Development of low cost range sensing instrumentation for collision avoidance applications

Nicholas Stone, John Billingsley
National Centre for Engineering in Agriculture (NCEA),
University of Southern Queensland,
Toowoomba, Queensland, Australia.

Abstract
Vehicle collision avoidance and warning systems presently exist, however are generally extremely expensive and limited to luxury vehicles. This paper describes the design of a very low cost vehicle range sensor intended for the detection of tailgating vehicles and imminent collisions. The produced system is completed and has been pursued to a stage ready for manufacture. It is compact, low cost (less than twenty US dollars), and capable of measuring ranges between 5cm and 70m. Because of the very low cost and configuration flexibility of this device it has widespread applications not just in vehicle collision avoidance but potentially in mobile robotics and mechatronic systems.

Keywords:
Tailgating, headway, range, distance, sensing.

1. Introduction

Vehicle Tailgating is one of the most significant causes of rear-end collisions, yet it is a common driving practice on today's busy roads. The 'Two Second Gap' project was initiated with the goal of developing electronic devices that can be used to discourage tailgating. This paper presents the development of one such device, an in-vehicle low cost Tailgating Warning Sensor (TWS). This device warns a driver if they are tailgating, or if there is a collision imminent.

1.1 The Headway Concept

Tailgating is the practice of a vehicle following another with an insufficient distance, or headway to prevent an accident in the event of a sudden deceleration. Headway is defined as the time separation between two vehicles, or the time it would take for a following vehicle to reach the instantaneous position of a leading vehicle. Headway is measured as a time seperation as it is independent of the speed being traveled and is closely related to driver reaction time. To monitor the headway between vehicles from on one of those vehicles, two parameters must be known, the distance between the back of the lead and the front of the tail vehicle and the speed of the tail vehicle. Speed is easily measured using a wheel speed sensor, measurement of the inter-vehicle distance, however, requires complicated range sensing instrumentation.

1.2 Design Constraints

The predominant requirement of the TWS design was that it be able to be produced for a very low cost. It was recommended from the outset that ideally the manufacture cost for the final product should not exceed \$20-\$30US. This stringent costing requirement placed significant constraints on the design. To meet this criterion many currently available sensing systems which fulfilled the necessary functionality could not be used. Instead the design process had to return to first principles and perform a complete new design, ensuring all aspects met the costing requirement.

The TWS is a warning system only and has no direct control over the vehicle. Because of this the need for precision accuracy and reliability has been greatly relaxed. It is allowable for the TWS to fail to give warnings on instances when they are due. It is even arguable that this in moderation would be a desirable feature as it would help to reduce the drivers reliance on the device. Conversely the TWS should aim to never issue false warnings when they are not warranted as if this regularly happens it will cause the driver to question the validity of genuine warnings and may result in them being disregarded.

2. System Design

A typical range finding device will cost upwards of \$400US with most systems costing many thousands of dollars. We have been successful in creating an accurate range finding circuit for approximately \$20US. This significant cost reduction has been possible through novel design practices and extreme circuit simplification. The resulting design is compact, measuring only 27mm x 55mm, and uses only low cost componentry totaling 66 surface mount components.

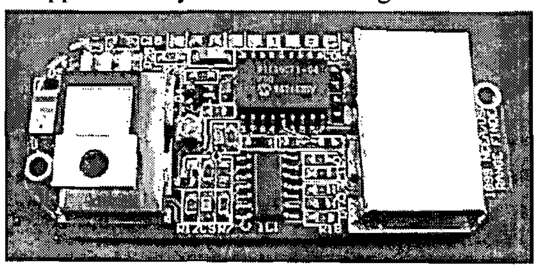

Fig 2.1 - TWS sensor board

2.1 Sensing Technique

After considerable research and experimentation it was determined to use the optical pulse time-of-flight range finding technique. Acoustical sensing techniques were discounted due to their failure to work in high wind and fast moving environments.

2.2 System Configuration and Operation

The tailgating warning system comprises a compact optical / electronic sensor which may be mounted either behind the windscreen or on the front of a vehicle. The prototype systems have an angled front face, which enables them to be adhered directly to the windscreen. The sensor contains two lenses that point directly forward ahead of the vehicle. Operation of the system is as follows. The device emits a pulse of light, which expands in a narrow conical beam. If a vehicle falls within this area then a reflection returns to the device. Due to the finite speed of light (3×10^8 m/s) the time between pulse emission and reception will be proportional to separation distance. This time delay, which is

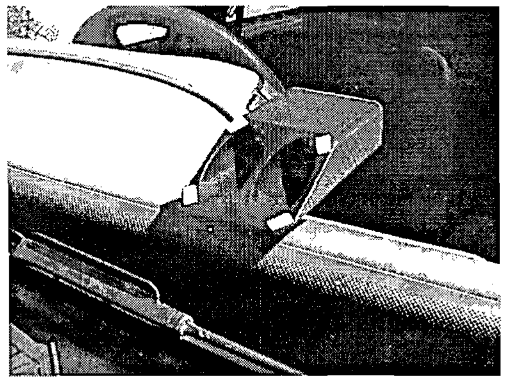

Fig 2.2 - TWS prototype mounted on the inside of a vehicle windscreen

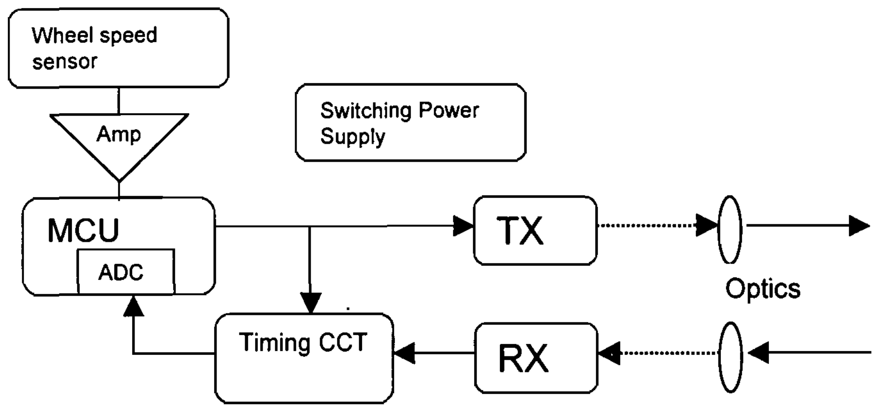

Fig 2.3 System block diagram

approximately 3.33ns/m or 6.67ns/m round trip, can be measured and used to calculate the distance. This distance measurement is then compared by a microcomputer with the current vehicle speed (measured from a wheel speed sensor) and preset headway warning distance. An audible warning is produced if the headway is deemed to be insufficient. The TWS will measure ranges between 0 and 70m.

2.3 Optical pulse transmission

The time-of-flight distance measurement technique requires the emission of a high energy light pulse with fast transition times. Typical range finding devices achieve this using a pulsed semiconductor laser driven by a discharge circuit. The TWS uses a similar circuit configuration, however it utilises a IR LED for emission. Although the LED has comparatively lower performance it is still satisfactory for this application and comes at a small fraction of the cost of a laser diode. To achieve the output amplitude and response speed required the LED is overdriven by factor of 100 times with a sharp short high voltage high current pulse. The pulse is generated by discharging a capacitor into the LED through a high speed avalanche effect discharge circuit. The discharge capacitor is 10nF and is charged to 60v. This results in a LED current of around 10 amps and a pulse time of 20ns. For increased performance a pulsed laser diode could be used in the place of the LED.

The LED utilised for the infra red pulse emission is being driven with a current approximately 40 times greater than its rated maximum level but for a much shorter pulse length than designated in the specifications. The emitter is able to withstand this overdriving due to the pulse being too short to create enough heat to destroy the junction. Reliability is a major concern when using a device this far outside its specifications. Unfortunately there is no easy way of calculating what effect this drive characteristic will have on the emitter lifespan. Instead a trial was undertaken to measure what effect a variety of input drive powers had on long-term emitter output. With the input power normalised to that which is used in the TWS the results are summarised by the following.

- 25 times input power resulted in an output degradation of approximately 50% after 24hours.
- 4 times input power resulted in no measurable output loss over a period of 10 weeks (1680 hours).

Seeing as 1680 hours operating time represents many years of normal vehicle driving, and even then with an increased power input there was no loss in output it was deemed that the LED's will have a satisfactory lifespan for the application. These tests were performed numerous times to ensure the results were repeatable. The LED's used were type HSDL 4230.

2.4 Reciever amplifier

The receiver circuit comprises of a high speed silicon PIN photodiode feeding into three high bandwidth NPN RF transistors. The first two transistors are arranged in a transimpedance amplifier configuration followed by a second stage of voltage gain. The transistors used have a low miller capacitance and therefore cascode configurations are not necessary. This receiver has extremely high gain and a typical rise time of 10-20ns which is satisfactory for the measurement accuracy required. The circuit layout used is optimised to prevent self oscillation and is shielded in a metal enclosure to reduce received electrical noise.

2.5 Timing Circuitry

The time interval between emission and receiving of the light pulse will generally be between 25ns and 400ns. To minimise cost a capacitor charging timing circuit is used to measure this interval; this is based around the NE521 IC. This device contains two comparitors feeding a configurable nand gate flip flop. A TX pulse will set the flip flop and arrival of the RX pulse will cause it to reset. While the flip flop is enabled, a capacitor will charge up to a voltage proportional to the time period and measured range. Figure 2.5 shows a timing diagram of these events.

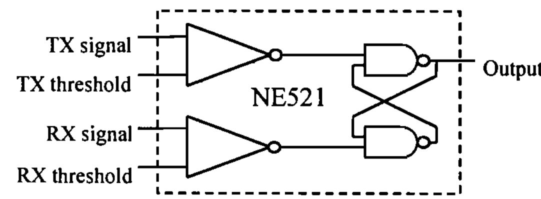

Fig 2.4 NE521 IC

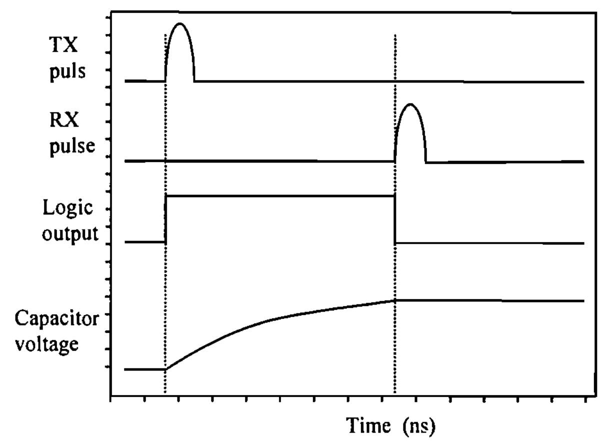

Fig 2.5 measurement timing

The capacitor in this configuration has a nonlinear charge characteristic which is compensated for in the software. This has the effect of giving a higher resolution at shorter distances and courser at the longer ranges. The charging circuit time constant is approximately 400ns. To clear the timing capacitor the ADC input pin is changed to an output and set low.

The TX and RX comparitor thresholds are at fixed levels although the RX threshold could be adaptive if required.

2.6 Microcontroller and Power Supply

A PIC16c71 microcontroller is used as the controll system to run the device. This processor was chosen for its low cost and low external component requirement. The MCU uses an external resistor and capacitor network to generate its clock. A variable resistor is used to vary the clock frequency which calibrates for the wheel diameter of the vehicle in which it is installed. Changing the clock frequency does not affect the range measurements only the wheel speed readings.

The instruction clock output drives the power supply switch mode inverters. The inverters will acceptably run on frequencies from 150 – 300kHz, which covers all the wheel size calibration ranges. Switch mode inverters are used to generate the +60v required by the transmitter discharge unit and –5v for the comparitors in the timing circuit. Each of these inverters comprise of a single inductor and a chopping transistor driven by the instruction clock of the microcontroller.

2.7 Wheel Speed Sensor

The TWS requires a pulse train signal with frequency proportional to vehicle speed. Most modern cars have a factory fitted speed sensor from which this signal may be derived. The prototype TWS systems use a Hall effect sensor mounted on the wheel hub which detects magnets mounted on the inside of the rim. The acquired signal is then amplified and fed into the microcontroller ADC. The comparison, hysterisis and detection are performed in the software to save on external components. Calibration for varying wheel diameters is done by adjusting the MCU clock rate, thus affecting its internal timing of the wheel pulse periods. A callibration mode in the microprocessor software allows this to be set correctly.

3. Optical Design

The TWS uses a fixed rather than a scanning sensing beam. The optics are designed so as to produce an expanding conical beam as the light travels from the transmitter. The purpose of this is so that when the target vehicle is further away there is still a good chance of acquisition even if the vehicle is not directly ahead of the TWS. At the longer ranges (>~30m) the TWS relies on a reflection from the vehicles retro reflective number plate. This generally provides a clean sharp reflection.

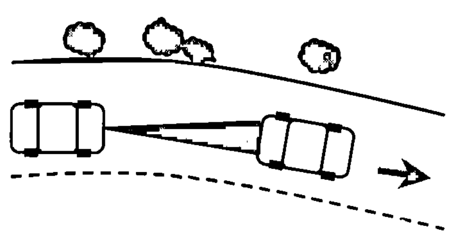

Fig 3.1 TWS field of view

4. Measurement procedure and detection algorithim

The TWS software takes up to 10 measurements per second. Each measurement is done as follows. Configure ADC pin as an input, enable light pulse, disable light pulse, read ADC, configure ADC pin as output and set low to clear the timing capacitor. The voltage read by the ADC is proportional to the distance of the target. This value is then compared with a threshold value read from a lookup table, depending on the current speed and set warning headway. If the read value exceeds the measured value then the warning is enabled.

To allow for momentary target losses from obstructions, such as the windscreen wipers, and to provide a certain confidence level against false triggering from spurious reflections, the following detection algorithm is used. Each measured range will increment a counter up to a maximum value of 5. A measurement with no target acquisition will decrement this count down to a minimum of zero. Warnings will only be enabled if this counter is greater than 3, ie 3 good target hits out of 5 or better. This algorithm provides excellent results.

5. The TWS range sensor in other applications

We have described a low cost sensor designed for vehicle range detection over a range of 0 to 70m. This sensor is equally applicable to mobile robotic based applications and may easily be reconfigured to suit the requirements. The optics can be changed to provide a narrow or wide beam and the timing circuit charging time constant can be varied to give a higher resolution but shorter range. A less than 5 cm discrimination is achievable over ranges of a few meters.

Acknowledgment

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