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Intelligent Sensors for Real-Time Hazard Detection and Visual Indication on Highways

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Abstract— Traffic collisions, in particular high speed car accidents often result in huge damages, long traffic queues and loss of human lives. In this work, we present an intelligent modular autonomous system that monitors traffic in highways and alerts drivers of sudden stops, in poor visual conditions. The system is composed of several identical modules, to be placed in the middle of a highway's lane, that sense the lights and communicate their presence and velocity to their neighbour modules via RF. With such information, the nearby modules estimate the velocity of the passing cars. When the module ahead detects a car passing at a much slower speed than what was previously estimated, it alerts the other modules, so they produce a visual indication for the oncoming drivers, preventing accidents.

Keywords: Intelligent Transportation Systems, Auto Traffic Monitoring, Low-Power Embedded System, Ad-hoc Wireless Communication, Sensor Network.

I. INTRODUCTION

Road Safety is a major societal issue. In 2015, more than 26,000 people died on the roads of the European Union, i.e. the equivalent of a medium town. Additionally, for every traffic death on Europe's roads there are an estimated 4 permanently disabling injuries (such as damage to the brain or spinal cord), 8 serious injuries and 50 minor injuries [2].

These statistics motivate the development of Intelligent Transportation Systems (ITS) [1] as innovative services related to different modes of transport and traffic management, aiming a smarter, and helpfully safer, use of transport networks.

This paper presents an autonomous embedded system that tries to improve safety in highways in poor visibility conditions due to the road profile, or adverse meteorological conditions. It acts as an active alert signal to other drivers.

Previous works [7,10] detect automatically traffic accidents using image processing techniques, based on images acquired by infrastructures deployed on road.

Other approaches consist of using in-vehicle systems [8], or smartphones [9], that try to automatically detect traffic accidents using accelerometers and acoustic data. These approaches aren't able to automatically warn oncoming traffic of the accident.

The proposed system is to be installed on the road, and is composed of several modules that work together to perform real-time traffic monitoring and detection of hazardous situations.

Each module incorporates very bright LEDs that are activated when an hazardous situation is identified, thus warning drivers approaching the location. One of the key features, that differentiates the proposed systems from others [6] is the fact that it is pro-active in detecting accidents by exchanging messages between modules.

Each module measures the time elapsed between the communication of a preceding module and the detection of the vehicle by the sensor. Therefore, knowing the distance between each device it is possible to determine a vehicle's speed, and if it reduced drastically the velocity, or even if it stopped.

The main contributions of this work are: definition of the architecture of the system and its requirements; definition of hardware and software for the embedded system; communication protocol; characterization and modelling of the light pattern produced by vehicles; simulation of the operation of the modules.

The rest of the article is organized as follows: section II presents the system architecture, giving a general overview of the system; it then describes the module, and the criteria used for the selection of the hardware, and decisions made for the software; section III give details about the experimental evaluation, and finally in section IV we outline the main conclusions and draw lines for future work.

II. PROPOSED SYSTEM

The proposed system is composed of several identical modules that acquire information about traffic from sensors, detecting vehicles, estimating its velocity and reacting to hazard situations. Fig. 1 demonstrates a schematic representation of the system, when installed on a highway. It is composed by several modules positioned equidistant from each other, installed on the middle of the road, and represented by an orange dot figure. On the right-hand lane, two cars are involved in an accident. The system identifies this situation and the preceding modules emit a visual warning (bright red light) for the drivers approaching the location, in order to reduce their velocity, hence avoiding an imminent chain crash.

The passage of each car can be detected using several methods [4], that are classified based on their intrusiveness in the road. The intrusive methods require the placing of sensors on or in the road, as pneumatic road tubes, piezoelectric sensors, magnetic loops [5]. The non-intrusive techniques are based on remote observation [7,10].

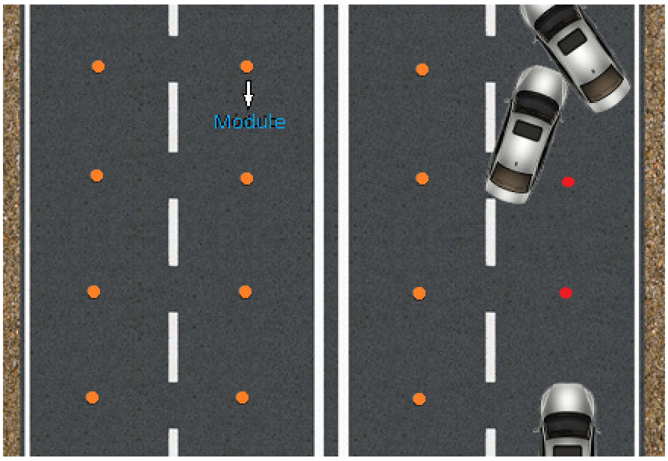

Fig. 1. Illustration of the deployed system in operation. On the right-hand lane after identification of an accident, the modules warn the drivers of the dangerous situation ahead.

On this work we follow an intrusive approach, but based on a light sensor. The detection of the car passage is performed by analysing the patterns of vehicles' head lights, using a photoelectric sensor.

The automatic decision about the existence of an accident is based on a message passing algorithm between modules, through a wireless ad-hoc network.

Each message informs the neighbour modules about each vehicle detection. If a module doesn't detect a passing vehicle during an expected period, either too slow or stopped, then it alerts its neighbourhood until de regular traffic flow is normalized.

A. Hardware

Due to the system's operating environment, and its implement restrictions, each module is comprised of a solar cell, a battery, a power management unit, a micro-controller (MCU), an RF transceiver, a light-sensor and LEDs, as illustrated in Fig. 2. The battery is charged via the solar cell. The MCU provides all the control logic of the module and its peripherals, e.g. LED, RF module, and light sensor.

Fig. 3 shows a 3D rendering of the system in its case. The solar cell is on the top, and the LEDs positioned to guarantee that drivers can see them. The light sensor, is positioned with an angle that better detects the vehicles' head lights. The translucent top panel is to be manufactured of resistant plastic such as Plexiglass, while the rest of the case can be manufactured of a less expensive, but equally resisting material.

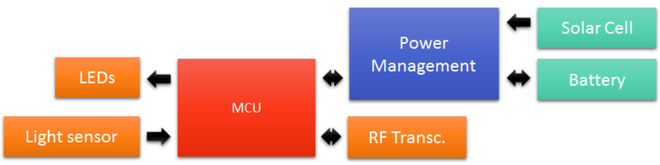

Fig. 2. Organization of the blocks in the module.

B. Software Intelligence

With mechanical and power restrictions, the modules had to be implemented by a very low-power, yet flexible, platform.

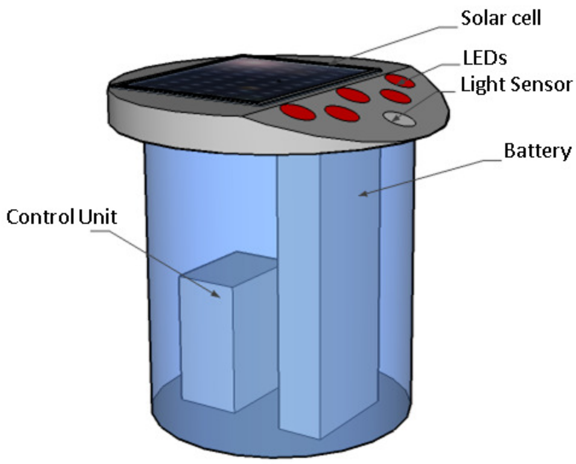

Fig. 3. A 3D rendering of the case for the modules, including its components.

On this account the intelligence of the system is modelled by a Finite State Machine (FSM).

The system is meant to react to 2 inputs: the light sensor, and reception of a message from the RF module; and actuate 2 outputs: visual indication via LEDs, and transmission of message to the RF module.

To support such functionality, an FSM was thought to be programmed on the MCU to control the system using 4 states: Sleep, Detection, Decoding, and Communication. Change of states are described in Fig. 4.

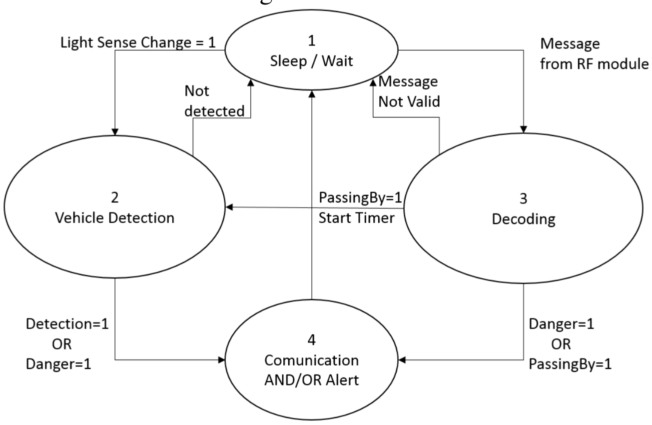

Fig. 4. State machine of the controller.

After reset, the system is in the initial state (State 1: Sleep), waiting for a message from another module (State 3: Decoding) or detection of a vehicle (State 2: Vehicle detection).

In state 3, the received status can be: a) Vehicle detection, b) Send a warning, and c) Reception acknowledgement. If the message received is a warning, then it goes to state 4 ("Communication / Alert") and activates the light signalling during a period of time and the message is retransmitted. At the end of transmission, the FSM goes back to the initial state.

In the second state ("Vehicle detection") it starts to count the time after receiving the message. The time stops when a vehicle is detected, and since the physical distance between modules is known an estimate of speed can be calculated. After the vehicle is detected, a corresponding message is sent to the neighbour modules. The system waits for acknowledgement messages.

If the time waiting is greater than a threshold, it changes to state 4, and turn on the LED light and send a warning message to be received by all nearby modules. The device then returns to state 1.

C. Communication

The modules communicate with each other via RF broadcast messages, so that other modules within coverage range can bypass a faulty module in the system and continue its operation.

There are 3 types of messages exchanged by the modules are:

- Detection: After a vehicle's detection, with is velocity estimate.
- Warning: When a vehicle doesn't pass on the expected time interval, due to abrupt speed decrease, or did not pass at all, due to an accident.
- Acknowledgement: Indication of the information received by the module.

Figs. 5-7 illustrate 3 scenarios of operation of the proposed system. In the first one, a car is detected and its information exchanged between modules and not abnormality is detected.

The second scenario shows the case where a car as drastically reduced its velocity, and consequently too longer to reach the second module, thus the second module broadcasts a warning message.

The third one illustrates the case where the second module failed to send an acknowledgement for the message sent by the first module, and a warning message is then broadcasted by the first module after a timeout period.

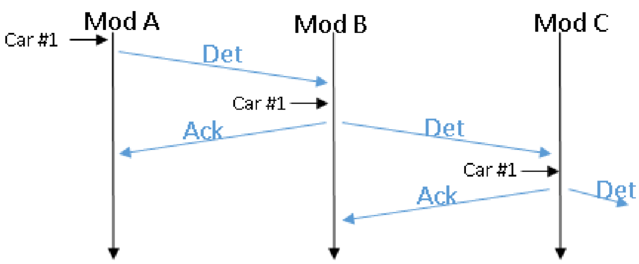

Fig. 5. Message sequence chart of normal situation while detecting a car and passing information between modules.

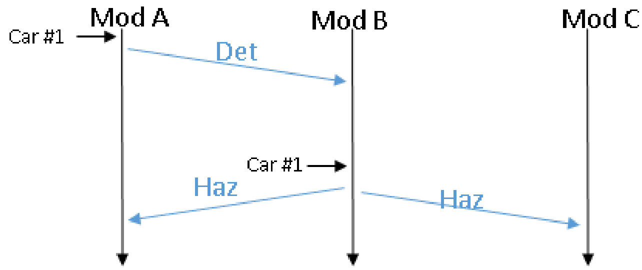

Fig. 6. Message sequence chart of an abnormal situation where the car is not detected in the expected interval by the second module, and a warning is broadcasted.

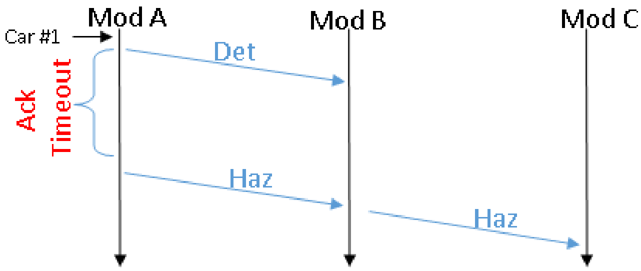

Fig. 7. Message sequence chart of an abnormal situation where the car is not acknowledged by the second module, and a warning is broadcasted by the first module.

III. EXPERIMENTAL VALIDATION

The first step taken for the implementation of the system consisted on a simulation in Matlab environment. It simulated the FSM, the detection algorithm, and the message passing scheme. Moreover, it allowed to study the behaviour of the modules to the passage of the light intensity profile of each vehicle, and check the transmitted messages.

Fig. 8. Structure over the road used to acquire the photos during the evening.

The light intensity profile is based on real data, which were obtained by filming part of a highway to collect several light patterns from different vehicles.

Fig. 8 shows the photograph of the structure over the road used to acquire the photos during the evening. Several frames with light footprints of vehicles' headlights were extracted from several video-recordings. They were then cropped and converted to grayscale, as illustrated on Fig. 9.

To simulate the light sensor analysis, only the intensity values of the footprint were considered, shown in blue in Fig. 10, and low frequency signal in red.

Fig. 9. Example of a photograph used to create the models for the different light patterns.

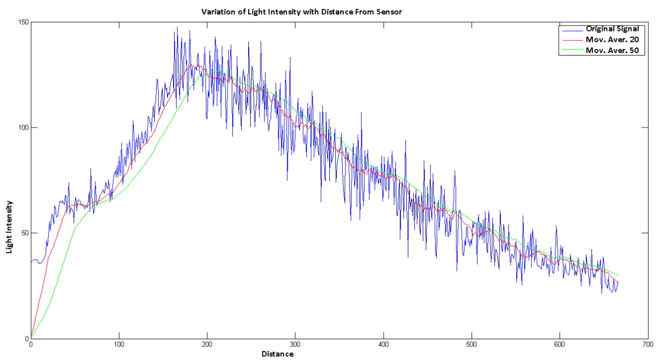

Fig. 10. Example of the data extracted from the light footprints to create the models for different vehicles.

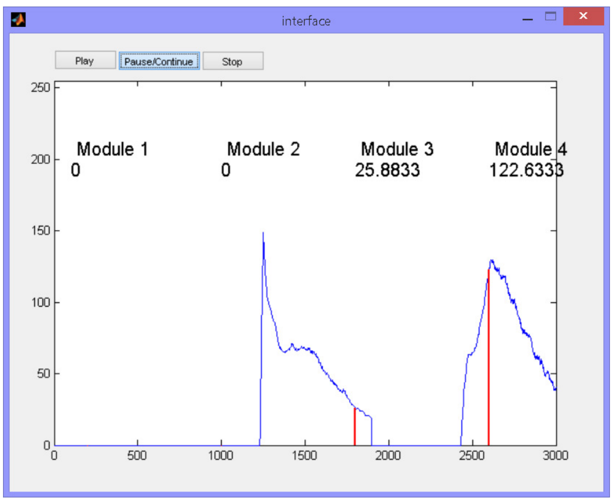

Fig. 11. Output of the simulator created to test the modules.

Fig. 11 presents the output of the simulation of the system. Here, the photo-sensors in the first module detect variation in the intensity of the light sensed, and identify it as a vehicle.

This information is then broadcasted to the following modules, and the module waits for the following vehicle before broadcasting new information. The other modules identify the origin of the received message and start counting the time passed between the reception of the message and the detection of the car.

The choice of hardware for the implementation involved the selection of the most adequate MCU, which is the unit supporting the intelligence of the module. The parameters used for this selection, were: power consumption, number of IO, number of timers, clock frequency, price, and the existence of a development kit. The chosen platform was the Texas Instruments MSP-EXP430FR5969 along with the 430BOOSTCC110L kit to provide RF communication using the 868-870MHz band for Short Range Devices (SRD). Fig. 12 presents the photos of the 2 modules.

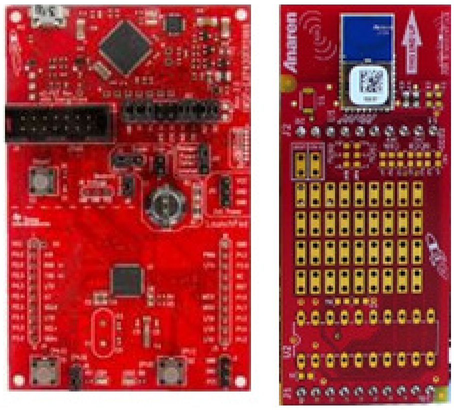

Fig. 12. Photographs of the development kits used: MSP-EXP430FR5969 (left) and 430BOOSTCC110L (right).

The MSP430FR5969 [3] has a very low power consumption, enough I/O ports an UART to connect with peripherals, and an acceptable number of timers needed to count the time that vehicles spend in between modules. The key features of this MCU are listed in Table 1.

TABLE 1
RELEVANT FEATURES OF MSP430FR5969

Parameter	**Value**
Frequency	16 MHz
Non-volatile Memory	64 kb
SRAM	2 Kb
GPIO	40 pins
UART	2 units
16-bit Timers	5 units
Active Power	101.25 µA / MHz
Standby Power	0.5 µA
Wake-up Time	7 µs
Price	$2,35 (USD)

III. CONCLUSION

We have proposed and demonstrate a novel system to detect hazardous conditions on highways due to sudden stops, or abrupt velocity reductions of vehicles, which are usually associated with accidents.

The system is to be used in poor visibility conditions, due to adverse weather conditions, and highway profile. It is composed of many modules present on the highway, that detect passing vehicles by sensing light from their headlights.

We have demonstrated the concept by presenting simulation results and an earlier implementation of the embedded system.

Future work involves exhaustive real-life measurements and tests on different roads and highways with distinctive characteristics, at different times of the day and under different weather conditions.

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