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### Evolution and process of electric bike

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#### ABSTRACT

In the past years the urban mobility problems have increased; the vehicle sharing systems are one of the possible solutions to reduce the mobility problems. Accordingly to these needs, the bike-sharing systems are becoming very popular, mostly in the cities grown on a flat area. Even if there are a lot of systems using traditional bikes, there are no systems using electric bikes. This paper presents a system architecture which allows the integration of commercial pedal assisted bikes in a vehicle sharing system; its characteristics do not require the redesign of the vehicle. After presenting the system architecture, the paper describes the design of the device allowing the integration. Some hints about the use of the same approach to lightweight electric vehicles are provided in the end.

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#### INTRODUCTION

In the past years, parallelly to the continuous increment of the traditional internal combustion vehicles, the urban mobility problems have increased. The irrational use of the private cars and the weak diffusion of public transportation systems have incremented the cities' traffic, with the consequence of the urban area congestion and the increase of the movement time. From the general point of view this has caused the increment of the fuel consumption with the direct consequence of the pollution increment both from the environmental and the acoustic point of view. In order to reduce all these problems, different solutions have been proposed:

##### Public transportation

It is the simplest form of sustainable mobility. The most big problems of these systems are the frequency and the coverage of the vehicles, which usually are not high enough, and the high cost for occasional users.

##### Road pricing

It is performed asking a fee to every polluting vehicle which enters in a specified area. The idea is to discourage the use of the private transportation means in favour of public transportation means.

##### Car pooling

A private user decides to share him/her car, often with work colleagues, to travel from home to workplace.

##### Vehicle sharing

A public or a private organization rents a set of vehicle, either cars for long distances or bikes for short ones. The idea is that more than one user share, in different periods of time, the same vehicle.

##### Promotion of electric vehicles

Its aim is to promote the purchase of electric or low environmental impact vehicles.

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Focusing on the vehicle sharing systems, they have had a different diffusion around the world. While in the east of the world they have been quite diffused since 1990s (Hook & Replogle 1996; Seik 2000) [5, 9], only in the last years they have been recognized as an innovative mobility solution all over the world; in particular where the traffic has grown quickly. Generally speaking, *shared-use vehicle systems* (or simply *vehicle sharing systems*) are based on a fleet of vehicles which are used by different individuals throughout the day. The shared vehicle offers the advantages of a private car and more flexibility than public transportation means. These systems are attractive since they contribute to reduce the transportation costs, to decrease the need of parking slots and to reduce the air pollution. Different kind of vehicle sharing systems exist. They mainly differ for the type of vehicle or for the fruition mode: Barth and Shaheen (2002) [11] defined a framework to classify them. What it has been observed until now – in implemented systems described in scientific literature – is that they are almost always composed by cars (Shaheen, Sperling & Wagner 1998; Seik 2000; Barth & Shaheen 2002, Shaheen & Meyn 2002, Shaheen, Meyn & Wiprywski 2003) [12].

The main reason of this common choice is that the integration, in a vehicle sharing system, of different kind of vehicles, usually produced by different manufacturers, needs a redesign of the vehicle or a deep sharing of intellectual property about their way of working. This could be feasible among producers which sell different kind of vehicles, because the technologies are not simply stealable, but it is almost impossible among those producers which operate in the same vehicle market segment. Another characteristic of the modern shared-use vehicle systems is that they are rarely composed by fleets of *electric* vehicle (Barth, Todd & Murakami 2000). Small and light-weight electric vehicle could be a very good solution for short movements inside big and crowded city without a big body effort from the driver side. Some trials in this direction have been done with bike-sharing systems. The bike is a traditional vehicle, in general without an engine; whether it is used as a transportation system, it is suitable for short-range

and flat trip. Alternatively, it can be used for sport or for leisure. The bike-sharing system suitable for the short-range personal mobility where the key concept is to share a pool of bikes among a group of people. There are main advantages in the use of this transportation system (Bouwman & Moll 2002) [4].

- The space needed by a bike is very small compared with the one required by other vehicles. This reduce the congestion of the roads and the need of parking slots.
- Bikes have the lowest energy consumption per person in relation with the distance [kJ/person/km].
- For short-range movements inside a city (less than 6 km), the bike is the fastest vehicle since it is agile and it does not need a parking place.

Typical actors involved in a bike-sharing system are institutions (either public or private) which *own* and administrate the system and a group of users. The main components of the system are:

- A fleet of bikes able to be used in shared-way;
- Some docking stations where the bicycles dwell and where the users can take and return them.
- An infrastructure and an information system which support the operations of subscription to the system, rent and payment (usually dependent to the usage time).

The access to the system could be free or limited to authorized users. In this case, the users could own a *key* which allows him/her to withdraw a bike from a docking station and park it in another one. One of the most known and large-scale bike-sharing system is *Velib'*. Implemented in the city of Paris (see Figure 1) in the 2008, it counts 20,000 vehicles and 1,450 docking stations, i.e. one every 300 meters in the most covered zones. This system is mainly used by tourists which would like to move themselves from a side to another of the city avoiding the use of public transportation.

One of the drawbacks of the bike as a transportation system is that it is comfortable only if the area is flat. To overtake this limitation, in the last years bicycle manufacturers have integrated the human propulsion with the energy coming from an electric engine. The result is an *electric pedal assisted bike*, also identified EPAC (*Electric*

*Powered Assisted Bike*) following the convention of European Law prEN 15194 (March 2005). These bikes own an electric engine either directly

mounted on a wheel or connected with it by a chain; the power is provided by a rechargeable battery.



**Figure 1 A Velib' docking station.**

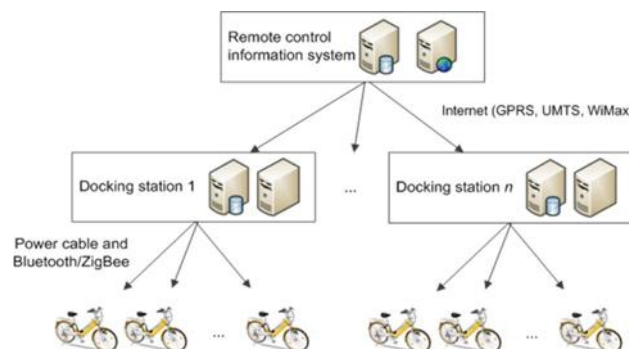
This vehicle can easily reach the speed of 25 km/h with a very low effort, also in cities not perfectly plane; however, by the European regulation, the vehicles can provide assistance only if the user is pedaling. With the current battery packs, the mileage in standard conditions is about 50 km.

This paper presents a study of feasibility of a bike-sharing system composed by electric bicycles. Particularly, it proposes a way to integrate commercial EPAC coming from different producers without uncover the own industrial know-how but just through the sharing of a protocol and a physical bus. This paper is organized as follow: Section 2 describes the architecture of the system and the electric bike chosen for the implementation; Section 3 presents in detail the AddOn – the hardware and protocol

interface between the vehicle and the sharing system infrastructure –; Section 4 concludes outlining the possible extensions to the model.

## ARCHITECTURE OF THE SHARING SYSTEM

Accordingly to the traditional bike-sharing architecture, the proposed system architecture is composed by three main components: bicycles, docking stations and a support infrastructure. The support infrastructure, managed by a central control information system, is connected to the docking stations via Internet through a wireless connection. Each docking station is connected to the electric pedal assisted bikes through a power cable and a short range wireless data connection. In Figure 2 the system architecture is shown.



**Figure 2 System architecture of the proposed electric bike-sharing.**

In the following sections, a description of each component of the architecture will be given. The presentation will be provided in a top-down fashion.

### Remote control information system

The central control information system has mainly three functions.

1. Collect all the information coming from the docking stations.
2. Offer an interface for the management and the maintenance.
3. Offer visual information to the consumer of the service about the displacement of the docking stations, the availability of bikes in every docking station and the charge condition (see Figure 3 for an example).



**Figure 3 Prototype of the control panel.**

A bike-sharing system composed by electric vehicles needs a richer support infrastructure than the traditional one, mainly due the necessity to provide the charge to the batteries. Furthermore, an electric bike is composed by components subject more often to failures and ageing. For these reasons the infrastructure has to be able to detect faults and report them to the central system.

### Docking station

The infrastructure of the system is composed by a network of docking stations, which allow a centralized and integrated management of the system. Each docking station aims to host the electric bikes, to recharge them and to monitoring their working status. This last functionality is very important since it allows designing strategies to balance the ageing of the fleet or to cope expected peaks of requests. Each docking station is composed by:

- A set of places where a vehicle can safely reside, thanks to an automatic antitheft mechanism;
- A short range wireless data link (docking station to bike), based on the standard ZigBee;
- A *smart* battery charger – connected to a power line
- –, able to charge batteries built with different technologies (e.g. the traditional lead-acid or the modern Li-ion) and requiring different charge curves;
- A PC-based system to coordinate the entire docking station, connected via Internet through a wireless modem (GPRS, UMTS or WiMax according to the coverage) to the central management node;
- A surveillance camera.

A pictorial representation of a typical docking station can be seen in Figure 4.



Figure 4 Pictorial representation of a docking station.

### Electric Pedal Assisted Bike

The electric pedal assisted bike used to develop the prototype is a commercial vehicle produced by the Italian company Tecnicarbur s.r.l. with the

brand Frisbee. It has a brushless electric engine mounted on the posterior wheel and a battery pack managed by a BMS (*Battery Management System*).

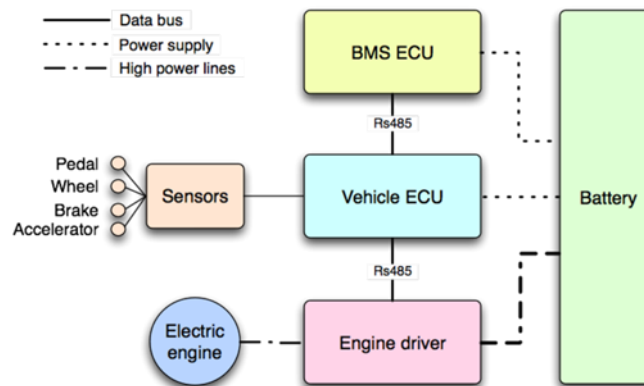


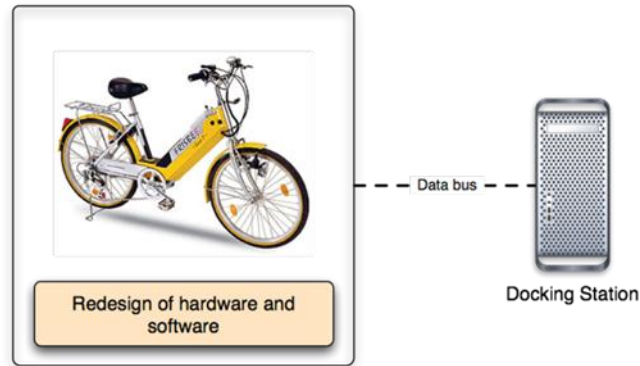
Figure 5 Bike's components and their connection.

Figure 5 shows the components and the connection among them: the engine is driven by a driver which, according to the European Community regulation, provides power only if the pedals are rotating. The vehicle is provided with two ECU (*Electronic Control Unit*): one is devoted to the control of the BMS and another one is devoted to the control of the engine. The two ECUs and the engine driver are connected all together by a serial bus: the multipoint, half-duplex EIA RS-485 bus.

The pedal-assisted bike described is just one of the bikes which are sold in the market. If the system shall be able to host vehicles coming from different manufacturers, the problem of compatibility shall be taken into account. The

nature of the differences among vehicles can be mechanical (e.g. the hook for the antitheft lock), electric (e.g. the power connector) or electronic (e.g. the communication bus or protocol, the authentication mechanism, the human-machine interface). In order to integrate a vehicle in the sharing system here described there are two solutions:

1. Redesign the vehicle accordingly to the guidelines of the sharing system owner (see Figure 6).
2. Design an adapter, called *AddOn*, which hides the differences among the vehicles, providing unified connectors with the docking station and grouping all of the high level functionalities (see Figure 7).



**Figure 6 First option: no interface and redesign of the hardware and the software.**



**Figure 7 Second option: design of an interface between the vehicle and the docking station.**

The first solution is not suitable for vehicles already on the market, which have to be redesigned, and it is feasible only if the number of producers is very small. Moreover, it requires a deep sharing of the industrial knowledge between the partners or at least with the owner of the bike-sharing system. From the other hand, the second solution – which often requires just a very small set of modifications – is adequate for every producer and it does not require sharing other information than the communication protocol and the specification of the physical connectors. Obviously, since the last is more interesting and challenging, we focused our attention on the second integration solution. In the following section, a presentation of the AddOn and its components will be given.

### The AddOn

The aim of the AddOn is twofold: first it is the link between the bike and the sharing system, second it is the borderline between the expertise of the electric bike manufacturer and the sharing system. The AddOn shall allow to provide:

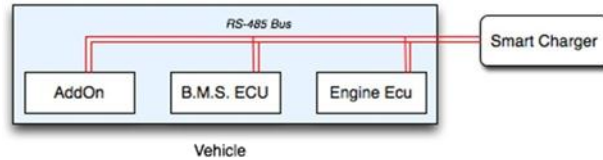
- A physical interface with the vehicle bus.

- A human machine interface, simply usable by the user to interact with the bike.
- An authentication method, usable by the user to authenticate himself to the system.
- A communication channel between the bike and the docking station.
- A computational unit which controls all the peripherals devoted to implement the functionality described in the previous points.

In the following sections, the functionalities and the technological solutions which have been adopted will be presented in detail.

### Interface with the vehicle bus

The physical interface with the bike is the only hardware characteristic which binds the AddOn with a specific vehicle. It is necessary to collect data from the vehicle bus for logging and for control purposes. In the case discussed in the paper, the bus installed on the bicycle we used is a RS-485 serial bus. Figure 8 presents how the AddOn is connected with the other devices (already described) which compose the vehicle.



**Figure 8 Architecture of the devices connected with the RS- 485 bus.**

In order to be flexible for the other well diffused bus in automotive field – the CAN bus – a microcontroller with both of them has been chosen (for further details, see the section 3.6). The signals carried by the bus follow a semantic agreed with the vehicle manufacturer and they represent the sole information that it has to share with the vehicle sharing system. In the case discussed, vehicle speed and battery state of charge are collected, while the electro-actuated catch is controlled by messages read and written on a RS-485 bus.

### Human Vehicle Interface

The usability of the vehicle human interface is very important, because it is the way the user of the bike-sharing system interacts with. It shall be able to provide the information to the user and to acquire the commands from the user. The research field of the vehicle human interaction is well studied and smart proposals for interfaces devoted to the management of shared vehicles has been done (see Lee, Lee & Xie 1999). For the purpose of the project described, the interface is made up by an LCD display with 2 rows and 16 characters and three buttons.

### Vehicle to docking station communication

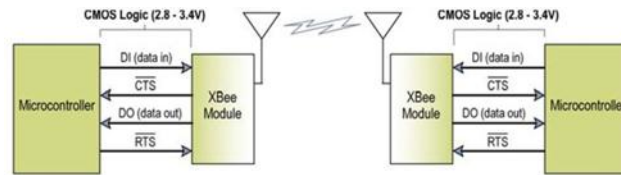
The communication channel between the AddOn and the docking station links the electric bike to the sharing system. It can be implemented in wired way or in wireless one. The security (in term of confidentiality of the information that *flow* on the communication channel) is a feature required by the project and the first solution is more robust against attacks like channel sniffing. The drawback of the wired approach is that another link is necessary – besides the power one – between the vehicle and the docking station. The second solution is more flexible because it does

not require a physical connection, but can be battery expensive and, since the communication is broadcast, potentially less secure. The networks able to established a connection between devices in a short range (few meters) are the so-called WPAN (*Wireless Personal Area Network*). Belong to the WPAN technologies like WiFi, Bluetooth, Wibree (recently renamed as Bluetooth low energy technology) and ZigBee.

ZigBee is a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for WPAN. ZigBee is targeted at radio-frequency applications which require a low data rate, long battery life and secure networking. For the application presented in this paper, WiFi and Wibree have not been taken into account; the first is oversized in term of communication range, electronic complexity and power consumption and the latter is too premature. In the end ZigBee has been chosen because:

- It is the simplest (from the point of view of the electronic and the program effort);
- It is the less expensive in term of power consumption;
  - It guarantees a higher security in term of confidentiality of information then the Bluetooth (Baker 2005).

ZigBee modules from MaxStream have been chosen. These modules, named XBee, are radio modems which operate with a frequency of 2.4 GHz with a serial interface. The communication range outdoor is 100 m with a power of 1 mW. The security is ensured by the algorithm AES. The device is controlled by AT commands and, after the configuration phase, it is managed by the microcontroller like a traditional serial interface (see Figure 9).



**Figure 9 Serial connection emulated by XBee modules.**

## Authentication

In the field of information security, the authentication is the process which has the aim to verify that someone is who is claiming to be. The AddOn shall contain a module that, starting from an unique identifier coming from the user and communicating with the docking station, is able to determine if the user is either allowed to take a bike or not – for example due to termination of the credit.

There exist different methods to implement the authorization, starting from the simplest based on a couple of username and password to the most complex based on biometrics information (fingerprints, hand geometry, iris and retina). The experience obtained in the design of automatic systems accessible also by *dummies* – for example, ATM – demonstrates that the most suitable methods in these situations are those based on tokens plus a PIN code (O’Gorman 2003) [7]. There are different technologies which can be used as tokens, for instance barcode, magnetic card, smart card, RFID. For the application here presented, the last one has been chosen.

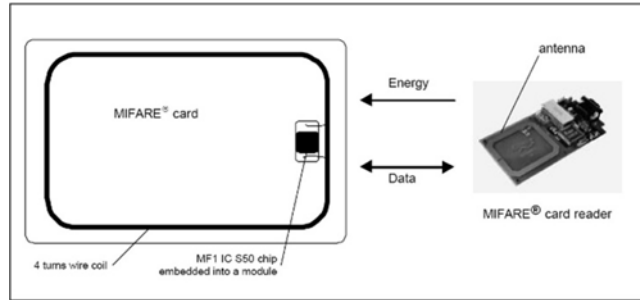
RFID (*Radio Frequency IDentification*) is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags (or transponders). Most RFID tags contain at least two parts. One is an integrated circuit for storing and processing information, modulating and demodulating a radio-frequency signal, and other specialized functions. The second is an antenna for receiving and transmitting the signal. There are generally two types of RFID tags: active RFID tags, which contain a battery, and

passive RFID tags, which have no battery. There is even another difference, based on the operating frequency (125/134 kHz, 13, 56 MHz, 868/915 MHz and above 2,4 GHz). The advantages of this technology are that tokens:

- Are contactless: it is enough to put the token near the antenna to read its content;
- Even the passive ones are able to store, other than an identification number, information of the user;
- Nevertheless Bruce Schneir (2005) has revealed flaws in some implementation, they implement encryption method to protect the communication.

The module integrated in the AddOn is a SonMicro SM130, an integrated circuit which includes all the features necessary to read and to write tags Mifare<sup>®</sup> at 13.56 MHz. Attached to it there is an external antenna; its aim is to provide the energy to the tag through the principle of induction and to receive the data transmitted by it. Smart cards Mifare Classic with 1 kB of memory have been chosen as tag because they are the most diffused among the contactless, passive ones; moreover they guarantee a high level of security due to the encryption system (certificated by VISA and TNO) and an high communication speed (106 kbit/s). They are quite diffused in applications like e-money, public transportation, access control, phone and credit cards. 1 kB of memory is not a limitation for our purposes because the sole information needed is a unique identification number. The integrated circuit is controlled by the microcontroller through the bus I2C. In Figure 10 the layout of the RFID chain is represented.





**Figure 10 The layout of the RFID-based authentication chain.**

The authentication process is composed by three phases.

1. The RFID reader waits until there is an RFID tag inside its operative range.
2. When a tag is close enough to the antenna, the reader reads the unique id and send it to the docking station.
3. The docking station is the actor in charge to verify, through a query to the local and up-to-date database, that the user has the right to take the bike.
4. If the user
  - a. Is authorized, the docking station releases the lock and the user can take the bike;
  - b. Otherwise the HMI of the AddOn shows a message to inform the user that he/she has not the right to take the bike.

The authentication process is represented using flow diagram in Figure 11.

### Data Persistence

The information permanently stored on the AddOn can be classified along two dimensions: the

duration in term of time and the size in term of memory. Data like the information of the authentication are very small in term of size (e.g. unique identification of the user, time of the withdraw) and they should persist just for the duration of the rent; telemetry and logging of the functioning are bigger in term of size and they should last more. The classification is summarized in Figure 12. For the first type of data, the most suitable data storage device is an EEPROM; it is fast and very cheap. Most of the microcontrollers has a certain amount of EEPROM inside them; if not, an external integrated circuit is needed. For the second one, the solution found was an SD card; cheap readers are not robust against vibrations, but on electric bicycle the vibrations are very low and do not affect the card reader behaviour. The capability to manage this two memory devices has been taken into account during the choose of the computational unit.

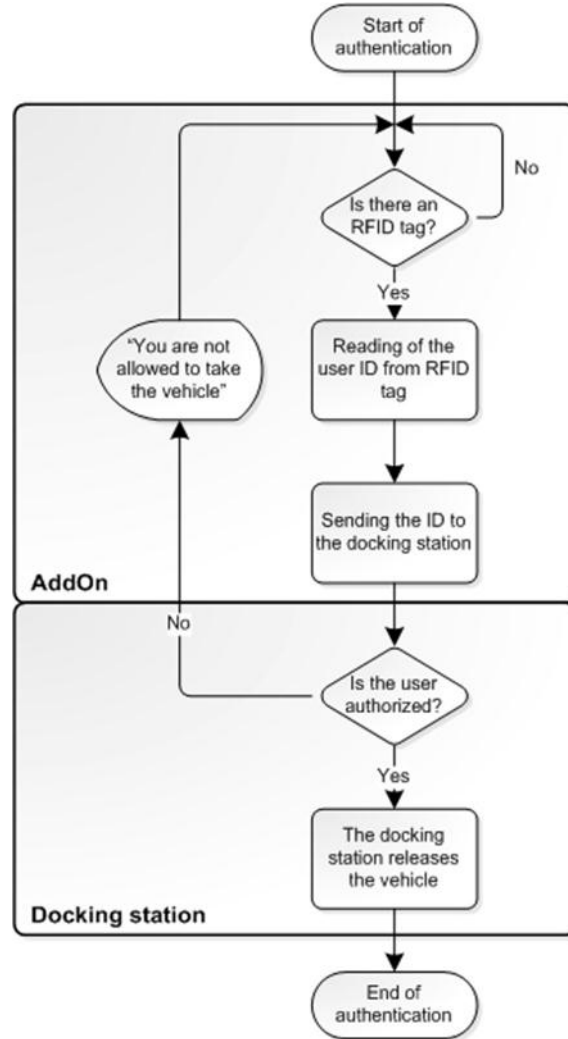


Figure 11 Flow diagram of the authentication process.

		Duration	
		Short-term	Long-term
Size	Small	Authentication information	
	Big		Telemetry

Figure 12 Classification of the data persistently stored.

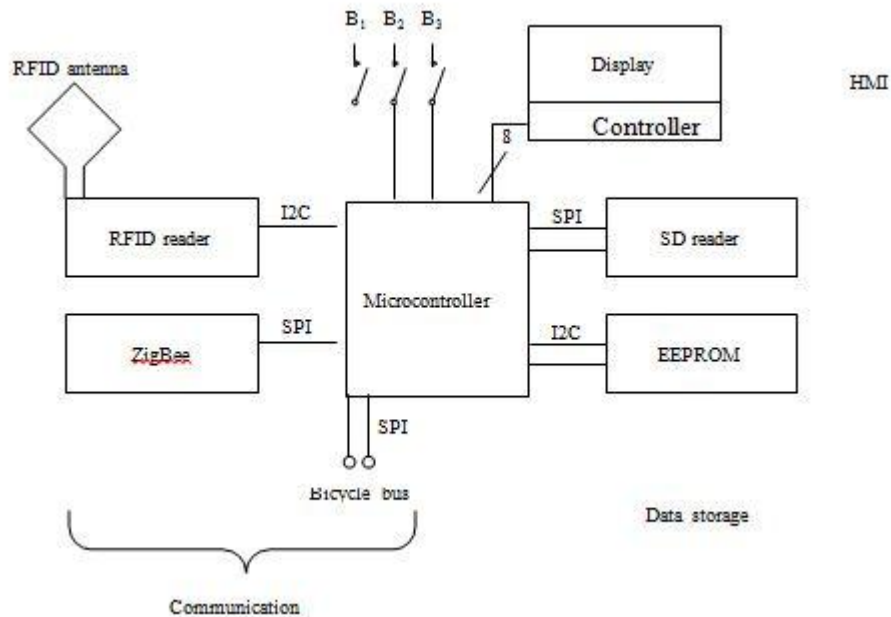
**Computational unit**

The choices of the high level functionalities and of the technologies that implement them affect

the choice of the computational unit which manage the entire AddOn. It has been chosen a 8-bit Freescale microcontroller with a flash memory of

32 kB, a RAM memory of 2 kB, a 10-bit ADC multiplexable on 16 channels, two serial communication interfaces, an interface for I2C communication and some input/output pins. It has been chosen because the SMT version (*Surface*

*Mounting Technology*) is very small, cheap and it allows to reuse the expertise of the designer. The connections among it and the peripherals are shown in the Figure 13. In the figure, the enabling signals of the components are not represented for clarity reason.



**Figure 13** Layout of the components and their connections on the AddOn.

## CONCLUSIONS

In this paper an innovative approach to integrate, in a vehicle sharing system, commercial electric pedal assisted bikes produced by different manufactures, without the redesign of the vehicle and avoiding the share of industrial know-how has been proposed. Following the principles proposed, demonstrate building a prototype, a manufactures which would produce a vehicle compliant with the system shall just to program the ECU to talk the same protocol of the AddOn.

The strength of this approach is that it is straightforwardly extensible to different electric vehicles, like electric scooters or electric microcars. In this way, it is possible to offer to the

clients of the system different vehicles according to their needs: bicycles for short movements in case of good weather, scooters for medium range distances or microcar for *long* journey or in case of bad weather.

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