver, as far as movement is concerned, without being provided that the commands transmitted from the outside are adequate and correspond with the movement that is desired. To get to perform and have controlled the movements of the vehicle has been automated the following elements: the steering wheel, the travel drive, the fifth wheel, the brakes, the lights and the installation of multiple emergency buttons.

3.1.1. Steering

It has made the installation of a servo motor and controller to transmit motion to the steering shaft; also to know the exact point where steering bar is a transducer is placed. To transmit the motion of the servomotor to the steering shaft is manufactured a pinion and a ring gear engaging the orbitrol, in addition of the motion to the wheels transmission, this automation is used to get the current steering angle.

(a) (b) (c)

Fig 2 (a) Servo motor, (b) Steering transducer, (c) Orbitrol detail.

3.1.2. Travel drive

To ensure that the vehicle is moving in the direction you are prompted, it has made an installation of a servo motor and controller to transmit motion to the steering shaft; also to know the exact point where steering bar transducer is placed.

In order to replicate the signals that should receive the serial driver: gear lever, throttle and brake; a new module is necessary, this has been achieved through a new PLC that reads information from the truck, both analogue and digital and data of the own vehicle CAN BUS, and transmitted by CAN to Ethernet to be read externally. The same PLC receives the commands transmitted from Ethernet to CAN by the external control system. These commands are sent to the truck and the replica for their digital and analog outputs using PWM-voltage converters. These are used to replicate the commands like „% Throttle", „% brake", etc., using the same type as when the truck is manually operated.

As in the case of management, to now the movement that makes the vehicle, has been installed in the transmission, a crown and a dual channel sensor that lets us know which meter is running and the direction of travel.

3.1.3. Hoisting Fifth wheel

In this case, for the displacement of electrical signals for raising and lowering replica, multiple elements have been installed. To know the position of the fifth wheel, has been installed a potentiometric sensor wire, which indicates each time the actual position is lifting cylinder.

Fig. 3. Fifth wheel position sensor.

3.1.4. Brakes

As noted above, if the parking brake has replicated the electrical signal through the PLC, and if the service brake (brake pedal) is connected to a throttle valve pressure, an electrical signal is sent to perform a similar pressure. that would make an operator by hitting the brakes. By this electrical signal we can regulate the pressure we want to convey to the circuit (hard braking or moderate braking).

3.1.5. Lights

To operate the lights are replicated by electrical signals installed new PLC.

3.1.6. Emergency buttons

Besides vehicle emergency buttons, it has been installed a new button on the right side of the truck, and another wireless button was created to increase the safety, and also a safety relay has been added, this receive for automatic mode the vehicle stop command in case of communication failure or the pressure of any emergency button.

3.2. Autonomous control

In this case the vehicle is not a regular car and the working area is not an open street of a city. The Tugmaster is a large vehicle that is used to move cargo from the port to the ship hold. This vehicle is composed with two important elements, the truck and the trailer. In order to drive correctly the vehicle -must take into account the dynamic movement of the trailer during the cargo transportation.

In order to command the truck and the trailer, a predictable autonomous controller is created. This controller is able to follow the received trajectory and commands, avoiding collisions and dangerous situations. This controller has two different phases, the first one is when the load is transported around the ship and the second one is when the truck must leave the ship without any load.

In the first phase, the controller has three control points. The first one is on the head of the truck, the second one is on the end of the trailer and the last one is on the axis between the truck and the trailer. With these control points, the controller is able to determine the vehicle state, and correct the trajectory in order to follow it. Also, taking into account the required maneuvers to transport the load, the vehicle is able to change the gear, change the fifth wheel elevation and the control points. These points must be different when the truck has left the trailer in the final destination. At the same time, it must be taking into account the trailer angle based on the truck yaw, this is used to maintain the trailer in line with the truck head and to avoid the excessive turning of the trailer.

(a) (b)

Fig. 4 (a) Required points when the trailer it's engaged; (b) Required points when the truck is leaving the ship.

In this second phase, the truck movement must be forward, and then the truck head must be the front side of the vehicle. Also, the control points change from three to two, and the control become more intuitive, because in this phase the truck moves like another regular vehicle. In this case the vehicle movement is based on the current position, orientation and speed to predict the future position of the truck and correct the trajectory in order to move along the correct way.

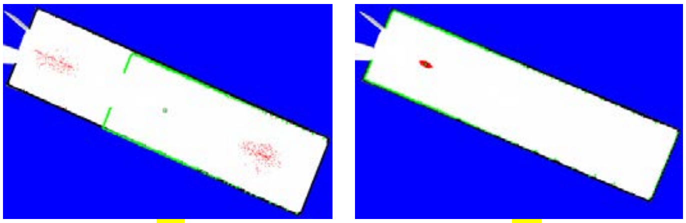
3.3. Vehicle positioning system

The state estimation of an articulated vehicle on a hold implies four different state variables: two variables corresponding to the position (x, y) of the geometrical center of the tugmaster in the hold, its orientation and the relative angle between the tugmaster and the rolltrailer.

An indoor positioning system was developed in order to perform this localization of the vehicle. Due to the application business area, one limitation encountered was the impossibility to modify the environment, so natural marks on the ships holds must be used.

A 360 degree laser scanner was installed on the topmost part of the tugmaster in order to acquire the surroundings of the vehicle, then performing a scan matching on a previously generated map. This information was feeded to a Monte Carlo Localization (MCL) algorithm (Thrun, 2001) for providing the final position (x, y, r) on the hold.

The initial particle distribution is performed around the surroundings of the entrance of the hold, in order to avoid localization problems due to simmetries present on the map. An actual example of this problem can be seen on Figure 5



(a) (b)

Fig. 5. Position initialization after a few MCL iterations; calculated position is indicated by the light circle and laser reflections are shown overlapping the occupancy map. (a) With homogeneous particle initialization on the whole map. (b) Initializing particles just on the surroundings of the hold entrance.

An occupancy grid mapping of each desired hold is performed offline from the measurements taken by the robot itself, by means of Simultaneous Localization and Mapping (SLAM) techniques (S. Thrun, 2005). Figure 6 shows the collected data and the occupancy grid mapping generated after processing.

(a) (b) (c)

Fig. 6. SLAM results: (a) Original data collected. (b) Odometry errors corrected by laser scan-matching. (c) Occupancy grid map.

The state estimation problem for this development implies one additional variable: the angle between the tugmaster and the rolltrailer. This additional state is measured by processing the information given of a laser scanner placed behind the rear differential gearbox of the vehicle. While the main purpose of this scanner is the detection of nearby obstacles, it also captures the rolltrailer profile. In order to track this angle and avoid false recognitions caused by nearby objects, such as previously stowed cargo or even other rolltrailers parked near the tugmaster, an additional particle filter was implemented. The widths of all the segments detected by this rear laser scanner are feeded to the particle filter, assigning a probability which depends on the difference with the nominal rolltrailer width (Figure 7).

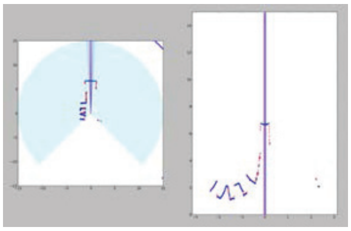


Fig. 7. Rolltrailer angle detection (left in polar coordinates; right, distance against angle).

3.4. Sensorization and recognition of environment

In order to avoid colliding with obstacles present on the hold and ensure the safety of operations, the robot has to perceive its surroundings and behave accordingly. Due to the highly cluttered nature of the environment and the highly constrained path the vehicle has to follow, complex collision avoiding maneuvers will be impossible most of the time, so reactive navigation capabilities were not implemented. Instead, a replanning path planning algorithm was provided, in combination with a collision detection system.

A safety area around the robot is constantly being monitored by means of two laser scanners (one under each differential gearbox) and several ultrasonic sensors, as shown in Figure 8. This safety area has two separated zones: a nearby one and a far one. When any object is detected inside the far zone, the vehicle reduces its speed proportionally to the distance to that obstacle. If the object enters the nearby zone, the vehicle stops completely. Thus, when an obstacle is detected to be in risk of collision, the robot can search for an alternative route, if possible, or wait until the risk disappears. If no alternative path is found possible and the obstacle is still, a manual intervention is required in order to guarantee the safety on the hold.

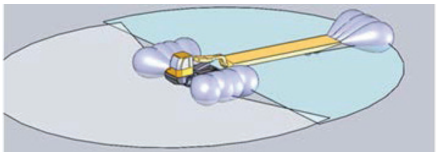


Fig. 8. Sensor coverage for obstacle detection.

The security areas are dynamic and constantly being computed in real time. This is necessary to maintain them small on low risk areas (for example, the rear part on the vehicle when moving forward) and extending ahead on high risk situations. The shape of these areas depends both on speed and steering. Separate areas are calculated for the tugmaster and the rolltrailer, when loaded, and then joined together to form the final envelope.

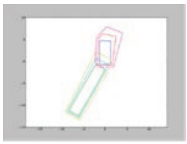


Fig. 9. Nearby and far safety areas calculated for a loaded robot moving forward while steering right.

As can be seen on figure 9, when the robot is pulling or pushing a rolltrailer, the rear part of the ensemble is not covered by any of the laser scanner. The number of rolltrailers on any port is huge, and they are often not property of the stowage company, but of the final clients. For this reason, sensing this part is unfeasible, so a different approach had to be taken.

A detachable bumper was designed and developed, equipped with a pack of ultrasonic rangefinders, a battery and wireless communications. This bumper is equipped with magnets, and can be easily attached and detached to any rolltrailer by untrained personnel in order to provide sensing capabilities to the rear part of the loaded vehicle, as shown in figure 10.

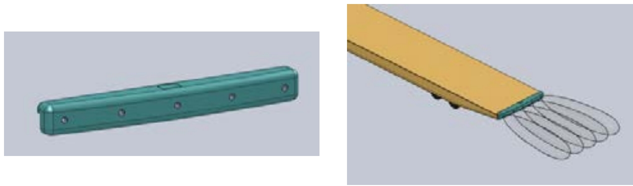


Fig. 10. Left: the designed magnetic backpack. Right: backpack coverage once installed

These detachable bumpers can be cheaply produced by using foam and aluminium profiles for body and structure respectively.

3.5. Roll-On / Roll-Off Operations intelligent management (IMATIA)

An autonomous stowage system aims to make possible the following characteristics without human intervention:

- Make the most of the volume of the vessel in order to load as much cargo as possible.
- Make stowage so that port operations are as fast as possible
- Set stowage so that the load is placed in reverse order of port arrival (so that no blockage between cargo is produced) and can be unloaded without delay or risk

In order to fully stow a hold, all locations must be visited, placing on each one the corresponding charge, so that the charging time should be independent of the order in which is performed. However, in practice, locations loaded and weight of the materials placed in them affect the stability of the ship, which can greatly complicate subsequent stowage of cargo. On extreme situations, when a heavy cargo has to be located on one side of the vessel under rough sea conditions, the keel of the ship produced by the cargo itself can make the maneuver impossible, to the point of being necessary to leave the cargo close to the side, stow a similar weight cargo on the opposite side of the vessel and then finish the initial load operation, now with the ship balanced.

So, in order to guarantee minimal load and unload time, an automatic stowage plan generator must meet the following conditions:

- The cargo has to be placed on the hold, in a feasible order. That is, from the locations farthest from the entrance to the closest ones. The unfulfilment of this rule is known as „load blockage"
- The cargo has to be placed so that no blockage is caused on any unload operations on the next ports of the trip, in order to avoid the need of unload a cargo from other port and load it again before departure. The unfulfilment of this rule is known as „unload blockage"
- The stability of the vessel at any time has to guarantee the feasibility of the tugmaster operations without the need of complex maneuvers.

A genetic algorithm (A. Fraser, 1970) was implemented to solve the described optimization problem. The genetic representation of the problem was made with cargo-location pairs (each pair is a chromosome). For calculation of the fitness of each individual, the angular momentum is used to express the resulting imbalance of the hold. Thus, the final cost of each individual is the summatory of the angular momentum of the hold after the stowage of each cargo. We call this „cumulative imbalance". In order to work with positive fitness enclosed between zero and one, we use the following fitness function:

$$F = \sqrt{\sum_i (L_i^2)} \quad (1)$$

Being F the fitness value and Li the angular momentum of the hold just after the stowage of the cargo i. The square power helps to prioritize many low imbalance intermediate states over a single highly imbalanced one. Individuals that are found invalid due to load or unload blockage are assigned a fitness of zero and automatically discarded on every iteration due to this low fitness value.

In order to provide genetic diversity beyond the provided by the initial population, two different mutation operators were implemented:

- Order swapping: the position of two random chromosomes (location-cargo pairs) of an individual are swapped, thus changing the order of stowage without a change on location-cargo assignment.
- Cargo swapping: The cargo values of two random chromosomes are swapped, effectively changing the position of each cargo in the hold without altering the cargo order of each location.

Regarding crossover, due to the dual nature of the chromosomes on this implementation, a double partially mapped crossover (D. Goldberg, 1985) was implemented to simultaneously manage locations and cargos on each crossover operation.

Fig. 11. Genetic algorithm result on a ninety location hold, stowed with ninety different rolltrailers, with six different destination ports. Destination port is coded by rolltrailer colour, showing no unload blockage is produced.

4. Results

During the last test multiple data has been obtained in order to check how effective is the automation and the control created for the Tugmaster. This data was recorded taking into account the two different modes, backward movement with rolltrailer and forward movement without any cargo. The following table shows a resumed data.

Table 1. Vehicle deviation at destination.

Backward	Min	Max	Median
Longitudinal deviation (cm)	-4.37	9.51	7.23
Lateral deviation (cm)	-15.32	35.94	22.36
Orientation deviation (º)	-2.51	4.55	2.86
Forward	Min	Max	Median
Longitudinal deviation (cm)	-2.69	4.31	2.24
Lateral deviation (cm)	-3.21	3.48	2.10
Orientation deviation (º)	-1.27	1.19	0.62

The data shows the most important information that was taking into account during the control refining: the longitudinal deviation, the lateral deviation and the orientation control. The resulting data is the values after 50 test runs. These indicators show how much the vehicle has deviate from the original destination. These data is showed in cm in case of the longitudinal and lateral deviation, and degrees in the case of the orientation. The data show the lateral deviation as the worst value, but taking into account the length of the rolltrailer, around 15 meters, it can be assume as very good results. Also is very remarkable the work space limitations, even if the sensors avoid in most cases the collision risks, the control is very smooth in order to decrease the same risks.

5. Conclusions

After finishing the AUTOPORT project, the result shows a successful development of a solution in order to increase the efficiency and decrease the pollution produced by the use of the required vehicles to move cargo along the ports. This solution is able to move autonomously the Tugmaster and the rolltrailer together inside the ship, avoiding the risks and inefficiencies produced when one person is the main driver of the vehicle.

Multiple different subjects were been involved during the development of the AUTOPORT project: vision systems, vehicle sensors, vehicle automation, vehicle autonomous control and intelligent management. The integration of all these subjects is not natural and increase the difficult as new are incorporated. Also must be taking into account the usage in a real time changing environment, out of any predefined conditions, where the risks increase according to the usage of the port.

AUTOPORT project it's only the first approach to aboard these solutions in the real world, this step allows understanding how the autonomous systems can be introduced in work areas, regardless of the typical approach focused on the city cars. This is only the beginning of the new cargo transportation system, and opens the door to the creation of more new scenarios where the autonomous vehicles can be useful for the cargo and persons transportation.

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