A ROBOTIC VEHICLE FOR FREIGHT DELIVERY IN URBAN AREAS

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ABSTRACT
The authors present new concept architecture of light duty full electrical vehicle for efficient sustainable urban freight transport that allows the movement of two Euro Pallets 800x1200 mm (or boxes with similar bottom part). Following a sustainable and efficient mobility approach, a robotic handling device has been designed and positioned on-board of the vehicle. The handling device realizes the loading-unloading operations on the right side of the vehicle and from the ground to the vehicle platform. Active suspensions of the vehicle have been designed to adapt the stiffness to the payload and at modifying the chassis height on the ground for travel and loading-unloading tasks.

Keywords: Freight Transport, Urban Areas, Robotic Vehicle, Electric Vehicle

1. INTRODUCTION
Freight transport is a critical issue for urban areas: the population is becoming more and more concentrated in cities and therefore the bulk of industrial production is dispatched to these areas. Moreover, the demand for freight transport is growing at a fast rate due to changes in industry logistics and consumer purchasing patterns.

As urban freight transport deals primarily with the distribution of goods at the end of the supply chain (Power 2005), many deliveries tend to be made in small loads and in frequent trips, thus resulting in many vehicle kilometres (Cepolina and Farina 2013).

Consuming behaviours have changed rapidly in the past years and they have transformed the way people travel for shopping. Surveys show that home deliveries are not marginal anymore and are growing at fast rate. Many householders have their groceries delivered at home on a regular basis. Many of them do it after online shopping. According to latest APAC and America forecast report, global e-commerce sales Business to Consumer, B2C, will surge up to 50% in the next 5 years, see Figure 1. Many transport companies are reluctant to serve householders: they consider home deliveries to be a difficult market, because of the high dispersal of delivery points, a high proportion of missed appointments, difficult delivery schedules and a large number of upper floor deliveries (Dablanc 2014).

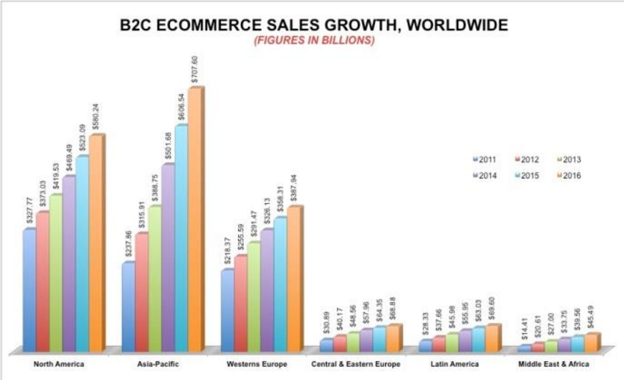


Figure 1: B2C e-commerce sales statistics and forecast (courtesy Amit Misra, July 2013)

As a result the scope of urban freight focuses on vehicles that visit many destinations, picking up and delivering many separate consignments (Muñuzuri 2009).

These urban freight movements cause problems within cities, e.g. due to: the lack of suitable infrastructure for deliveries, the conflicts with other users during freight delivery operations, the accessibility of these vehicles to pedestrian areas and historic city centres, environmental and noise pollution, generation of accidents in the urban areas and compromising the mobility of citizens.

The primary focus of urban transport planners in recent years has been to address the demand for people movement, and more specifically, to reduce the collective dependence on motorcars and on fossil fuels. As a result, we have seen the gradual conversion of road and street networks towards the inclusion of bus lanes, larger footpaths, cycle lanes, etc. and the reduction of road space available for cars. So the road space available for the freight distribution, both in terms of available road lanes and loading space has been reduced (Crainic at al. 2004).

2. FURBOT MAIN FEATURES
The vehicle architecture is conceived modularly: the main modules are the cab and the chassis. The payload is assumed to be packaged in freight boxes and Euro pallets. The vehicle integrates electrical modules for power generation and supply together with the relative software control modules. The power is used either for

the vehicle motion or for the loading/unloading operations; this is also a safety measure, because in this way it will not be possible to move the vehicle during the loading/unloading operation.

FURBOT is environmentally cleaner and less noisy than traditional vehicles. This allows it to operate in urban center without any access restriction in term of zones and time windows. For instance, thanks to the low noise emissions, off-peak and night-time deliveries can be performed.

Great attention has been devoted to improve the energy efficiency of the system (Amjadi and Williamson 2010) by exploiting different aspects: a new power train layout specially designed and suitably integrated in the chassis design; a new battery and energy management system; last generation lightweight, direct drive electric motors; regenerative braking on the four driving wheels; reduced mass of the vehicle due to a by-wire transmission that allows the realization of the active driving controls via software instead of using heavy mechanical components; and driver-assistant or autonomous-guidance software able to minimize power use.

The freight loading/unloading operations are performed automatically through robotized procedure. Freight boxes have been specially designed together with the architecture of the FURBOT vehicle: the boxes have standard size and their bottom is shaped exactly as a Euro pallet in order to be handled by the robotized forklift. The FURBOT unloads these boxes in specific locations in the urban area. In this way the conflicts with other road users during the loading and unloading operation, and the resulting congestion due to urban freight movements, are limited. The number of stops for the loading/unloading operations is kept low because many parcels, with small volumes and near-by destinations, are aggregated in a single box. Once the delivery is made, the consignee will open the door containing his/her parcel. This is done within a predefined time window, scheduled in advance during the purchase of the item. When the time window expires, the empty boxes will be collected by FURBOT, leaving the urban space free again for other land uses (such as parking).

The FURBOT vehicle is kept very small in size and in the amount of transported freight. It represents a transport agent that can be used by alone but that better exploits its power if used in a fleet as a multi-agent system yielding a new sustainable and adaptable urban freight transport system (Cepolina et al. 2013).

3. THE FURBOT VEHICLE

The dominant paradigms of the new vehicle design were life-cycle approach and high energy efficiency. The first required to take into account, at the design level, of the manufacturing processes, the modularization of subsystems, the standardization of components, functionality performance, the maintenance, repair, and reconfiguration issues, as well as the disassembly and recycling needs, while targeting low cost figure. The second required the right selection and sizing of all the electric supply system components, the definition and set up of suitable rules for the battery management system, the automatic regenerating of the braking energy and its use to charge the batteries, the definition of logics managed by the driving assistant.

Great attention was devoted to the optimization of the vehicle layout in order to increase the freight-payload to vehicle-weight ratio and improve crashworthiness.

3.1. The Structure

The main innovative characteristics are: (a) a light-weight agile frame equipped with active suspension wheels (this novel architecture will allow a better usability in urban environment and improve intrinsic stability and safety); and (b) the adoption of standardized freight boxes dedicated to different categories of cargo and (c) the integration of a robotic module responsible for the loading/unloading operations.

The vehicle body was designed with the aim to tightly envelop the maximum freight volume consisting of two Euro pallet or dedicated boxes (800x1200 mm footprint). The freight weight is supported by a minimalist network of welded stainless steel tubes with square and rectangular section, Figure 2. The body frame cage was optimized through static and dynamic computational analyses and simulations.

The vehicle mobility is realized by two traction wheels located in the rear part of the chassis; the two electric motors are mounted near to the wheels, due to the lack of in-wheel motors with suitable diameter and power available in the market. The two front wheels are steering.

The suspension of the vehicle is constituted by a McPherson strut with a telescopic dumper integrated with a lifting hydraulic cylinder that allows to move vertically the entire chassis, making possible to shift from the driving configuration to the loading/unloading one and vice-versa, Figure 3. It allows reduced transversal dimensions and high distance between the lower and the upper attachments, resulting in a reduction of the stress applied to the vehicle body.

Figure 2: The FURBOT vehicle body and structure

The structural design of the frame has been developed through two sets of analyses: static for the first definition of the geometry and sections; dynamic with time variant external loads at the interfaces of the suspensions to minimize the mass of the structure.

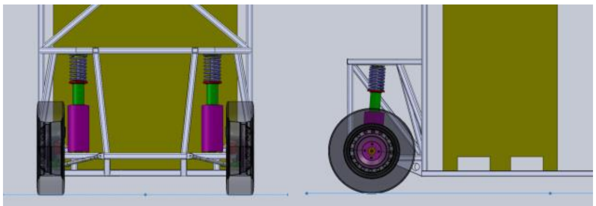
3.2. The Freight Handling Robotic System

A new robotic device, supplied by on-board electricity, is developed and integrated in the platform of the vehicle (Dinale et al. 2013). The kinematic architecture is specially targeted for service tasks, with minimized mass and degrees of freedom, thus simplifying the control system and allowing for an intuitive Human Machine Interface (HMI). The pallet/box loading/unloading tasks are performed by moving the whole pallet/box to and from the chassis-frame side, so this operation can be done very quickly reducing the parking manoeuvres. The main features of the robotic module are: (a) full flexibility and ability to handle (in particular load and unload) automatically the freight modules; (b) sensorization to prevent errors and accidents while performing the operations without compromising timing; (c) ability to determine automatically the mass and inertial properties of the package (typically by reading an RFID tag) and to optimize the handling operations according to the specific need.

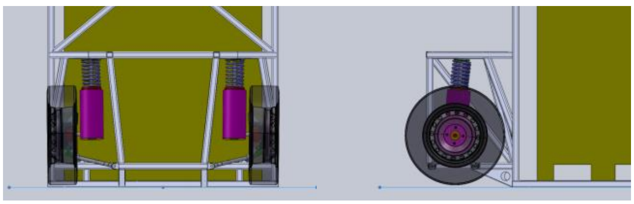
The actuation system of the robotic handling device is constituted of two DOFs: a horizontal (Y direction) and a vertical (Z direction) motion (see Figure 2). These movements are generated by two hydraulic motors with telescopic elongation.

The actuation system of the vehicle contributes with one DOF in Z (see Figure 2 and Figure 3) direction during loading/unloading operations. The movement is generated by active suspensions mounted on the wheels of the FURBOT vehicle.

More information on the freight handling device could be found in (Muscolo et al 2014).



(a)



(b)

Figure 3: Driving configuration (a) and loading/unloading configuration (b) of the FURBOT vehicle

3.3. The Body Embedded Sensorial System

A suitable distribution and intelligent use of exteroceptive sensors plays a key role in the implementation of the driver-assistant and automated-driving functions (Pollard et al. 2014). This will contribute to: (a) safe behaviour within city environments; (b) vehicle steering, accelerating and braking by wire; and (c) a more efficient use of electric power for vehicle propulsion, freight handling and regenerative braking. Figure 4 shows the main sensors equipping the vehicle body.

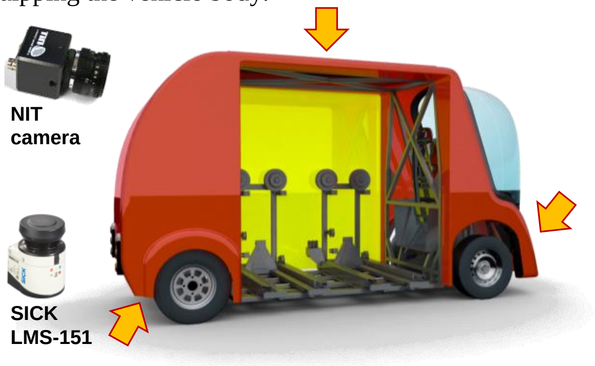


Figure 4: Main exteroceptive sensors positioning

3.4. The Electronic Power System

A fully electrical power train that allows to overcome the low fuel efficiency of traditional gasoline engines or diesel engines has been adopted. Furthermore, the energy efficiency of present-day electrical vehicles (about 60%, taking into consideration the efficiencies of all power chain components charger, battery, power control, motors, transmissions) has been improved in three ways: (a) by regenerating braking energy and using it to charge the batteries; (b) by using intelligent power management rules within the driving assistant; and (c) by targeting the conversion efficiency of standard electric vehicles to obtain a satisfactory power system for small light weight vehicles.

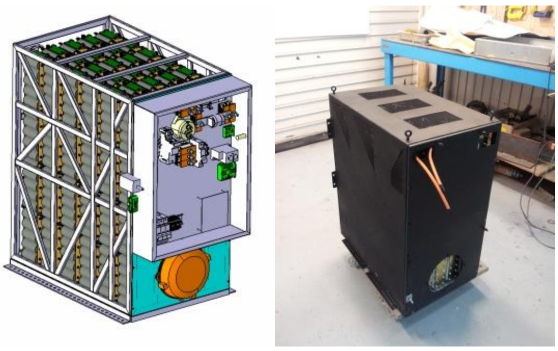


Figure 5: Battery model and box (Courtesy Mazel Ingenieros)

The battery box includes the cells, the monitoring and balancing system. The communication is obtained via can bus.

3.5. The Loading/unloading operation

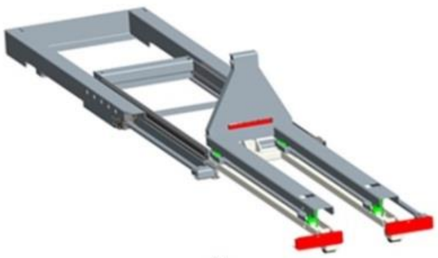
Hereafter the loading/unloading cycle is described. Once the vehicle has been positioned correctly, the following steps are applied:

1. check that the distance between box/pallet is less than 500 mm and all other position tolerances are satisfied;
2. use the active suspensions to move the loading deck until the proper height with respect to the pallet/box to load is reached; the frame with forks translates with

respect to the base and a short lift is available (120 mm), sufficient to move the bottom face of the pallet/box above the floor surface of the loading deck;
3. move outward the forks in lower configuration, insert them in the slots of the pallet/box, lift up the forks, retract the forks, translate down the forks to position the pallet/box on the loading deck;
4. lift up the suspensions to driving height.

The unloading is done analogously in reverse order. Figure 6 shows the two robotic handling devices: the digital mock-up and the real prototype of the robotic handling device. Figure 7 shows frames explaining the motion of the forks during a loading cycle.

(a)



(b)

(c)

Figure 6: Robotic Handling Device: a) digital mock-up closed configuration; b) digital mock-up open and lifted configuration; c) real prototype open and lifted configuration.

Figures 8, 9 and 10 show the complete realized vehicle (without cover), respectively in a frontal, rear, and side view.

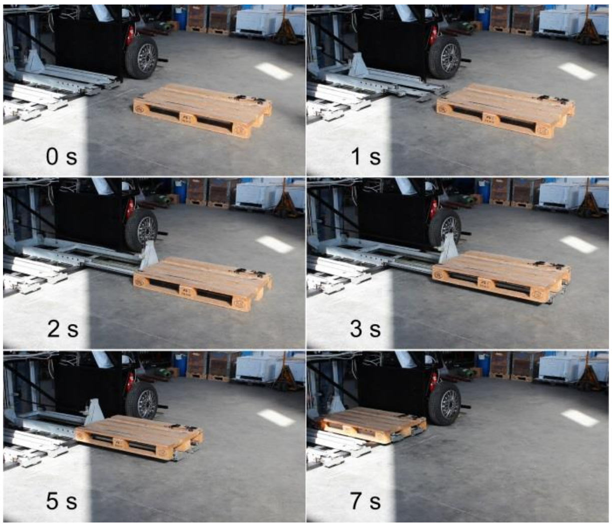


Figure 7: FURBOT loading cycle (from top to bottom, from left to right): intermediate positions of the fork loading an empty pallet.

4. THE FURBOT PROTOTYPE

The different modules of the vehicle are realized and tested stand alone. The assembly and cabling operations are in progress.

The frame is made of welded AISI304 square hollow pipes. The floor of the loading bay uses four 100 mm x 40 mm x 2 mm thickness pipes with transversal connection beams (see Figure 8).

The four suspensions span 180 mm vertical translation and let move the loading deck from driving height (maximum height) to any intermediate loading/unloading height up to deck laying on the ground (minimum height). Each suspension comprises a hydraulic ram with gas spring and a shock absorber in series; this assembly pivots on a ball joint on the chassis and is hinged to the wheel assembly. This original solution transforms the vehicle in a platform with the ability to adjust its height from the ground continuously.

The steering of the front wheels is operated by a servo electric motor driving a mechanical commercial steering bar. The traction power is 15 kW at wheels (tire size 165/75 R14). Full loaded, the vehicle negotiates slopes up to 10% and the max speed is 30 km/h. These speed and slope data have been collected during the delivery simulations in Lisbon (Portugal) and Genoa (Italy), where typical delivery path have been considered.

A view of the vehicle from the rear shows the battery and electronics housing, Figure 9.

The two freight handling robotic systems can be seen on the side view of the vehicle in Figure 10.

Figure 8: FURBOT Vehicle: frontal view

Figure 9: FURBOT Vehicle: rear view

Figure 10: FURBOT Vehicle: side view

5. CONCLUSION

The paper addresses the main features of the FURBOT vehicle. This vehicle has been designed with the aim to offer an innovative platform for freight delivery in urban areas with full respect of the inhabitants and the local environment. In few months, the FURBOT prototype will be ready for testing in real cities that will request its use.

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