On-board Intelligence for the Furbot: a new Concept for Urban Freight Transport

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Abstract

The Furbot project proposes to develop a new concept for urban freight transport. The novelty of the concept is twofold. A new architecture of light-duty, full-electrical vehicle is proposed. A great effort is devoted to energy management: new power train layout integrated in the chassis; new battery and energy management system; regenerative braking… But if attention is given to energy management for one vehicle, the Furbot concept consists in having a fleet of several vehicles offering a new sustainable and very adaptable (evolvable) urban freight transport system. In this article, we focus on the intelligent on-board unit. It has mainly two functions. First, it offers assistance to the driver: emergency braking, obstacle avoidance, parking assistance, itinerary assistance or adaptive speed control. Second, it proposes automation abilities for the loading/unloading of the payload. Regarding the multi-sensorial perception system, an intelligent human-machine interface is also conceived in order to let the driver choose between the driving modes (fully manual, assisted, automated loading), in order to provide him general information (map, mission, fleet state...) and warn him about safety issues, power caution and vehicle diagnosis.

Keywords: urban freight transport, on-board intelligence, automatic loading/unloading

Résumé

Le projet Furbot propose de développer un nouveau concept de transport de fret. La nouveauté du concept est double. Tout d'abord, un nouveau type de véhicule est proposée : léger et complètement électrique. Un grand effort est consacré à la gestion de l'énergie : nouveau système de propulsion intégré dans le châssis, batterie innovante et système de gestion de l'énergie intelligent; *etc.* Mais si une attention particulière est dédiée à la gestion de l'énergie pour un véhicule, le concept Furbot consiste à avoir une flotte de plusieurs véhicules qui constitue un nouveau système de transport de marchandises durable et très adapté au milieu urbain. Dans cet article, nous nous concentrons sur l'intelligence embarquée à bord du véhicule. Il a principalement deux fonctions. Tout d'abord, il offre une assistance au conducteur : freinage d'urgence, évitement d'obstacles, aide au stationnement, assistance pour le choix d'itinéraire ou de contrôle de vitesse adaptatif. Deuxièmement, il propose le chargement / déchargement de la charge utile (boîte de marchandise) en mode complètement automatique. Fort de ces innovations technologiques, une interface homme- machine intelligente est également conçu pour permettre au conducteur de choisir entre les modes de conduite (entièrement manuel, assisté, le chargement automatisé), et afin de lui fournir des renseignements généraux (carte, mission, état de la flotte, *etc.*) et l'avertir en cas de problème de sécurité ou de diagnostic du véhicule.

Mots-clé: transport de fret urbain, véhicule intelligent, système de chargement automatique

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1. Introduction

Nowadays, main Intelligent Transportation Systems (ITS) issues is to offer new mobility solutions for traffic regulation and gas-emission limitation in order to reduce congestion and air pollution. Moreover, since 94% of the road accidents in France are due to human errors, it clearly appears that the vehicle of the future, from a safety point of view, should offer automation options. The Furbot project clearly offers solutions to these triple issues, by handling the problem of freight transportation.

The Furbot vehicle is designed as a new freight transportation system, to deliver merchandise from Urban Distribution Centers to the city center. It is equipped with loading/unloading robotic device in order to load until two boxes. Boxes have been also specially designed in order to be dropped off in the street, where customers can pick up their merchandise. The loading robotic device is placed on the left side of the Furbot vehicle instead of vehicle back for most of freight vehicles to be more efficient. When the vehicle is well positioned by regarding the box position and orientation, then the vehicle chassis goes down by using active suspension and a forklift, equipped with casters in order to avoid imbalance due to the box weight, goes out to take the box, placed on a European pallet. The automatic loading/unloading operation takes only 25 seconds.

In these years, developments of information and communication technologies become the basis of ITS. The advances of global positioning systems (GPS) and communication techniques enable realization of new fleet management strategies. And indeed, the Furbot vehicle was thought as a transport agent that can be used by alone but that better exploits its power if used in a fleet offering a new sustainable and very adaptable urban freight transport system.

In addition to design a new vehicle (illustrated in Figure 1: the Furbot protoype) and a new freight transportation system, the concrete objective of the FURBOT project is also to develop driver assistance systems on-board. There are several functions. The first function (and the most ambitious one) is more than a simple driving assistance since it consists in providing automated assistance during the box loading-unloading process. During the automated handling of the box, the safety responsibility goes to the system; the goal is therefore to ensure safety during any automation stage by using obstacle detection algorithm. This is to ensure that no collisions will occur during the loading or unloading operations.

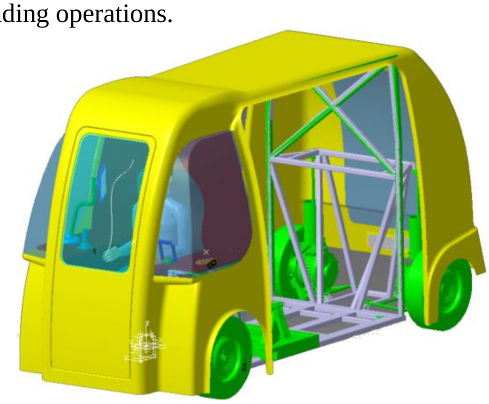

Figure 1: the Furbot protoype

Also, in order to help the driver in the driving process, some assistance (*eg.* ADAS) is provided, such as emergency braking or parking assistance, the final goal being to improve road safety and driver comfort. Special attention will be given to the obstacle detection and tracking, as well as the collision risk assessment. In order to help the driver to accomplish his mission, a precise localization is provided with a basic GPS device, as well as a map of the environment. This map-matching function is a part of the assistance systems that will be displayed and provided by the graphical Human Machine Interface (HMI) dedicated to the driver.

The paper is organized as follows. Section 2 carefully describes the automation during the loading/unloading process, which is the most ambitious part of the project. Section 3 explains the obstacle detection and tracking strategy, which is critical for safety reasons. Section 4 describes the ego-localization techniques and Section 5 shows the HMI developed for the prototype.

2. Automation during the loading/unloading process

Several cases must be considered for the automation of box loading/unloading.

2.1. Loading scenarios

- <u>Loading of a box in a urban distribution centre</u>

In this scenario, we suppose that the driver has been assigned a mission and is now looking for the right box to load in the Urban Distribution Centre (UDC). He is going all over the UDC to find the box with the manual or assisted driving mode. He can then monitor the box research through the "box" tab of the HMI. When the vehicle becomes close enough of the right box, the RFID receptor is activated by the RFID tag of the right box (from a distance of one meter) and the box is identified. The driver can visualize it in real time on the HMI (Figure 2) through the side camera. At this moment, the automatic driving mode is available and can be chosen by the driver through the HMI. When the "loading mode" is activated (see Figure 2), a confirmation order message is sent and the Furbot vehicle will automatically move until it gets well positioned regarding the box (see Figure 4).

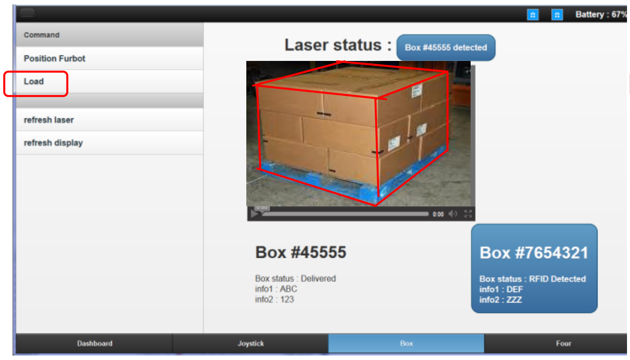

Figure 2: Box detected through the HMI

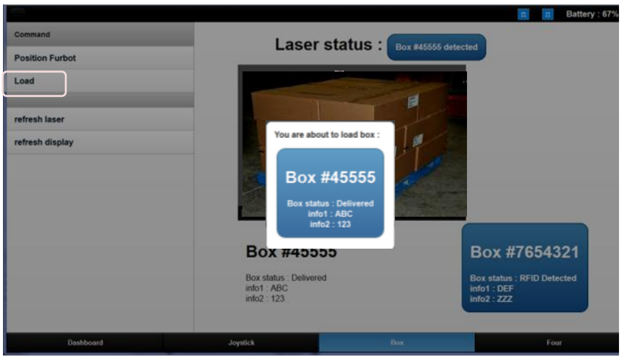

Figure 3: Confirmation of the loading order

The good positioning is defined in terms of parallelism and longitudinal/lateral errors (see Figure 4) (a few centimeters). The box is supposed to be well positioned on the pallet. When the loading is processed, then the Furbot vehicle can be driven with or without assistance and can pursue its mission.

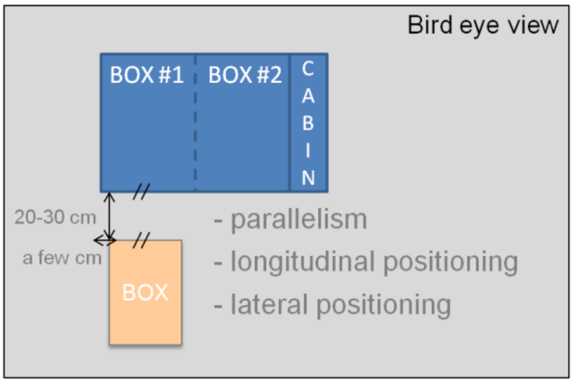

Figure 4: Conditions for good positioning

- <u>Loading of a box in bay areas</u>

Bay areas are located inside the cities and are chosen as flat areas with large free space to let the Furbot vehicle go. However, contrarily to the UDC, the environment is not controlled and some obstacles can obstruct the path of the Furbot preventing it to position itself regarding the box. In this case, the vehicle has to maneuver (front and rear maneuvers) and elaborate complex paths to pursue its goal. Fuzzy controllers will be used to achieve the longitudinal/lateral control (Perez, 2013).

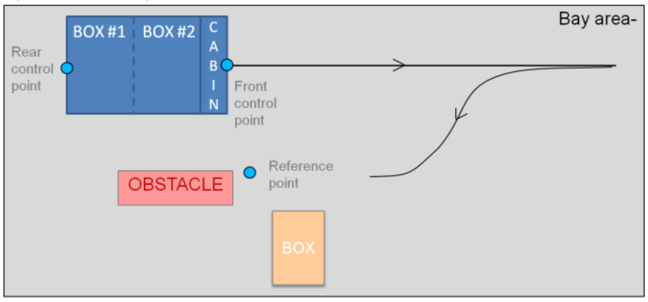

Figure 5: Illustration of the box loading in a bay area with an obstacle

2.2. Unloading scenarios

- <u>Unloading a box</u>

For the unloading case, there is no distinction between UDC and bay areas. The driver is in charge of choosing the unloading location. The role of the system is twofold for this task. First, it has to inform the driver about the future location of the box using templates which will be projected onto the images of a videostream provided by the Furbot external camera. It implies that the camera should point at the loading/unloading area.
The second task consists in ensuring that there is enough space to unload the box. It allows the driver to choose the "unloading mode" only if no obstacle is detected. If a moving obstacle is detected on the box path and if the collision risk increases, then the unloading process will automatically stop. Laser data are used for the obstacle detection. Laser impacts are segmented in order to detect objects and they are projected on the image to inform the driver. The fusion of data coming from camera and the laser sensors implies the use of a very precise calibration process. This calibration process is ready to be applied on the Furbot prototype using a method described in (Zhang, 2004).
In Figure 6, the HMI provides some augmented reality to help the driver to choose the location of the unloading. Free space is delimited by orange color. Bounding boxes surround the potential obstacles (here another vehicle). And the location of the box if unloaded is projected on the image. Green color indicates that the location is free (red color will mean the opposite), and the "unload" button is available.

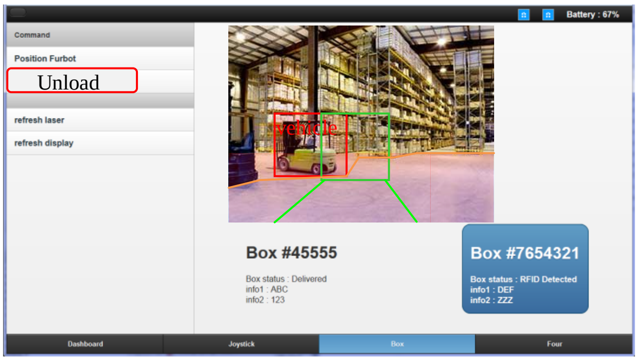

Figure 6: Augmented reality through the HMI

3. Obstacle detection and tracking

3.1. Principle

The proposed obstacle detection and tracking approach is a classical 6 step approach (F. Nashashibi and B. Bargeton, 2008) illustrated in Figure 7.

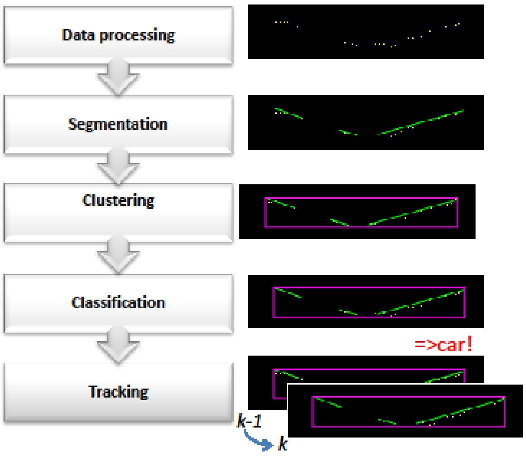

Figure 7: Obstacle detection and tracking: general scheme

- **Data processing step**, distances coming from the several laser sensors are converted into *(x,y,z)* points in the local Cartesian coordinate system centered on the middle back of the chassis of the vehicle. They are then sorted depending on their angle from the coordinate system center.
- In the **Segmentation** step, a Recursive Line fitting algorithm is used as in (a. Mendes, 2004) with parameters d_1 and d_2 for the maximum distances to the closest segment and between two successive segments respectively. Before applying the Recursive Line fitting algorithm on the point set, it is clustered. Each sorted point is recursively associated to an existing cluster by measuring its distance to the last point of the cluster or it is initializing a new one if the distance to each existing cluster is bigger than the same threshold d_2.
- In the **Clustering** step, segments are associated to create objects. Objects with less than 5 laser impacts are filtered. This number has been established by expertise. Then, only objects on the current lane are considered for ACC or emergency braking to limit false alarms.
- In the **Classification** step, size and shape consideration are used to obtain a raw classification of the object. This raw consideration is used to update the type probability over time only, but motion model is not yet considered.
- In the **Tracking** step, information about the vehicle dynamics are considered (velocity and steering angle) to improve the tracking of the object in the local Cartesian coordinate system. Object tracking is done in relative coordinates regarding the ego-vehicle using a Constant Velocity Kalman filter and Nearest Neighbor approach for data association to deal with real time constraint.

3.2. Application

- Adaptive Cruise Control (ACC) with lane information

In order to perform an ACC system, the closest obstacle on the current lane must be detected. Lane information (coming from the map) are used to filter obstacle on the current lane. As illustrated in Figure 8, obstacles are tracked in the detection area (limits are the pink lines) and considered for the ACC only on the current lane (limits are the blue lines).

Figure 8: Obstacle detection with lane information

In order to provide an ACC system, the relative velocity of the front obstacle must be calculated. This is done by the derivation of its relative distance (P. Resende, 2013).

- Emergency braking

As front and rear obstacles are detected in real time, an emergency braking will be proposed following 5 steps:

1. Detect closest front obstacle on the lane
2. From its relative distance, derivate the obstacle relative velocity
3. Calculate the collision risk
4. Warn the driver (audio signal through the HMI)
5. Activate the emergency braking if the collision risk is too high

In addition, visual information are provided to the driver in order to warn him on the presence of an obstacle.

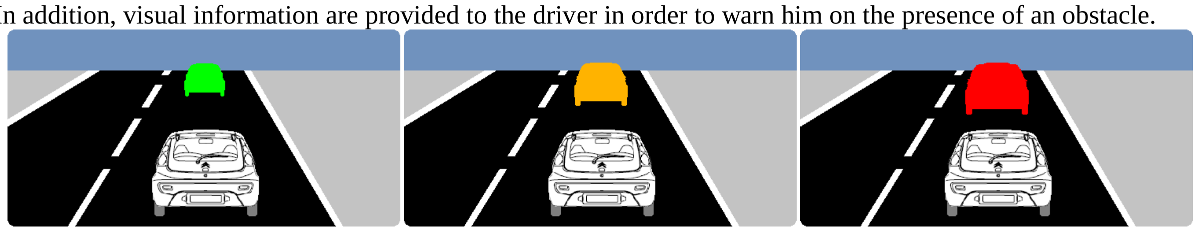

Figure 9: obstacle information given to the driver (green= low, orange= medium, ref=high risk level)

4. Ego-localization with map-matching

4.1. Principle

Presuming that road vehicles are moving on the road, the map matching principle is to take advantage of a geo-referenced map to improve the localization of the vehicle. It consists in determining in real-time the position of the vehicle on the map according to the GPS position. The position must rely on a "map segment" that exists in the GIS. There are two levels of precision to deal with that:

- First, the road segment where the vehicle is driving must be determined
- Then, the lateral and longitudinal position on the segment must be estimated. In other words, the lateral position will determine on which lane the vehicle is (and what is the flow direction) and the longitudinal position will be used to calculate the distance to the next "node" of the road network.

Several techniques exist in the literature. The simplest one is to directly project the GPS measurement on the map and to look for the closest segment. This technique can quickly be limited due to the GPS positioning accuracy (error in the segment determination) and will not allow determining the current vehicle lane.

In order to limit these deficiencies, target tracking can be first considered in order to know the flow direction of the vehicle. However, the longitudinal position is still inaccurate and, in case of multi-lane, there is still an ambiguity on the current lane. To improve the localization estimation, it is current to use "dead reckoning" sensors, which estimate the ego-motion of the vehicle. The following are among the best-known: wheel encoders, steering angle, accelerometer, gyrometer as well as Inertial Measurement Unit (IMU). All these measurement are integrated with the GPS measurements, which produces a global positioning.

For the Furbot project, map format will be supported by OpenStreetMap (OSM).

4.2. Results

OSM is used through the Caorto software, which is used inside the RTMaps development middleware used by Inria and integrated in the Furbot processing unit. In Figure 10, GPS measurements are merged with OSM database. Information about the geographical areas are displayed, such as the name of the street, the speed limitation or the distance to the next intersection. This information will be very useful for the driver in the Furbot vehicle. Moreover, knowing precisely the position on the road will help the system to provide an itinerary to the driver as shown in Figure 11

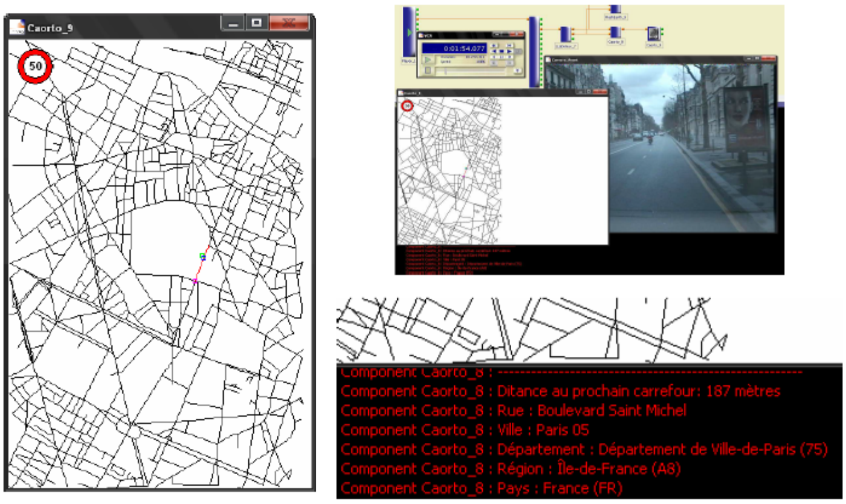

Figure 10: Interfacing OSM and RTMaps

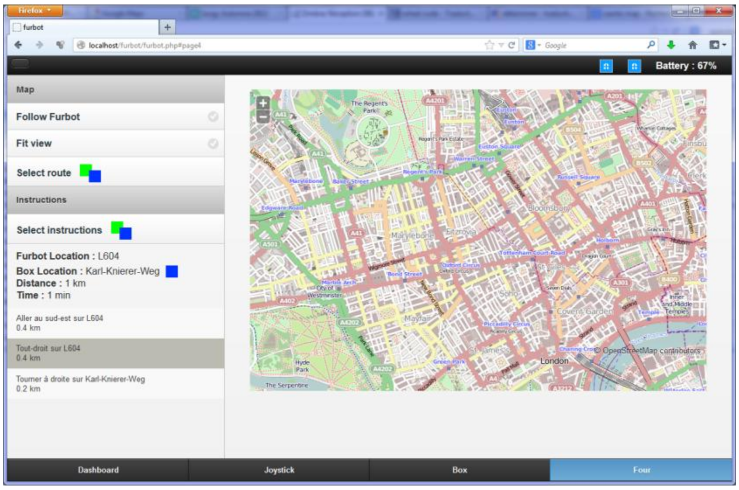

Figure 11: Itinerary options on the HMI

5. Interaction with the driver

System and driver interact with each other's through one interface. This Human to Machine Interface Interface (HMI) is deployed on a touch screen. It plays three key roles:

1. Control: choice between several driving modes
    - Fully manual
    - Highly assisted driving: automatic obstacle avoidance, lane keeping warning, adaptive speed control
    - Platooning: input and output
    - Loading/unloading: box pick-up, moving and placing or box unloading and moving to the dedicated area
2. Inform: provide general information to the driver on:
    - The road environment, the real-time traffic, the map
    - The itinerary and the mission
    - The fleet vehicle state, platooning options
3. Warne/Inform: safety warning, power caution, vehicle inner diagnose pre-caution
    - Vehicle and obstacle state: position state, velocity, collision avoidance
    - Battery state (low battery signal, battery recharging signal,...)
    - Box state: information on the box, loaded/unloaded, in loading/unloading

The HMI takes the form of a web interface. Information is shared between the HMI and RTMaps through a MySQL database. An example of RTMaps diagram including communication with a webinterface is shown in Figure 12.

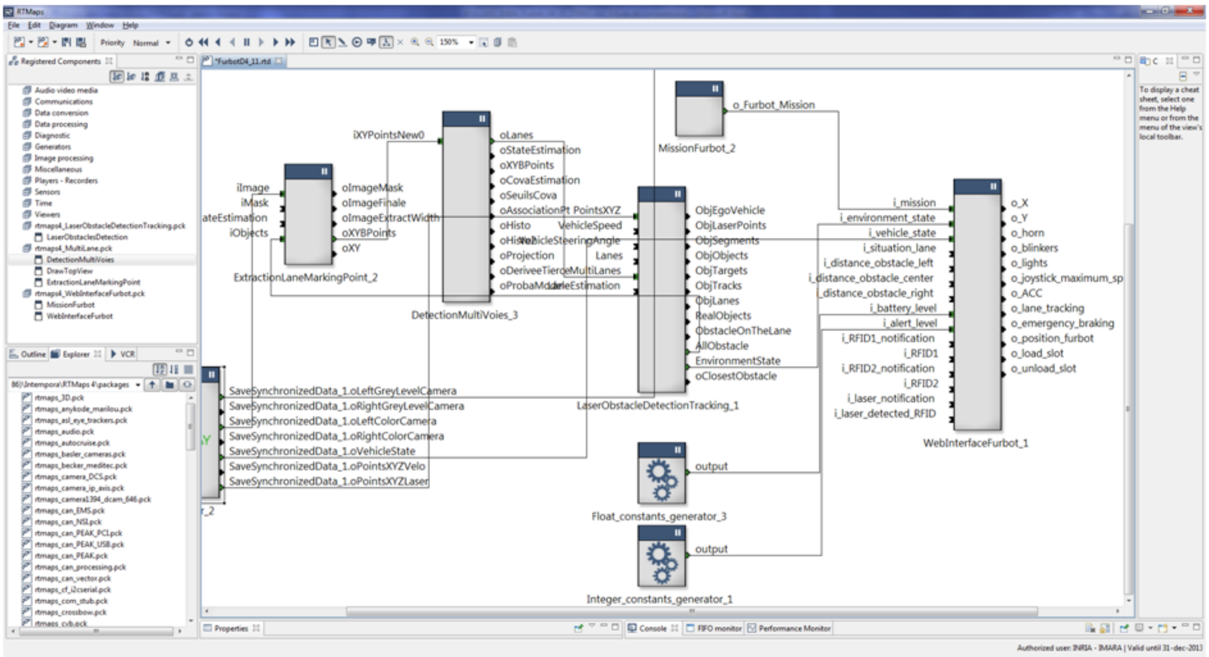

Figure 12: Interfacing RTMaps with a web interface

5.1. General dashboard

The dashboard is the by default webpage which is displayed on the HMI (see Figure 13). It contains all the general information about the Furbot: battery level, presence of boxes, velocity and steering angle, position on the map. It controls some functionality: activation of the driving assistance, blinkers, etc.

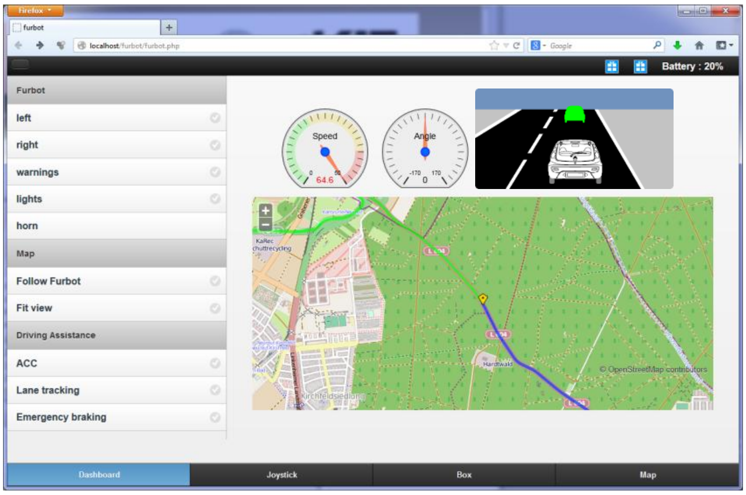

Figure 13: Dashboard

5.2. Virtual joystick: outside control

The Human Machine Interface is mainly displayed on a tablet to let the driver the opportunity to drive the Furbot vehicle from outside (see Figure 14).

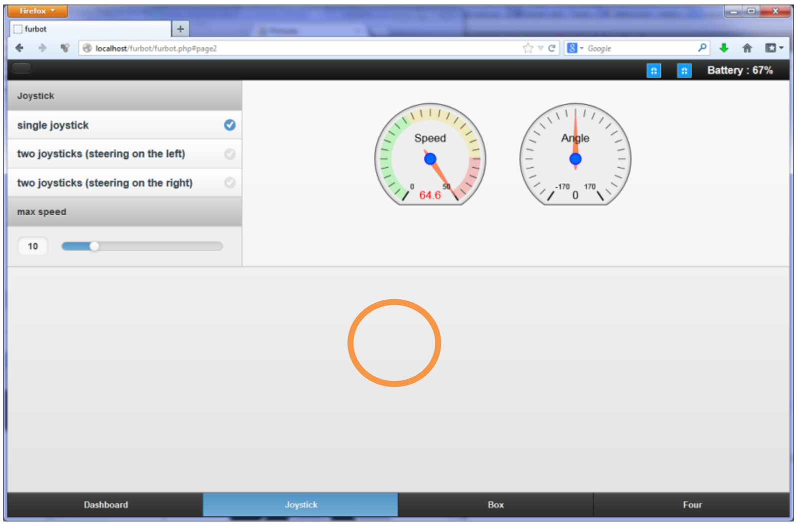

Figure 14: Virtual joystick

6. Conclusion

A multi-sensorial system has been designed for the Furbot vehicle in order to perform all the automation and assistance tasks, and guaranty the maximum possible le safety level. It has been conceived in a minimalist way, with a maximum cost-effectiveness. Some functionality is ready to use. Some others will be tested as soon as the prototype will be built in January 2014.

Acknowledgements

This work is part of Furbot, a 3-year international research project. The authors would like to thank the Seventh Framework Programme (FP7) of the European commission for supporting the project.

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