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Radar Vehicle Detector Mote

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Abstract: There are many techniques used for detection and counting vehicles commercially and reported in scientific literature. Each technique has its own advantages and disadvantages. This paper presents a low cost vehicle detector system. The system consumes a very low amount of power and it can be operated by using only batteries. The vehicle detector system is capable of identifying vehicles and counting the number of vehicles traveling on a road. The captured data is sent to a remote computer using a wireless data communication module. The system can be used to monitor a road or counting the number of vehicles travelling on the road. The proposed system is based on a MSP430 microcontroller based design. Low power operating modes of the microcontroller are used to reduce the power consumption of the electronic circuits.

Keywords: Vehicle Detector System, Road Monitoring, Power Consumption, Radar Vehicle Detector System.

I. INTRODUCTION

There are many types of commercially available vehicle detection and counting techniques such as pneumatic road tube, inductive loops piezoelectric sensors, video image processors and magnetic sensors. Most of those techniques either consume high power or installing the sensor requires damaging road surface or the pavement. The primary objective of this paper is to develop a low power consuming and a low cost vehicle detector and counting system which can be used to log data with a wireless link. Due to the low power consumption, the system should be powered with batteries for a long time. The capability of wireless data logging allows rapid installation without specialist input and performs reliably for recording data even with multiple detector modules. A fully functional proof-of-concept system is developed to fulfill the objectives of the research.

A research on the background of vehicle detection and counting techniques is the starting point of the project, to gain the understanding of these techniques and identify their advantages and disadvantages. Specifications of the proof-of-concept system are decided after identifying the system requirements. The objectives of the project are fully achieved and the developed system performs all of its intended functions.

In this paper, the proposed system integrates a microwave radar sensor module operating at 10.525 GHz with Texas Instruments MSP430 microcontroller to identify the vehicles and movements of vehicles with a 2.4 GHz wireless communication module to transmit acquired information to a remote location. The present state of the project is fully functional and designed to operate in low power modes. The possible immediate applications of the proof-of-concept product are detection of the movements of vehicles and counting the number of vehicles crossed in the range of the detector module. It is possible to add more functionality such as detection of speed and identify the type of the vehicles with more signal processing techniques. This will extend the usefulness of the system to provide more specific information about vehicles and can be used in motor traffic management systems.

II. VEHICLE DETECTION TECHNIQUES

Vehicle detection and counting systems have verity of purposes, such as: security systems, control entries and departures, information collection for traffic management. However, in many places these works are carried out by humans. Despite that, automating vehicle detection and counting with electronic systems can perform the vehicle detection and counting with higher accuracy and more affordable cost.

Vehicle detection and counting sensors can be categorized into two main groups [1]:

1. **In-roadway sensors:**
   The sensors which are embedded in the pavement of the road, merged in the subgrade of the road or attached to the surface of the road.
2. **Over-roadway sensors:**
   The sensors which are installed above the road or alongside the road offset from the traffic lances by some distance.

TABLE I. TYPES OF SENSORS USED FOR DETECTING AND COUNTING VEHICLES [1].

In-roadway sensors	Over-roadway sensors
Inductive loops	Microwave Radar
Pneumatic road tubes	Laser radar
Piezoelectric sensors	Passive Infrared
Capacitive Mats	Ultrasonic sensors
Magnetometers	Video image processor

III. VEHICLE DETECTOR SYSTEM DESIGN

A. Requirments of the System

The primary objective of this paper is to design and develop a low power consuming, a low cost vehicle detector, and counting system. As a result, the requirements of the system are derived based on the advantages and disadvantages of currently available vehicle detection and counting techniques. The derived list of requirements for the project is as follows:

- Developing a prototype board to detect the presence of vehicles
- Log data send via Wireless link
- Low power consumption
- Battery operated
- Low implementation cost
- Compact design

To fulfill the above requirements, it was decided to use microwave radar technique for detecting the vehicles. Based on the review presented in section II and research on available techniques, microwave radar technique gives following advantages which are suitable for a low cost and power consuming and compact system.

- High immunity to whether effects
- Ability to detect the speed of the vehicle and direction of the movement
- Shorter wavelength frequencies allow convenient transmission and reception by smaller antennas
- Smaller physical size
- Availability of suitable sensor modules for battery operated systems
- Availability of sensor modules for a reasonable price

For the signal processing and controlling the vehicle detection mote and the remote receiver unit, TI MSP430 family microcontrollers are used. An analog circuit consists of signal amplifier and comparator for conditioning the signal output from the microwave radar module. The wireless communication between the mote and the remote PC is established using a TI CC2500 2.4 GHz wireless data communication module. This wireless communication module is selected due to the operation in 2.4GHz Industrial, Scientific and Medical (ISM) frequency band which require no license. A block diagram of the vehicle detector system is given in figure 1. The designs of each unit are discussed in following sections.

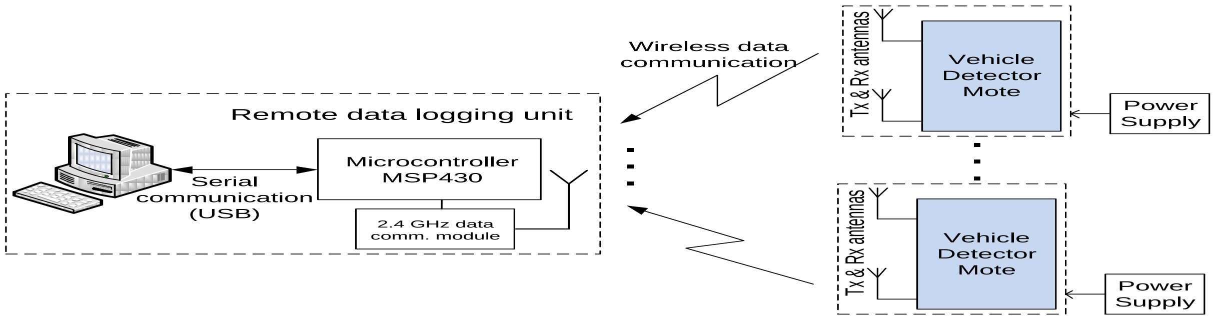

Figure 1. Block diagram of the proposed vehicle detector and counting system.

In figure 2, there can be multiple detector motes with wireless data communication modules. Each module can be named with a unique identification number. The remote data logging unit is kept inside the wireless communication range of the motes and collects data from the motes with their unique identification number. The data logging software records received information on a file for further analysis. This paper presents a proof-of-concept system for the system shown in figure 2, with one remote data logging unit and one vehicle detector mote.

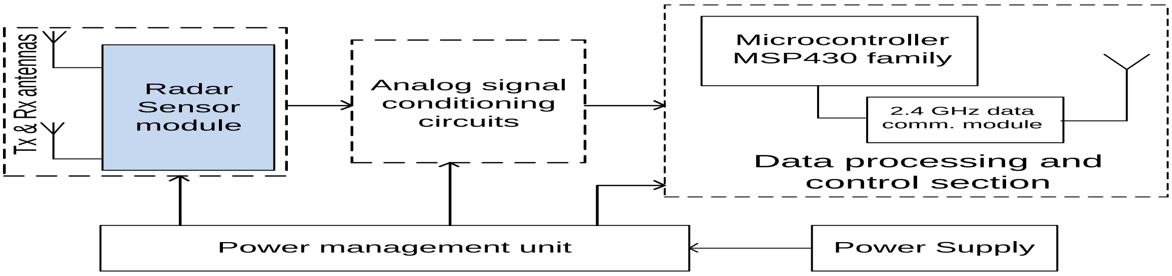

Figure 2. A detailed block diagram of vehicle detection mote.

B. Design of the proof-of-concept system

The proof of concept system consists of two units:

- One remote data logging base station unit
- One vehicle detector mote.

The hardware and firmware designs are divided into a number of modules and the design and integration of each module to build the system is presented in the following section.

IV. HARDWARE DESIGN OF RADAR VEHICLE DETECTOR SYSTEM

This section presents the hardware design of the vehicle detector and counting system. The system hardware is divided into two main parts as shown in figure 2:

1. Vehicle Detector Mote
2. Remote data logging base station unit

One of the major advantages of the modular design is that if a significant expansion or modification required for the system, it can be easily implemented. On the other hand, if a module failed, it can be easily replaced. Thereforel, the system down time can be minimized.

A. Hardware Designs of Vehicle Detector Mote

The major section and the most important part of the vehicle detector system is the vehicle detector mote. The basic requirements of the mote are as follows:

- Battery operated
- Low power consumption
- Small physical size – compact design
- Wireless connectivity

Considering the requirements and functionality, the vehicle detector mote can be divided into five modules:

- Microwave radar sensor
- Analog signal conditioning section
- Data processing and control unit
- Wireless data communication module
- Power management and power supply unit

A detailed block diagram of the vehicle detector mote showing the interconnection of the five modules mentioned above is shown in figure 2.

The output of the radar sensor module is passed through the analog signal conditioning circuits. A voltage summing amplifier and a comparator are used for the signal conditioning. The output of the signal conditioning block becomes a stream of pulses. This stream of pulses is fed into the microcontroller module and the firmware of the microcontroller identifies the presence of a vehicle and transmits the status to the remote base station. Power management unit consists of low dropout (LDO) voltage regulators and digital pins for controlling those via the microcontroller module. This allows implementing the power saving features such as shutting down power of some sections of the unit. The module is powered with four AAA batteries. The detailed description on the design of each module is given in the following sections.

1) Microwave radar sensor

A HB100 microwave radar sensor [7] operating at 10.525 GHz was selected by considering the operating voltage, physical size and the cost. The specifications of the module are given in table 2.

TABLE II. SPECIFICATIONS OF HB 100 RADAR SENSOR MODULE

Parameter	Value
Operating frequency	10.525 GHz
Radiated power	15 dBm
Settling time	3 us
Antenna beamwidth (3dB) – Azimuth	800
Antenna beamwidth (3 dB) – elevation	400
Supply voltage	5 V
Operating current	30 mA
Dimensions	46.5 mm x 40 mm

To understand the theory of operation, few simulations are carried out with Matlab. Next some experiments carried to verify the simulation results and specifications of the data sheet. The following section presents radar module simulations with Matlab and results of the carried out laboratory experiments.

2) Microwave radar module simulations

The Doppler shift between the transmitted and the received microwave signals is used to detect a moving vehicle. The block diagram of the radar sensor module given in figure 3, shows the internal connections of HB 100 – Microwave Sensor Module. The sensor module transmits CW microwave signal at 10.525 GHz. The transmitted and the received signals can be mixed using the internal signal mixer; the mixer output provides a signature of the frequency difference between the two signals.

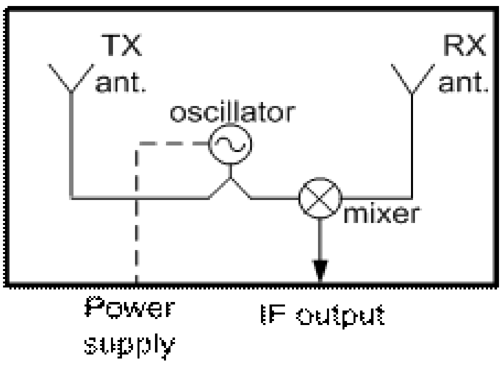

Figure 3. A block diagram of the HB 100 radar sensor module.

Figure 4 shows an application of detecting the movement of a vehicle using the radar module. Let's assume the frequencies of the CW transmitted and received signals are f_{Tx} and f_{Rx}, respectively.
Then the mixer output f_{IF} is given as:

$$f_{IF}(t) = \cos(2\pi f_{Tx} t).\cos(2\pi f_{Rx} t)$$

VOL. 2 ISSUE 3, MARCH-2013 ISSN NO: 2319-7463

which can be rewritten in the following form:

$$f_{IF}(t) = \frac{1}{2}\{\cos[2\pi(f_{Tx} + f_{Rx})t] + \cos[2\pi(f_{Tx} - f_{Rx})t]\}$$

Observed frequency (f_{Rx}) can be written in terms of the transmitted frequency and the speed of the vehicle using the Doppler formula as

$$f_{Rx} = \left(1 + \frac{2V}{C}\right) f_{Tx}$$

where $C = 3 \times 10^8$ m/s is the speed of electromagnetic waves at free space.

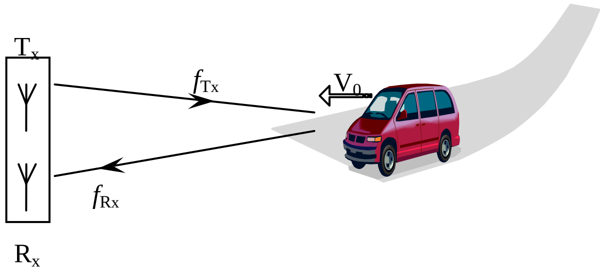

Figure 4. An application of using the Doppler radar principle to detect a movement of a vehicle.

It can be clearly seen that the output of the mixer contains the signals, the addition and the difference of the transmitted and received frequencies. By appropriate band pass filtering, the difference frequency (i.e. $f_{Tx} - f_{Rx}$) component can be filtered out. It should be noted that mixer output between the transmitted signal and reflections from stationary obstacles consists of a DC component and CW wave with twice the transmitted frequency.

V. FIRMWARE DESIGN OF THE VEHICLE DETECTOR SYSTEM

The vehicle detector is comprised of two sub-systems: remote data logging base station and vehicle detector mote. The vehicle detector mote is supposed to be kept on the road and it comprises analog section (radar module, amplifier, and analog comparator) and wireless communication module (TI MSP430F2274 microcontroller and CC2500 transceiver). The remote data logging base station contains wireless communication module (TI MSP430F2274 microcontroller and CC2500 radio) and UART communication.

The wireless communication system is developed using Texas Instrument EZ430-RF2500 Development Stick. The eZ430-RF2500 is a complete wireless development environment that includes all the hardware and software required to develop a wireless project. The eZ430-RF2500 uses the MSP430F22F4 microcontroller, which combines 16-MIPS performance with a 200-ksps 10-bit ADC and 2 op-amps and is paired with the CC2500 multi-channel RF transceiver designed for low-power wireless applications.

A. Vehicle Detector Mote

The radar module detects on-coming vehicles. The radar output is then processed by attached analog circuits to get appropriate digital pulse for the microcontroller in eZ430-RF2500. Upon receiving a vehicle-detected pulse, the eZ430-RF2500 module tries to link with the remote data logging base station. The Remote Device uses Texas Instrument SimpliciTI network protocol [12], [13] to link and communicate with the Base Station.

Low Power Modes (LPMs) represents the ability to scale the microcontroller's power usage by shutting off parts of the MSP430 microcontroller unit. In order to conserve battery power of the Remote Device, LPM3 mode is utilized. LPM3 disables CPU, MCLK, SMCLK, DCO, and DC generator and enables only ACLK [9].
After configuring the hardware (such as clock, timer, radio, and indicating LEDs), the radio is set to sleep mode in order to conserve battery power of the Remote Device. Also, an interrupt service routine (ISR) is configured to be triggered upon detecting a vehicle. The microcontroller of the Remote Device is driven into the low power mode 3 (LPM3) and stays in LPM3 for 2 seconds; the Timer0 interrupt is configured to count 2 seconds. Once the Timer0 interrupt is triggered, the microcontroller is driven into normal operating mode and the wireless sensor is switched on for 0.25 seconds. If a vehicle is detected by the microwave sensor, the firmware algorithm jumps into ISR1. Soon at ISR1, the radio (wireless transceiver) is awaked. A guard time of 0.25 seconds is set (in terms of pause) for de-bouncing.

B. Remote Data Logging Base Station

The remote data logging base station always listens to the vehicle detector mote and accepts receiving messages (number of detected-vehicles). Subsequently, number of detected-vehicles is sent to PC through application UART. The flow chart shown in figure 5, describes the firmware algorithm implemented in Base Station.

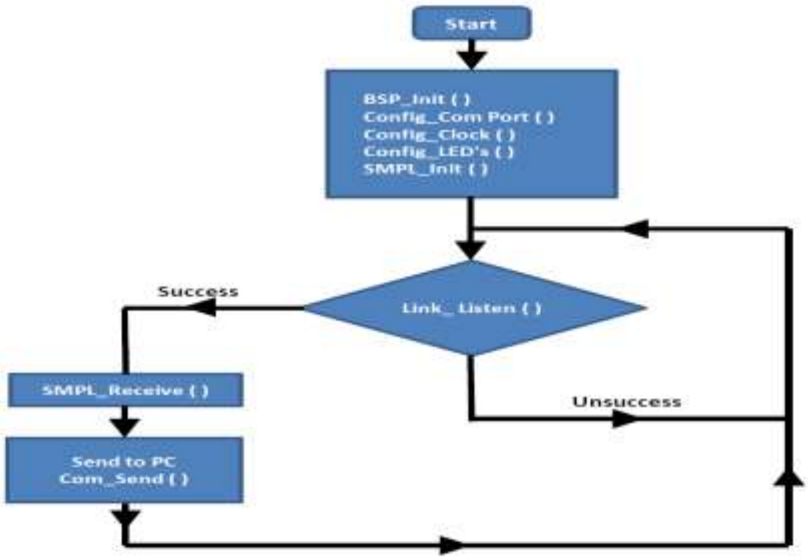

Figure 5. The flowchart of the firmware of the remote data logging base station.

VI. RADAR VEHICLE DETECTOR SYSTEM INTEGRATION

The previous sections have presented the design of hardware and firmware of the two main components of the vehicle detector and counting system: the vehicle detector mote and remote data logging base station. As described in the previous sections, the vehicle detector mote is fully battery powered and a compact device which can be easily install on the road or side of the road. The remote data logging base station is USB powered and having a wireless range of around 20 m non-line of sight.

This section explains the system level integration of the vehicle detector mote and the remote data logging base station along with the data logging software running on the remote PC. Special settings required for the system level integration as well as testing the performance of the system with real vehicles. The measured performance of the implemented battery power saving methods on vehicle detector mote is also presented.

A. Configuring and testing the vehicle detector mote

There are three variable resistors on the analog signal conditioning section of the vehicle detector mote. By using these variable resistors, the sensitivity of the mote can be changed according to the microwave radar sensor module and where it is installed on the road. If the radar module is installed on the surface of the road, the distance to the vehicle body is less and less sensitivity is required for the vehicle detector mote. If the vehicle detector mote is installed in a side of the road, a high sensitivity is required for detecting the movement of the vehicles as the reflected signal strength from the vehicle body is weak. In addition to the distance to the moving vehicle, it was observed that some microwave radar sensor modules give different output levels due to manufacturing variations. To accommodate all these variations, three variable resistors were introduced.

The best sequence for configuring the variable resistors is as follows. First measure the DC offset of the output of the radar sensor module. Then adjust the DC shift value using the variable resistor. Next set the gain of the amplifier using the variable resistor related to the gain. Finally set the reference voltage using the next variable resistor to generate a pulse upon the reception of reflected signal from a metal body of a vehicle. It is easier to use an oscilloscope to see the waveform at each output if the tuning is done in a laboratory. Otherwise a multi-meter can be used to measure the outputs with few trial and error rounds to obtain the proper results.

B. Vehicle Detection System Testing

The configured system was tested with few vehicles to verify the proper operation. It was observed that without proper sensitivity adjustments, the count of vehicles does not show the correct count of vehicles. Therefore, for the different applications, the sensitivity of the vehicle detector module should be adjusted. The wireless data communication range of the vehicle detector mote for non-line-of-sight operation is around 20 m. The line-of-sight between the vehicle detector mote and the remote data logging base station becomes around 50 m.

VOL. 2 ISSUE 3, MARCH-2013 ISSN NO: 2319-7463

VII. EXPERIMENTAL SETUP USED FOR POWER CONSUMPTION MEASUREMENT

The block diagram of the experimental setup used for measuring the power consumption is shown in figure. 6. As shown in the figure 1.5 ohm resistor is connected in series with the battery pack. An oscilloscope was connected to measure the voltage drop across the resistor. Since the current drawn by the system is varying rapidly a milli-ammeter cannot be used to measure the current [14], [15].

The voltage drop across the resistor with resistance R, can be expressed with:

$$V_{drop} = I_{out} R$$

Therefore, by measuring the voltage drop across the resistor, the current drawn by the vehicle detector mote can be calculated by using a known resistor.

Since the voltage drop across the series external resistor is very small (in mV range) the power drawn by the battery can be expressed with:

$$P_{out} \approx I_{out} V_{bat}.$$

The battery life for a battery pack having the capacity, C is:

$$\text{operating time} = \frac{C}{\text{current drawn by the battery}}$$

The voltage drop across the resistor is 40 mV in this case. Therefore the current drawn from the power supply is:

$$I_{out} = \frac{V}{R}$$

$$I_{out} = \frac{40\times 10^{-3}}{1.5} = 26 \text{ mA}$$

Consequently the power supplied by the battery pack to the microcontroller and the radar sensor module:

$$P_{out} \approx 26 \times 10^{-3} \times 6 \approx 156 \text{ mW}$$

Battery life for the continuous operation as described above for AAA battery packs having a capacity of 1100 mAh:

$$\text{operating time} = \frac{1100}{26} = 42.30 \text{ hours}$$

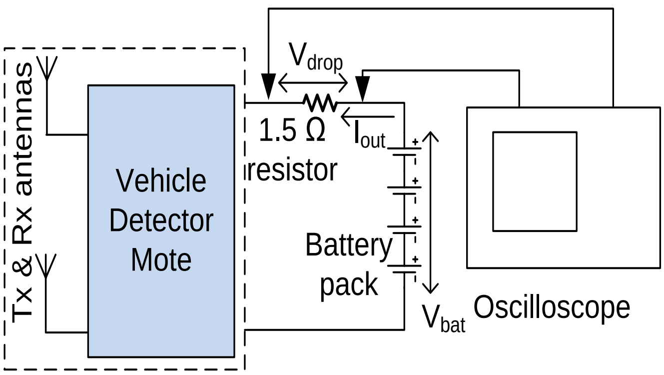

Figure 6. Experimental setup used for measuring the current drawn from the battery pack [9].

VIII. CONCLUSIONS AND FUTURE WORK

A. Conclusions

The primary aim of this paper is to implement a battery operated, compact system to detect and count the number of vehicles. A proof-of-concept system was designed and successfully implemented with one vehicle detector module, a remote data logging base station and a data logging software running on the PC. All the primary goals are successfully achieved.

The work done in this paper provides low cost systems development to the areas of transportation management and security applications. We hope it can provides a platform upon which future work in these fields can be based.

B. Future work

Clearly the immediate work should be implementing the vehicle speed detection using the received signal from the radar sensor module. Furthermore, there is a possibility to detect the length of the vehicle so that a better understanding of the type of the vehicles travelling on a road can be achieved.

Adding more vehicle detection motes and implementing a wireless sensor network will be another interesting application which will open up much more applications areas. Moreover, introducing a secured wireless data communication can be another important work for the future development of this work.

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