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Wireless Sensor Networks in Intelligent Transportation Systems

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Abstract: *One of the main goals of intelligent transportation systems (ITS) is economical profit in the form of fuel consumption reduction, efficient use of existing infrastructure, pollution reduction and so on. Certainly, the economical goal is not the only one. Increasing mobility, safety and passenger comfort are other very strong motivations for implementation of ITS in practice. The paper analyzes the possibilities of exploitation the technology of wireless sensor networks (WSN) in ITS. Detailed description of sensor node designed for sensing intensity of magnetic field and acceleration is provided. As an example, the proposed sensor is used to sense the speed of moving vehicles and to classify the vehicles according their estimated length.*

Keywords: *Intelligent Transportation System, Sensor Node, Wireless Sensor Network*

I. INTRODUCTION

Transportation is inseparably linked to the life of every person, whether in the form of passenger transport or material transport. The amount of transported people and goods continues to grow and with it the economic importance of transport. With around € 533 billion in Gross Value Added (GVA) at basic prices, the transport and storage services sector (including postal and courier activities) accounted for about 5.1 % (4.6 % in 2008) of total GVA in the EU-27 in 2009 [1]. It should be noted, however, that this figure only includes the GVA of companies whose main activity is the provision of transport (and transport-related) services and that own account transport operations are not included. The transport services sector employed around 10.6 million persons, i.e. 5 % of the total workforce. In 2010, private households in the EU spent € 904 billion (13 %) of their total consumption on transport-related items, e.g. to purchase vehicles, to buy fuel for cars or tickets for bus, train, plane and so on. Referring to above mentioned information, transportation sector represents one of core ones in the EU. In general, meaningful activities in transportation field have positive influence on economy growing as well as decreasing of unemployment. Unfortunately, growing number of vehicles and traffic volume in any transportation mode, e.g. road, railway, aerospace, marine one, has implied increasing of traffic accidents, congestion and environmental problems. In order to solve these problems, international organizations, governmental authorities, industry corporations have been putting effort into supporting of applying electronics, information and communication technologies in the field of transportation, so that intelligent transport systems became reality. The economic impact of the ITS industry is significant. U.S. ITS market revenues are estimated for about $48 billion in present days and exceed those for electronic computers, motion picture and video products, direct mail advertising, or internet advertising. U.S. private sector ITS market revenues are expected to climb to $67 billion by CY 2015 [2].

Economical profit represents one of core motivation factors of research and development (R&D) activities in the field of ITS. Certainly, it is not the only one. Increasing transport safety, traffic flow fluidity, environment protection and In 2010, 31 030 persons were killed in road accidents and 62 passengers lost their lives in railway sector in EU. Statistically, the most dangerous transportation mode is the road one. Table 1 presents number of road fatalities in several countries of the world. At this moment comparison of the countries statistics is not a goal. In general, it is possible to state that there are too many road fatalities per year even in the most developed countries.

Table 1. Transport safety – road fatalities

Year 2010	**EU-27**	**USA**	**JAPAN**	**CHINA**	**RUSSIA**
Total number of road fatalities	31 030	32 885	4 863	70 000	26 600
Per million inhabitants	62	106	38	52	186

Effectiveness of the transport could be evaluated on the basis of various criteria, e.g. cost of journey, coming in time, delay on the way and so on. Principally, passengers or goods are transported via selected transport mode (road, air, railway, etc.) to arrive to destination with minimal delay, i.e. to avoid congestions on the way, and expenses.

Table 2 shows volume of passenger transport in selected world countries. Analyzing the data, it is possible to state that road transportation mode is dominant one concerning passengers transport. It is valid globally. Core problem of the mobility represents road traffic congestions. Improving mobility effectiveness will be depended on fluidity of traffic flows. ITS technologies could significantly help to increase road throughput. Certainly, extension of existing infrastructure and selection of proper transport mode increases effectiveness of the mobility as well. Concerning freight transport, multimodal goods distribution allows very effective utilizing of complex transportation infrastructure. This strategy can increase the probability of congestion avoiding significantly.

Table 2. Passenger transport in pkm
(Passenger-kilometer: a unit of measure: 1 passenger transported a distance of 1 kilometer)

	EU-27 2010	USA 2009	JAPAN 2010	CHINA 2010	RUSSIA 2010
Passenger car	4738	5828	766	1491	
Bus + trolley-bus + coach	510	490	87		148
Railway	404	40	393	876	139
Tram + metro	90	18			49
Waterborne	38	0.6	4.3	7.2	0.9
Air (domestic)	524	888	74	403	147

Ecology programs are focused on decreasing of environmental pollution, reduction of massive consumption of fossil fuels. Emission is dominantly related to road transportation. Protection of environment must be principally based on the development of new “zero emission” fuels for cars, replacing fossil fuels motors by electro/hybrid motors, managing traffic flows fluidity in compliance with avoiding congestions, providing relevant and real time traffic information to driver, supporting Eco-driving mode and so on.

Comfort could be characterized by following factors: vehicle`s technologies perform complicated operations instead of driver; real-time as well as value-added information are available to the driver for in-time and correct decision making.

Referring to above mentioned information, it is possible to conclude that implementation of Intelligent transport systems is reasonable and have positive influence on mobility safety, ecology as well as economies. It is now undisputed that intelligent transportation system brings significant benefits to users and operators of transport infrastructure. Getting information about the current state of transport infrastructure and transport parameters is essential for effective management of traffic on the roads. One promising means of obtaining the necessary information is a wireless sensor network, which is able to obtain relevant data from spatially distributed sources. WSN is composed of simple, inexpensive elements (nodes) that are able to capture the necessary data, to pre-process them and to transfer them to the center using wireless transmission paths. The center is able to handle the data and to implement appropriate intervention action, or it can provide the data to the operator or users of the transport system. Today we meet the fact that WSNs are becoming an integral subsystem of each ITS.

II. WIRELESS SENSOR NETWORKS

Development and successful deployment of WSNs depend on advances in different areas such as: low-power electronics, micro-electro-mechanical system (MEMS) components, new reliable sensors, power sources with high energy density, devices with ability to generate energy from the environment and new RF communication standards. The most promising application areas of WSNs are:

- Transport,
- Medicine,
- Monitoring and protection of the environment,
- Military,
- Guarding, protecting and tracking,
- Industry and many more.

WSN can be applied wherever we encounter spatially distributed information sources. An interesting application area of the WSN is the traffic. It is clear that monitoring and managing the traffic requires information sources that are geographically dispersed over a large area. A comprehensive overview about the state of transport can be obtained only on the basis of information obtained from a large number of properly deployed sensors. Therefore, the monitoring and management of the traffic naturally tends to the applications of sensor networks. Currently, the most frequently used WSN applications in the field of transport applications are: monitoring of traffic and dynamic routing [3], [4], monitoring and management of parking lots [5], [6], adaptive control of intersections [7], [8].

Successful deployment of WSN in different applications depends on parameters of the sensor nodes. The most important parameters are:

- The processing power and memory capacity of the sensor,
- Low power consumption/long lifetime,
- Production cost,
- Security,
- Fault tolerance and other.

Note that it is impossible to develop a universal node that is optimal in terms of all the above requirements as some of these requirements are contradictory: large computing power at minimal cost and power consumption; long life without operator intervention at small dimensions of the energy source; sufficient speed of communication within a limited frequency band, low transmission power and low sensitivity of the receiver (Transmit power and the receiver sensitivity is closely related to the consumption of communication units.). For these reasons, parameters of the resultant sensor node represent kind of a compromise between the requirements of applications and capabilities of current technology.

III. SENSOR NODE STRUCTURE

Despite the variety of application areas the basic structure of the node is the same. Each sensor node must be able to perform three basic functions: data collection, data preprocessing, and data transmission. Each function is provided by another subsystem. In addition to these three basic subsystems we need power subsystem to provide energy to all other subsystems.

3.1. Data collection subsystem

Data collection subsystem is application depended and consists of sensor elements sensing relevant signal values in compliance with defined aim. The diversity of application areas cause that it is difficult to define universal properties and parameters of data collection subsystem. Any application requires a little bit specific approach from subsystem design point of view. The data collection subsystems are mostly focused on: temperature, pressure, humidity, acoustic noise level, lighting conditions, biological and chemical agents, vehicle movement, the presence/absence of the object etc.

Basic functions of the data collection subsystem are:

- Sensing of selected signals by proper sensors and transforming of measured signals to ones which are suitable for additional processing (most often electrical voltage).
- Adjusting of signal level in such way that dynamic range of A/D converters is utilized in the best manner.
- Filtration of the additive inherent and interfered noise from the signal. The useful part of the signal should not be distorted.
- Filtration in order to limit the frequency spectrum of the signal so it is in compliance with selected sampling period (ant aliasing filter).

Besides presented basic functions additive functions are often provided by the subsystem e.g. periodic evaluation of the signal level and activating the processor if the measured signal reaches predefined threshold value.

As the data collection subsystem is application depended it is often realized as a compact module connected to the sensor node via a set of connectors. For its construction are used modern electronic elements, especially sensors, operational amplifiers, amplifiers with programmable gain, comparators and other microelectronic components.

3.2. Data processing subsystem

The role of data processing subsystem depends on how the WSN process the data. If the network is decentralized each node must have sufficient processing power to process all relevant data and to calculate results. In the case of centralized network structure the node just collects data and sends them to the central unit for further processing. However, usually it is impossible to transmit all the measured data as the data transmission is very energy intensive. Therefore, we try to minimize the volume of transmitted data. It is important to realize essential part of the data processing directly at the point of its origin **-** in a sensor node. Data transmitted to other network nodes should contain just information essential for problem solving. Basic data preprocessing algorithms thus relates to the methods of information content extracting (compression). Another possibility is to use collaborative signal processing algorithms. These algorithms use the smart distribution of data processing between the different network nodes in order to increase overall computing power of the network while minimizing the total energy consumption.

Basic functions of processing subsystem are: digital processing of measured signal values, controlling of individual modules of the sensor node, securing of transmitted data and potentially another additive functions required by particular application. It is possible to use different devices as the core of the processing subsystem: ASIC, FPGA or universal microcontrollers. All requirements related to technical solution is necessary to consider during selection of proper unit core. Nowadays, microcontrollers (MCU) are mostly used as a control system of sensor node. It is clear that it is very important to carefully consider required computing performance because increasing of it will increase energy consumption. In current solutions are used mainly 32-bit processors StrongARM with energy consumption of 0.3W@1.5V/200MHz in active state, different MCUs from 32-bit Atmel ARM7 90mW@3.3V/48MHz, through 16-bit MCUs TI MSP430F5437 1mW@3.0V/8MHz to 8-bit Atmel ATmega644 0.72 mW@1.8V/1MHz. Note that mentioned data has only informative character. In case of selection of proper type of MCU is necessary to take into account significantly more parameters (capacity of program memory, data memory, integrated peripheries, circuit architecture, availability of development tools and many other factors).

3.3. Communication subsystem

Communication subsystem provides ability of wireless communication – fundamental property of a wireless network. Communication capability of WNS nodes are in most practical cases limited by communication range and data rate. It is important to remember that increasing of communication range requires increasing of transmit power/receiver sensitivity, i.e. energy consumption is increased as well. Above mentioned conclusions result from Friis transmission equation:

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2 \quad (1)$$

where G_T and G_R are the antenna gain of the transmitting and receiving antennas, respectively, λ is wavelength, d is the distance, P_R is power available at the receive antenna terminals and P_T is power delivered to transmit antenna. The factor in parentheses is the so-called free-space path loss. The antenna gains are with respect to isotropic, and the wavelength and distance units must be the same. The formula is valid only is the antennas are in unobstructed free space and the bandwidth is narrow enough that a single value for the wavelength can be assumed.

Increasing of communication range of individual sensor node increases interference among network elements so that it has negative influence on total throughput of the network. This is the reason why the most common communication range is between 10 and 300 m, for transmit power 0 to 10 dBm and receiver sensitivities -90 to -102 dBm. The transceivers operate the most often in frequency bands: ISM 443 MHz, 886/916MHz and 2.4 GHz. Note that limitation of communication distance has no influence on the ability of the network to exchange information between two remote nodes as the multi-hop message routing techniques are used [9].

As communication subsystem can be used commercial module produced by companies NXP, AUREL, MaxStream, RF Digital Corporation, etc. The second option is to design proprietary radio unit satisfying requirements of the application. Let us notice that in each case it is necessary to respect limits defined by European normalization and state telecommunication authorities.

3.4. Power subsystem

For every WSN application is important period of network operation without maintenance. Energizing of sensor nodes by electrical energy is critical problem. To solve the problem it is possible to choose from one of following energy sources:

- Primary batteries,
- Rechargeable batteries,
- Energy harvesting (collecting energy from surrounding environment),
- Combination of rechargeable batteries and energy harvesting.

During energy resource selection process it is necessary to evaluate parameters limiting range of applicability. One of such parameters is self-discharging that could be in case of some types of batteries even 30 % per month. Another important parameter is the range of operation temperatures, number of charging cycles, etc. For the purpose of planned long term service-less operation of the network (i.e. longer than 6 months) most favorite energizing is based on using primary lithium batteries, potentially with the system of energy harvesting and super-capacitor.

Figure 1 shows basic structure of sensor node consisting from above mentioned four subsystems.

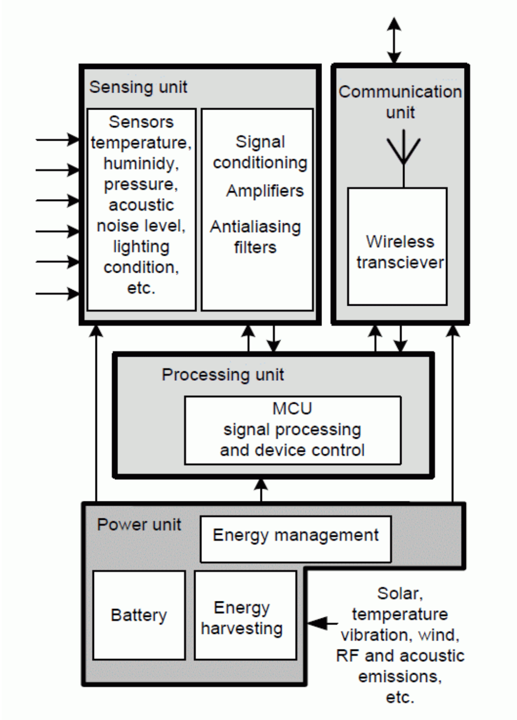

Figure 1. Node structure

IV. NODE FOR ROAD TRAFFIC MONITORING

At University of Zilina, Department of technical cybernetics, we developed a node prototype for monitoring the traffic. As the node is not dedicated for commercial utilizing, questions related to energy severity, reliability and cost of product were not prioritized at the time of sensor node design. Monitoring of the traffic is based on a magnetometer. As the cars consist mainly from a metal, they influence magnetic field of Earth and the changes can be sensed by a magnetometer even from relatively large distance from the car.

The node is based on a low-power 32-bit microcontroller STM32F100RB. The MCU is based on the ARM-Cortex M3 core. It has two types of memory: SRAM with capacity of 8 kB and Flash memory with capacity of 128 kB. Microcontroller integrates many standard peripherals supporting extension of application possibilities. Memory subsystem is extended by micro SD card that allows saving of big amount of data content for off-line evaluation. MCU´s power management unit supports several energy saving modes. Sensing part of the node consists from the sensor LSM303 containing 3-axis magnetometer with a 3-axis accelerometer. Magnetometer sensitivity is adjustable in range from ± 1.3 Gauss to ± 8.1 Gauss. Accelerometer range is possible to adjust in interval from ± 2 g to ± 8 g. The communication subsystem can be based on module RFM70 or XBee. Module RFM70 enables communication over short distances in the ISM 2.4 GHz band with data rates up to 2 Mbps. XBee module uses the same ISM band and has better communication range but slower data rate (up to 250 kbps) than RFM70. Motherboard dimensions are 49 x 33 mm (Fig. 2).

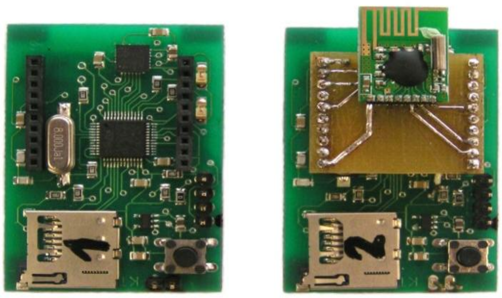

Figure 2. Node prototype – without and with RFM70 module

Data collecting center of the WSN is based on a personal computer equipped with a special USB adapter that enables communication with both mentioned communication modules.

Power unit allows using primary or rechargeable cells or super capacitors recharged by solar cells [10], [11]. Under development is a new super capacitor charging system using a thermo generator?

V. EXPERIMENT

Sensor nodes basic testing was realized as follows. Two nodes were placed on the verge of the road with spacing of 2 m. One module transmitted the measured data and the second module stored both measurements to the SD card. The sampling frequency was 220 Hz (highest supported by the magnetometer) and sensitivity was set to ± 1.3 gauss. The measurement took 18 minutes. During the measurement the vehicles were recorded by a camera. Analysis of the camera recording has provided the number and type of vehicles: 131 passenger cars, 4 vans, 4 trucks, 2 buses and a bicycle - altogether 142 vehicles. Very good sensitivity of the magnetometer is confirmed by the fact that it was able to detect even a bicycle.

Figure 3 shows data acquired from both sensors during a 8 second interval. Let us notice that sensor 2 is located 2 m ahead of sensor 1. Time difference between measured signals is depended on localization of sensor elements, speed of passing vehicle and orientation of vehicle movement. Average speed of vehicle passing the sensors can be calculated on the basis of the evaluation of time difference between corresponding changes of magnetic induction measured by sensors 1 and 2. The first part of the record belongs to a vehicle going in the right direction and the second part to a vehicle in the opposite direction. Evaluating shift between records is very useful for eliminating false-positives.

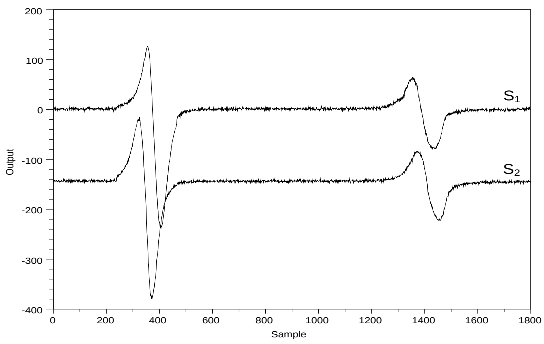

Figure 3. Different direction of vehicle movement

For each vehicle we can determine its speed. Assuming a uniform speed of the vehicle, the relation for vehicle speed is:

$$v = d * Fs / s \qquad (2)$$

Where Fs is the sampling frequency, s is the shift between the measurements calculated using correlation and d is the distance between the sensors. Using the calculated speed of vehicle we can estimate its length l, which is proportionally dependent on the length of the vehicle record (N) by the relation:

$$l = N * v / Fs \qquad (3)$$

In Fig. 4 are depicted the lengths of all detected vehicles. It is well possible to distinguish between two groups of vehicles: smaller (personal) and larger vehicles (vans, trucks and buses). The reason why the calculated length of some passenger cars is unusually large has not yet been determined. However, we must remember that the calculated length is not the length of the vehicle but rather the length the magnetic profile of the vehicle. As such, it is very dependent on the material from which is the car made.

Presented measurements illustrate usability of sensor nodes with magnetic induction sensing for monitoring of traffic flow parameters. Influences of the second sensed parameter (vibration) were not involved in the test. More measurements can be found in [12].

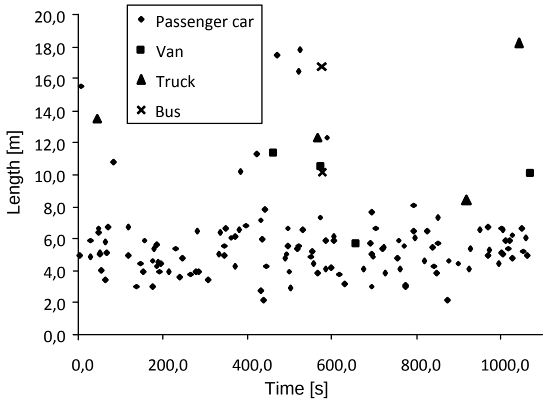

Figure 4. Estimated lengths of all vehicles

Future research activities will be focused on building of a whole WSN and online evaluating of measured signals. Our ultimate goal is to get enough information to adaptive control of intersections.

VI. Conclusion

Problematic of intelligent transport systems is subject of interest of many authorities, institutions as well as commercial corporations in present days. The paper shortly introduces basic attributes of transportation processes from safety, effectiveness, environmental and comfort point of views. Referring to key technologies using in transportation applications: sensing, data processing, data transmission etc., problematic of wireless sensor networks is presented in the paper as well. It is possible to state that both of research areas (ITS and WSN) are using principally comparable technologies for data collection, processing and transmission. It means that WSN technologies are well applicable in the field of intelligent transportation systems. Certainly, selection of applications must correlate with specific WSN characteristics. Finally, it is possible to state that implementation of wireless autonomous devices in the field of intelligent transportation systems has very good perspective.

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