U-Park : Parking Management System Based on Wireless Sensor Network Technology

Nikos Larisis[1], Leonidas Perlepes[1], Panayiotis Kikiras[2], George Stamoulis[1]
[1]Department of Computer and Communications
University of Thessaly, Volos, Greece
[2]AGT Germany, Darmstadt, Germany
nilarisi, leperlep, georges@inf.uth.gr, pkikiras@agtgermany.com

***Abstract*—Wireless Sensor Networks can be entitled as one of the most challenging and emerging technologies empowering the provision of enhanced services to miscellaneous application domains. The objective of this paper is to examine and present an implementation of a real-time parking management system. This system adapts efficiently into a contemporary urban environment, and eventually provides to users the ability to find and navigate easily to a free curb space. The system is comprised of a deployed sensor network based on two collaborative vehicle detection schemes supported by an event-driven processing algorithm and a web based application. The evaluation of the system is performed by conducting a number of experiments in order to select the optimal sensing modality and confirm the feasibility of the proposed application system in actual running conditions. Results demonstrate that the proposed system is capable of effectively detecting overlying automobiles and robustly distinguishing false positive indications.**

Keywords-wireless sensor network; vehicle detection; magnetic sensor; passive infrared sensor; web based interface

I. INTRODUCTION

The very viable and sustainable development of urban environment is inextricably connected with contemporary approaches concerning traffic congestion issues. A basic aspect of this problem is undeniably the parking procedure, a costly and time-consuming stage within urban transports and an everyday headache for millions of drivers and urban planning departments. Modeling this procedure is not an easy task due to problems in measuring the overall time since it being dependent upon inherently random factors. Looking for parking duration it has been proven that is not negligible and indeed according to [1], "cruising in congested downtowns takes between 3.5 and 14 minutes to find a curb space, and between 8% and 74% of the traffic can be appointed to cruising for parking". In addition to that, a variety of studies, as [2] states, infer that automobiles spend approximately over 95% of their time parked and for trucks this percentage is over 85%.

In this paper, an innovative approach in solving the aforementioned problem is proposed utilizing WSNs (Wireless Sensor Networks). WSN technology has a wide spectrum of applications which are deeply embedded into the everyday world ranging from health monitoring and disaster early-warning systems up to vehicle detection and military purpose application scenarios. Such a sensor network is comprised of a large number of microelectronic devices capable of monitoring and collecting raw data in different environments and conditions. Typically, each device –often characterized as a node– is consisted of a microcontroller, a power source, a radio frequency transceiver, an external memory, and various sensors. These resource constrained sensor devices communicate wirelessly and untethered, forming complex mesh networks through which data is being disseminated.

Our objective is to investigate, simulate and experimentally verify the prospect of implementing an intelligent parking management system that provides to drivers the possibility to conveniently locate and be guided towards a free parking lot near their destination. From a system design perspective, WSN solution offers a number of unrivaled advantages. Firstly, we can hugely benefit from its low-cost deployment. Secondly, there is flexibility with regards to vehicle detection approaches since a wide spectrum of applicable sensing techniques is being offered. Finally, autonomous and long-term operation of the system compounds is another important feature. The latter can be achieved thanks to the enhanced administrative capability since extra information can be retrieved in real-time concerning features like illegal parking activity, time duration of each occupied lot, and other metrics that are indicative of a robust system operability.

Although there is an abundance of existing solutions focusing on parking assistance applications that are employing WSN techniques, our approach differentiates in many aspects. We propose a hybrid detection scheme utilizing magnetic and passive infrared sensors. A pair of sensors, located at a distinct parking spot within the urban fabric, collects the raw data. Then this information is received and processed at the sinks, and ultimately evaluated whether if the correspondent spot is occupied or not. The result is appropriately stored in databases in the base station and then it is uploaded to a web interface and finally, depicted onto a user friendly map.

The ensuing content of this paper is organized as follows. Section 2 briefly describes the related work and

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how it is correlated with our approach. Section 3 overviews the design stages of our system, the operating principle of the utilized devices and the system architecture. Section 4 describes system's implementation. Section 5 reports the system's testing results with respect to the various simulation scenarios and requirements. Finally, Section 6 concludes with general remarks and discussion about the potential for future expansion.

II. RELATED WORK

Confronting the problem of park cruising within the context of urban transportation planning is not something new to this research field. Besides theoretical approaches in analyzing the problem [1][2][3], there are numerous research projects [4] utilizing intelligent transportation systems (ITS) techniques outside the WSN research area. Indicatively, we can mention mobiPARK [5], a free parking lot indicating system based on a text messaging service platform for a driver that departs from a previously occupied lot. NYU-Poly and Rutgers University [6] collaborating research teams attempt to provide a multimedia stream application that could display free parking spots within the congested Brooklyn. As drivers cruise streets, sensors feed real-time visual information regarding parking availability uploaded via a 4G network and depicted onto special graphic user interface (GUI) platforms.

From another perspective that focuses mainly on WSN technologies there can be found a number of similar approaches. Parking Finder [7] is a Mica2Dot/MIB510-based WSN platform implemented for detecting the presence of a car over a designated parking lot within a metropolitan city infrastructure. It employs magnetic sensors (HMC1001) for vehicle detection with each mote running on a TinyOS [8] environment. After data aggregation and storage in the basestation the processed data can be accessed via a Java-based GUI. Although there are many commonalities with our presented approach, it lacks specific characteristics that pose serious threats to its overall credibility. The absence of experimental verification is more than evident. The GUI does not fully utilize the advantages of a web-based implementation that our version benefits from and does not offer enough interoperability. Above all, the unilateral usage of magnetic sensors does not take into consideration the inherent abnormalities of the application environment. Thorough experimentation within our research proved as necessary the complementary usage of infrared sensors which Parking Finder excluded as inappropriate at the initial stages of its implementation.

In Intelligent parking lot application using WSN [9], it was proposed and proven as optimal the combinatory usage of magnetic and ultrasonic sensors for an accurate and reliable detection of vehicles within a multi-storied parking space. Although there are similarities in the deployment scenery since Tmote Sky sensors are also utilized, their proposal undeniably cannot withstand a boisterous and hectic city center environment. Moreover, their data processing and detection algorithm followed a different approach employing a modified version of the min-max algorithm suitable for analyzing the waveformed raw magnetic and acoustic data. Their extensive experimental results imply and strengthen the necessity for assiduous system verification, an important attribute for every kind of such an application area systems.

Design considerations for a WSN for locating parking spaces [10] presents a scheme for reliable detection of automobiles employing the same type of sensor nodes, Mica2/MTS310/MIB510 equipped with the same 2-axis magnetometer HMC1002. Their proposed platform refers to public parking garages and is consisted of a network of nodes that are distributed in strategic locations throughout the targeted public parking area instead of at every parking spot. Although the prominent differences in the objective, the deployment environment and the algorithmic notion of the detection process, the important commonality lies in the crucial analysis of the peculiarity in the operating nature of the magnetic sensor. The obtained through trial and error accurate positioning and orientation of the node was also observed in this paper. Despite that, their proposed algorithmic approach in order to surpass this obstacle differentiates from our more practically orientated perspective.

III. DESIGN CONSIDERATIONS

In this section, the design process is presented detailing the procedure under which the specific combination of magnetic and passive infrared sensors was promoted as the optimal choice. Moreover, the operating principle of these sensing devices is briefly discussed and finally, the system architecture is unfolded.

A. Design Process

Solving a complicated issue such as cruising for curb-space parking, it is relevant upon multilateral research derived from distinct launching perspectives. Figure 1 indicates the initial attempt to address a solution via the usage of a mechanical arm with a sensor node attached at its base, placed under the road surface or enclosed in a protective sealing. A vehicle while in parking process would drag down the joint and an actuator would recognize the corresponding slope if a predefined critical angle ($\Phi critical$) was breached. This in turn would enable the record of a vehicle's presence for the designated spot and this information would be propagated throughout the network for further processing. After consideration, this scheme was aborted from being a plausible implementation due to the inappropriateness of joint's material while colliding with vehicle parts and the inherent difficulties in implementing such a mechanical arm based on the laboratory's available apparatus.

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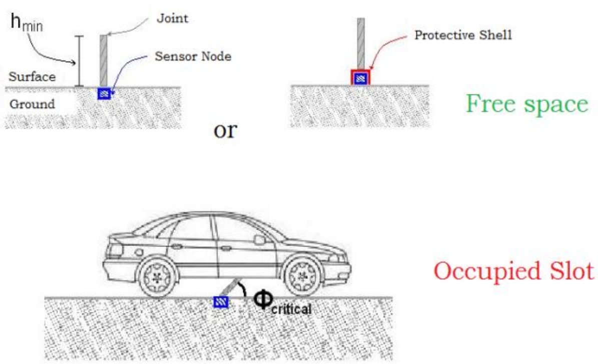

Figure 1. Initial system implementation.

As a next step passive infrared sensors (PIR) were selected as a plausible detection scheme within a deployed sensor network. Their advantage lies within their passive nature, that is, independence from external conditions since receiving and not emitting signal. Experimental verification proved that the PIR sensors were extremely sensitive in response to environment stimuli and their detection range was exceedingly wide. This results to the sensor being constantly triggered after the initial successful detection of the vehicle, in case later on another car or pedestrian was mobile within the detection zone. The unilateral usage of PIR was thus rejected since neither the detection zone nor the detection sensitivity can be recalibrated to custom needs according to its manual [11].

As a next designing stage, the viability of acoustic sensors' usage was investigated. Various experiments were conducted but without deducing sufficient and credible conclusions regarding neither a unilateral nor a collaborative usage of acoustic sensors. A detection pattern for overlying and passing vehicles could not be concluded and thus uniformly applied since noise in an urban fabric, and especially near road surface, is an unpredicted factor.

In order to select the optimal sensing device, and consequently scheme, we ought to consider the very nature of the object to be detected. Since a vehicle is in fact a sizable metal mass, the subsequent distortion it enforces in the earth's magnetic field is easily tractable by a magnetic sensor, thus resulting to its imperative usage. This distortion is unique for every ferromagnetic object and under ideal conditions can be perceived as its magnetic footprint, a useful characteristic for a wide spectrum of ITS applications relevant to tracking and detecting automobiles [12].

In addition to that, an auxiliary operation of passive infrared sensors would benefit the most to the system. In order to narrow their detection area it is obligatory to place them under road surface and inside a protective enclosure. The road penetrating costs can be compensated if considering the advantages that can be obtained through this enclosure approach such as, extra protection from theft and harsh weather conditions [13].

At the initial experiments, there were observed minor discrepancies in the magnetic sensor's output waveform. Strangely enough, it remained idle at a maximum value of approximately 780 (based on the range the utilized Oscilloscope/TinyOS application produces as an output, see Figure 2). Moreover, it did not respond to the presence of any ferrous objects unless a material with high magnetic permeability was presented in a distance less than 2cm. According to [14], "the NiFe core of the magnetic sensor is extremely sensitive. However, it is also subject to saturation. Saturation occurs when the sensor is exposed to a large magnetic field. Unfortunately the MTS310 circuit does not have an automatic saturation recovery circuit". After experimentation, and having excluded the prospect of implementing such a recovery circuit, it was elicited that the sensor can be calibrated via appropriate nesC [15] coding of the relevant interfaces and components. Its sensitivity level can be set manually within a range between 0 and 255, and accordingly to the ambient earth's magnetic field. Thus, as the sensor is moved around in the field its output waveform will ultimately exhibit transitions. It was experimentally proven that the exact sensitivity level for each deployment site can be calculated and eventually a waveform in between the desired range can be received. The sensor is thus ready for use.

B. Device Specification

The magnetic sensor module is based on Crossbow's Mica2 [16] motes equipped with the Atmega128L MCU (128KB flash, 521KB storage, 4KB RAM) that are attended with the MIB510CA programming board [17] both depicted in Figure 3. Sensing operation is performed via the MTS310 sensor board [18] equipped with the HMC1002 2-axis anisotropic magneto-resistive (AMR) sensor that functions under the following principle. Since the earth's magnetic field is uniformly distributed along an area of several kilometers a ferrous object (e.g., automobile) causes local disturbances in this field while idle and/or moving [19][20]. The AMR sensor, implemented as Wheatstone bridge, detects such disturbances in the X or Y axis and interprets them as a differential input voltage that can be transformed into exploitable information regarding the presence or not of an overlying ferrous object.

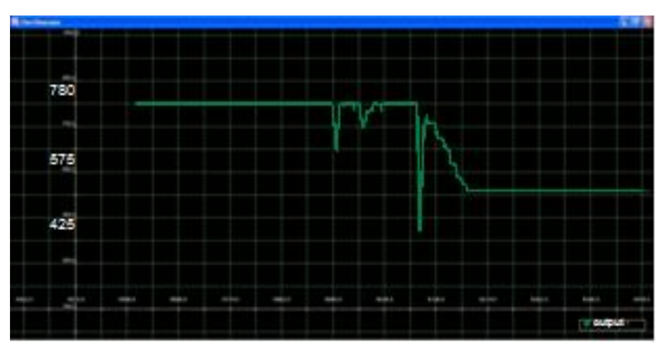

Figure 2. Transitions of the magnetic sensor's output while being moved.

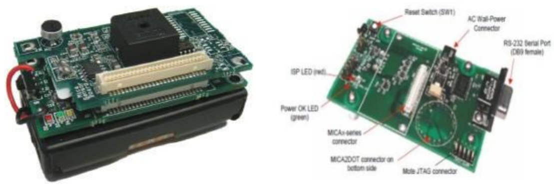

Figure 3. Mica2 mote equipped with the MTS310 sensing board and the MIB510 programming board, [16][17].

Figure 4. Tmote Sky equipped with WiEye sensor board, [22].

The other subsystem is constituted of a number of deployed Sentilla's Tmote Sky [21] nodes based on TI-MSP430F1611 MCU (48KB flash, 1MB storage, 10KBRAM). Sensing operation is performed via the WiEye sensor board [22] equipped with the AMN44121 PIR motion sensor, NaPiOn [23], all shown in Figure 4. According to the pyroelecrtic phenomenon [24], crystalline compounds can produce electric charge while being exposed to thermal energy. A variable thermal flux within the infrared spectrum will deduct a variable load onto the quad-type pyroelectric element of the Napion which's output amplitude into the measuring circuitry will be analogous to the amplitude of the changing flux. Thus, when an object enters the detection zone, NaPiOn identifies the temperature difference between the target and its surroundings and transforms this difference into a processable value-signal.

C. System Architecture

The proposed real-time parking management system is a hierarchical module comprised of collaborating subsystems and based on a three tier architectural design (see Figure 5).

At the lowest level the data collection subsystem developed in TinyOS-2.x samples the environmental stimuli which are then aggregated to the appropriate sinks. Current system implementation directs a one hop routing scheme containing four motes, two sensor motes (one magnetic and one PIR) that comprise a deployed system node, and the two correspondent base stations. Scalability though can be easily achieved via the usage of proper disseminating nesC interfaces, since the other hierarchical levels are already set for a larger number of deployed nodes.

The second level is comprised of the data processing applications residing in the two base stations. Specially implemented detection algorithms indicate the occurrence of a magnetic or a PIR triggering event. This information is then stored with a timestamp at a database named sensor_state. Each record refers to the status of the pair of magnetic and PIR sensors that are located at each parking lot. A second database named nodes is used for correlating these data with the third level. Analogously, each record corresponds to a deployed node and contains information regarding the status of the node and thus the availability of the parking lot, as well as timestamps and various spatial information. Moreover, there are Java-based algorithms responsible for the initialization of the system, the execution of the surveying algorithm and the update of all the databases' records correspondent to each node deployed.

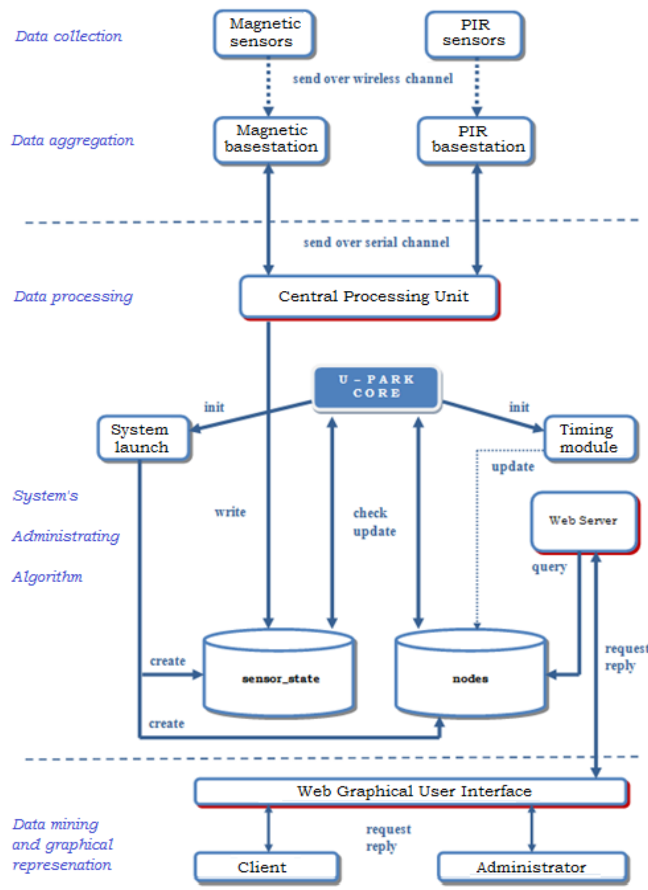

Figure 5. System's information flow chart.

Finally, a web server program is implemented with the task of uploading the information of the nodes database to a web GUI. There are two interfaces implemented with distinct layout, one for the administrator (providing extra functionality) and one for the potential clients that both offer a customized query processing operability. The end user can select an area of interest within the urban fabric and he is given a real-time graphical representation of the available parking lots with green dots appearing on a google map. The user is also provided if requested with routing directions. The administrator on the contrary has access to extra information such as lot's duration of occupation, overall system view, or error node's indication. An overall illustration of the system's information flow is presented in Figure 5.

IV. SYSTEM IMPLEMENTATION

In the current section, the algorithmic perspectives of raw data processing as well as the administrative principles of our system are explained.

A. *Raw Data Analysis*

The designing process for an algorithm appointed with the magnetic raw data analysis is crucial for the overall credibility of the system. The initial experiments regarding HMC1002's response to ferromagnetic stimuli proved that a rather simple detection algorithm can be utilized based on two fundamental notions deriving from the Statistics field, the arithmetic mean and the population variance. It was observed and verified that in idling state the collected data is characterized by a mean value within a predefined equilibrium level and by a variance tending to zero. Upon the approximation of a ferrous object the output waveform would effect a drastic transition also indicative via an increase in the variance of the samples. Moreover, a constant presence of the object would be accompanied with a progressive stabilization of the samples' mean and with a variance again tending to zero. To this extend, the subsystem's states can be concluded (Table I), provided that appropriate operating levels are predefined with regards to the output waveform (see Figure 6).

As mentioned before, the processing algorithm of the infrared data has an auxiliary role due to the fact that after experimentation it was proven that PIR sensor was constantly triggered and thus, implementing an accurate pattern detection scheme was unfeasible. Its final contribution was confined in confirming an overlying ferrous object after consulting for a potential magnetic triggering recorded event. Nevertheless, its usage cannot be excluded otherwise the overall system's credibility can be dramatically hindered. Through its utilization all false positive magnetic triggering events can be neglected. On a similar basis we can define the correspondent operating states, as well as a state diagram (see Figure 7).

B. *Core Algorithm*

The core of the administrative algorithm consists of a infinite loop in which the node statuses are retrieved from the databases and according to various combinations we can define updating functions calculating the next system state.

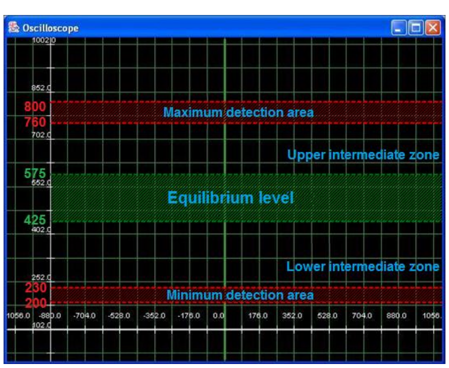

Figure 6. Magnetic sensing subsystem's operational levels.

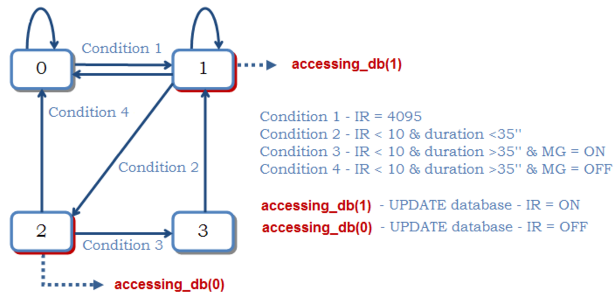

Figure 7. Infrared sensing subsystem's finite state machine.

These combinations are explained in Table II (OFF stands for a sensor not detecting any stimuli, and ON otherwise). In case A, both sensors are activated and thus we deduce that the corresponding parking lot is occupied. Cases B and C are referring to undesirable circumstances whenever either an object with low magnetic permeability (animal, pedestrian, other) is revolving near and/or above the protective enclosure or an automobile has not parked within the designated lines of the parking slot. In both cases the specific parking slot is consider to be in error state**.** After experimentation it was derived that the PIR sensor detection range (placed within the enclosure) is under 20cm, and the magnetic sensor less than 2m. The last combination (case D,E) corresponds to both sensors being deactivated. That is either when the system has recuperated from an error state (due to hardware failure, false positive magnetic triggering or cease of constant PIR triggering) or the parking lot is free after a vehicle completed its withdrawal. In both cases, the space is free and the nodes are reinstantiated.

TABLE I. MAGNETIC SENSING SUBSYSTEM STATES

STATE	System State	Interpretation
0	System Idle	Absence of ambient magnetic stimuli
1	Detecting	Variation detected
2	Parking slot - Busy	Overlying ferromagnetic object
3	Car unparking	Withdrawal initialization
4	Car withdrawing	Disengage. Final stage of withdrawal
5	Parking slot - Clear	Initial idling stage
6	B U S Y@MID - checking	Check for potential malicious parking behavior
7	B U S Y@MID - PICKED	Potential malicious parking behavior confirmed

TABLE II. SYSTEM STATUS

Magnetic (MG)	Passive Infrared (PIR)	Interpretation
ON	ON	Case A - Car detected
OFF	ON	Case B - Error : MG = OFF ^PIR = ON
ON	OFF	Case C - Error : MG = ON ^PIR = Off
OFF	OFF	Case D - Node reinstated
		Case E - Car withdrawing

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V. System Evaluation

In this section, the experimental setup is presented including a detailed description of the experiments that were conducted and the evaluation results that reinforce the system's credibility.

A. Simulation Scenarios

System verification and evaluation process included different simulation scenarios that reassured the correctness and the preciseness of the detection procedure. These scenarios involved among others,

- detecting an overlying and/or passing bicycle, motorbike, and distinct manufacturer car models (and thus distinct ferromagnetic footprints),
- conducting measurements for sensor's response while a vehicle could be approaching from different directions and approximating distances,
- simulating a parking procedure with different kinds of maneuvers and total moves,
- executing an experiment emulating actual parking conditions in a free spot between two parked cars,
- verifying system's response while using two magnetic sensors in order to simulate a malicious driver behavior,
- evaluating system's response in full-scale and real-time operating conditions.

Especially for the latter two scenarios, they were crucial in verifying the system's credibility. As previously stated, NaPiOn can benefit the most for the system. Its usage is essential in detecting a malicious driver parking between two nodes. As depicted in Figure 8, although magnetic sensors are initially triggered (t1 and t2 timestamps) the car stops in between them and outside their detection area. If NaPiOn sensor is used then the magnetic initial triggering event could be verified and act accordingly, resulting in successful vehicle error detection (Case B in Table II). The final scenarios included experiments being conducted in actual urban conditions. A picture of the developed WSN within a real parking area is given in Figure 9 with green arrow indicating the deployed pair of sensor nodes.

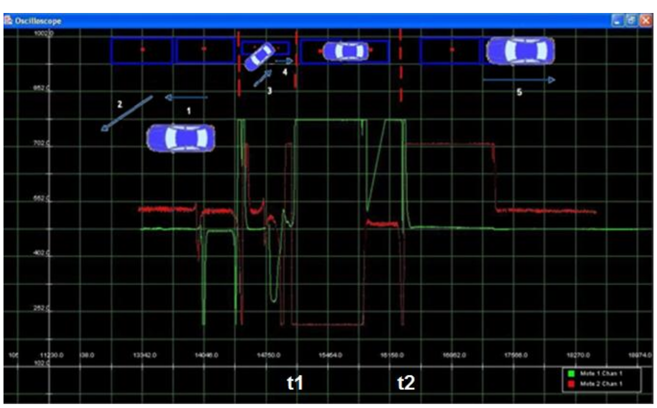

Figure 8. Setup justifing the necessity of NaPiOn's usage.

Figure 9. Deployed WSN in actual parking conditions.

B. Experimental Results

The experimental procedure evolved according to the following stages. Initially, the response of each sensor was measured individually and in laboratory environment. This was a compulsory step in order to become familiarized with the sensors' operating principle and in order to assure that the design of the detection algorithm would follow the correct path. As a next stage, experiments involving sensors' response within outdoor conditions were conducted.

The NaPiOn's outdoor experiments verified the initial studies and assumptions regarding its response to ambient stimuli. NaPiOn reacts independently from the object's nature to be detected and the weather conditions. On the contrary, magnetic sensor's experiments demanded a much more strenuous treatment since an assiduous comprehension of HMC1002's sensing philosophy was imperative before embarking on fully designing its detection algorithm.

In order to conclude to as safe experimental results as possible, it was necessary that the experiments were to be repeated under different environmental conditions and simulating scenarios. In Table III the characteristic environmental conditions of such distinct experiment are presented. As implied from the data, experiments on different dates and times of day were conducted in order to benefit from variable weather conditions. Regarding the magnetic sensor, its sensitivity function was invoked with different parameters for the scenarios were one and two Mica2 motes (n1, n2 in table) were deployed respectively.

TABLE III. Experiments Environmental Conditions

Date	09/04	13/04	16/04	17/04	18/04
Sensitivity	50,100 for n1	50 for n1	50 for n1 - 45 for n2	50 for n1 - 45 for n2	50 for n1
Time	17:00 – 19:00	18:23 – 20:10	17:30 – 21:00	20:30 – 21:30	17:30 – 19:30
Temperature	17ºC	23 ºC	16 ºC - 13 ºC	9 ºC - 8 ºC	10 ºC
Humidity	~60%	~50%	~55%	~92%	~77%

An important characteristic is the fact that night and rain conditions were present on 17.04.2011 day adding therefore more credibility to our experimental set. Apart from the above, more experiments were conducted on laboratory conditions regarding the evaluation and the correctness of the detection algorithm while it was being implemented throughout its various design stages.

Moreover, real-time system verification was performed including a final full-scale emulation of an actual parking procedure. The conducted experiments included active participation of all the operational components of the system that ranged from the initialization of the sensor nodes, verifying the response of the administrative algorithm and until projecting the information of the system onto the map of our web GUI. These experiments were performed both in safe and hostile environments. The former was performed in the scenery depicted in Figure 9 and the latter in front of the University building in one of the most traffic congested avenues and during evening rush hour. Truly, in both cases the response of the system was exceptional after carefully selecting such a sensitivity level that would avoid passing vehicles (even buses) hinders its functionality. Performing experiments with such a wide range of conditions verified the anticipated behavior of both the utilized sensors and verified the correctness of the utilized combinatory sensing modality. In Figure 10 the hand-crafted protective enclosure containing the pair of sensor nodes used during experimentation process is presented. The enclosure is made of a material with zero magnetic permeability (wood) and on the top it is protected from overlying leakage by a PVC surface enabling radiation penetration and thus not hindering NaPiOn's operability. More information on the verification procedure including photo shoots and video raw footage can be found on the application's support website [25].

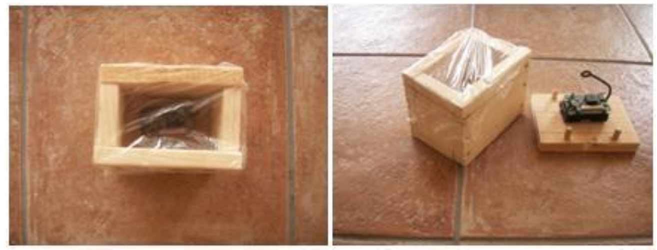

Figure 10. Nodes' hand-crafted protective enclosure.

VI. CONCLUSION

In this section, the overall knowledge obtained throughout the research procedure is presented and future work concludes the implementation presented.

A. *Lessons Learnt*

This research idea was developed in an attempt to seek an applicable solution for a major problem of contemporary urban environments. Cruising for parking contributes significantly in exaggerating air pollution due to traffic congestion issues, phenomena that ought to be reduced or even evicted from our future envisioned megacities. Our objective was to assiduously examine the viability of such a proposed application system by evaluating it on a small-scale deployed WSN in real-time and actual conditions. After examination the optimal WSN sensing technology was utilized, comprised of a collaborative usage of magnetic and passive infrared sensors. The data sampling procedure was implemented in Java via customizing the default TinyOS-1.x and 2.x functionalities, and the administrative algorithm included various other features responsible for processing, storing, uploading and retrieving the collected information. Ultimately, a designated parking curb space can be monitored and accordingly stamped onto a web GUI map if it is occupied or not. The experimental and simulation procedure involved testing a great range of detection scenarios and under variable ambient conditions. Concrete evidence was derived in terms of the specific utilized detection scheme and in comparison with the related work proposals. The magnetic sensor can be manually calibrated in order to adjust to custom needs and thus can efficiently detect any overlying vehicle with merely zero error rate. The auxiliary operation of the passive infrared sensor was proven obligatory since it enables the system to be aware of any kind of malicious parking behavior or false positive magnetic indications. Thus, the overall system error rate is substantially low, a fact proven through the strenuous full-scale experimental results.

B. *Prespectives for Future work*

The current implementation scale can be considered as a rather limited one if we contemplate upon the actual capabilities this system can offer at a full-scale deployment. To that extend, its further expansion could enable further optimization of the administrative algorithm in terms of reducing its response time from the moment that ambient stimuli is recorded until when the information is depicted onto the google map. Another important feature that should be ensured is expanding into a multihop networking architecture. On the same notion, when a multihop scheme will be adopted charging machines (present in every urban fabric) can be equipped with a pair of motes so as to operate with the form of relay nodes with extra powering capabilities that would reduce in this sense the overall networking strain. Some optimistic scenarios would even promote this parking assistance system as a platform responsible for traffic management system based on the knowledge that each driver declares his destination and thus he could receive distinct routing directions towards each free parking space. To that extend, routing algorithms can be adopted from relevant research areas in order to facilitate such kind of expansion.

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