Intelligent Power Management Device for Street Lighting Control Incorporating Long Range Static and Non-Static Hybrid Infrared Detection System

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Abstract

Intelligent "street lighting", along with its immense energy saving potential, relies upon many factors, not least, the importance of maintaining useable levels of light for both vehicles and pedestrian traffic. One element in the establishment of such a regime is the development of sensory equipment capable of vehicle and human detection with a negligible degree of error. The paper proposes a hybrid long range passive sensory system based on both static (IR Photodiode) and non-static (PIR) sensors.

Introduction

With the development of the street light came also the accompanying energy consumption, and being an indispensable infrastructure much research is devoted to smart lighting systems and control. Efficient management, energy saving and safety within the lighting system are factors to take into account [1]. The advent of the WSN, (wireless sensory network) promise many variants for solutions to street lighting efficiencies [2], though this paper will deal specifically with the sensory aspects of the system.

Pyroelectric Infrared sensors (PIR) permit us to sense the motion of a hot body passing within and usually directionally across the range of the sensor. The range of the sensor is increased in normal circumstances with the introduction of a Fresnel lens which increases the range and detection angle, therefore amplifying the amount of IR received. The detection or viewing angle is generally from 90^o through 180^o with a standard range of 6 to 12 meters, rendering the PIR very useful in common motion detection applications such as security where used to detect whether a human has crossed into or out of the sensors range. Static infrared sensors however allow us to measure either by digital or photovoltaic methods the average radiation within an environment, or alternatively being emitted from a specific object. Predominantly the PIR sensor has been utilized also in street lighting scenarios and street surveillance cameras to set off a series of functions according to predetermined rule blocks, however the sensors used provide insufficient prior knowledge (event trigger) to the device due to the short range limitations of the sensors.

In order to obtain sufficient prior knowledge of an event trigger the detection range must be far greater than is currently available. Long range sensors exist within the marketplace, combinations of PIR and Microwave technologies, however they are prohibitively expensive and bulky solutions having a form factor around 150mm square and due to internal mirror construction, require individual adjustment for each installation. At the same time it is envisaged that it will not be necessary for installation of the proposed system at each pole of the street lighting array, but one every 100 meters dependant on existing specific pole separation.

Public safety remains the prevalent issue when the automatic brightening and dimming of lights is involved with a critical factor being the temporary blinding of a driver if lights are activated to full brightness in a very short time frame, or in the alternative removal of light at inappropriate times.

Reduction in erroneous errors is also of prime concern as the PIR detector is prone to activation from many sources, to name a few, the non-static movement of trees in the wind, various animals moving into the range of the sensors and even a sudden warm breeze may activate the sensors.

System model

The system model consists of the following parts being the PIR sensor, one passive IR photodiode, zoom lens, amplification and comparator circuitry (PIR and Passive IR) and the author has opted to utilise fuzzy logic methods for vehicle and human identification and error reduction due to the variance in the nature of received signals. The sensor prototype circuit includes a PCB mounted Dual PIR with a vertical topography (Fig, 1) as opposed to the horizontal topography used in standard motion detector applications. Together with a fixed IR sensor with λ of 700nm to 1100nm and spectral peak of 900nm, the model is able to capture moving vehicles or pedestrian traffic. Due to the extension of the angle of detection and the method of sensor signal amplification the system become bi-directional, enabling real time assessment of approaching or departing movement.
Preliminary observations have been performed with the use of an 8X zoom lens with a 9^{o} field of view, at 100 meter distance this represents 1.6 percent of a 1X area, giving the field of view as a cross section of road and pedestrian path only at approximately 100 meters. It is important to note that plastic lens give improved responsivity due to the IR dispersion qualities of glass.

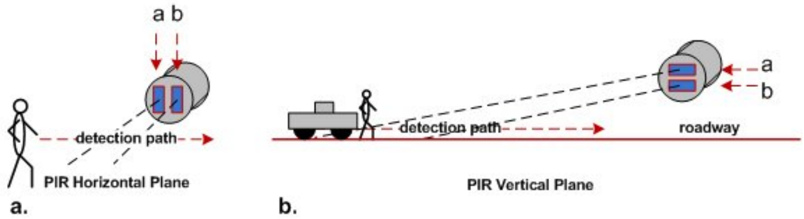

Fig. 1: Standard PIR motion detection and b. Vertical plane used within the model. Not to scale.

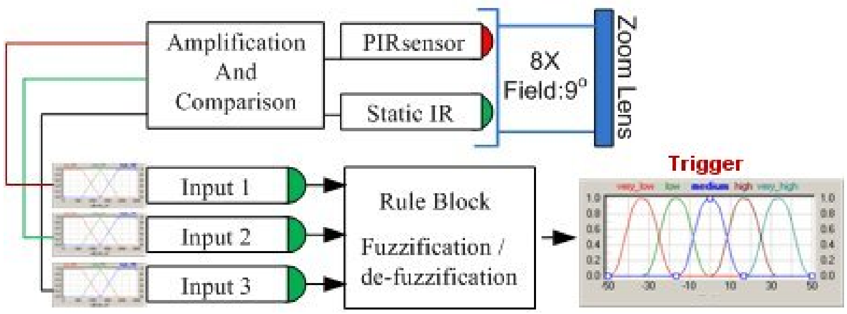

Fig. 2: System model

Considerations

When tuning the PIR sensor with the IR Photodiode it is necessary to apply an identical infrared source. This will ensure that both sensors produce a similar photovoltaic output from the amplifier, which is necessary from various aspects. Firstly, it will correctly identify because both sensors receive approximately the same view from the zoom, irrespective that the IR Photodiode will receive a static view and the PIR will transfer its view from the a) substrate to the b) substrate or vise verse. Fig, 3 below shows the configuration of the prototype board for easier understanding.

Fig. 3: Hybrid sensor board and off the shelf zoom 8X Field 9^o.

Responsivity

Being in effect, two small flat plate capacitors the PIR have a typical capacitance of 30pF. Insulation resistance is $5x10^{12}$ Ohms. PIR's are constructed using either a JFET source follower, for voltage mode or a trans-impedance amplifier to obtain current mode. The simplified equation found in Formula 1, allows estimation of the expected signal from a common PIR sensor. Where: I = from 0.5 to 1 micro-ampere per watt, R is the load or feedback resistor and C is the detector capacitance: Voltage mode = 30pF or Current Mode using stray feedback capacitance of around 0.03pF [3]. Further analysis of the Pyroelectric substrates, indicating the wavelength dependency of the voltage responsivity for different materials may be located at [3], though the following is adequate where amplification through transimpedence is utilized.

$$I * \left(\frac{R}{\sqrt{1+(2\pi fRC)^2}}\right) \qquad (1)$$

Wavelength amplification and comparison

To convert the photodiode current to voltage the prototype incorporates high sensitivity transimpedance amplifiers with a gain of around 10000, sufficient to amplify the received signals to the millivolt range. Output voltage as a function of incident light is linear over 7-9 orders of magnitude, and electrical response is dependent on the response of the detectors due to incident radiation across their substrates [3][4]. The circuitry in (Fig, 4) enables both amplification and trigger definition, (a – b) or (b – a) of the two PIR substrates allowing bi-directional knowledge of a triggered event. The modified PIR sensor, necessary for correct operation of the device may be found in detail at [5].

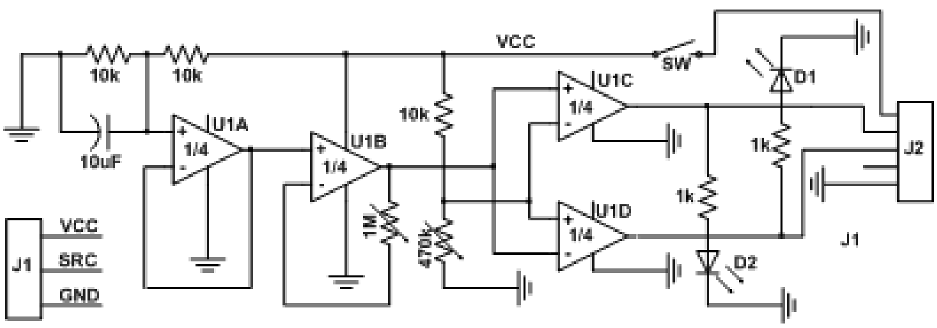

Fig. 4: Amplification and comparator circuit.

Indications of direction, where forward motion is indicated with a positive first half cycle response and reverse motion is indicated with a negative first half cycle response, determines the appropriate output from the microprocessor and peak to peak timing allows accurate calculation of velocity as in (Fig 5).

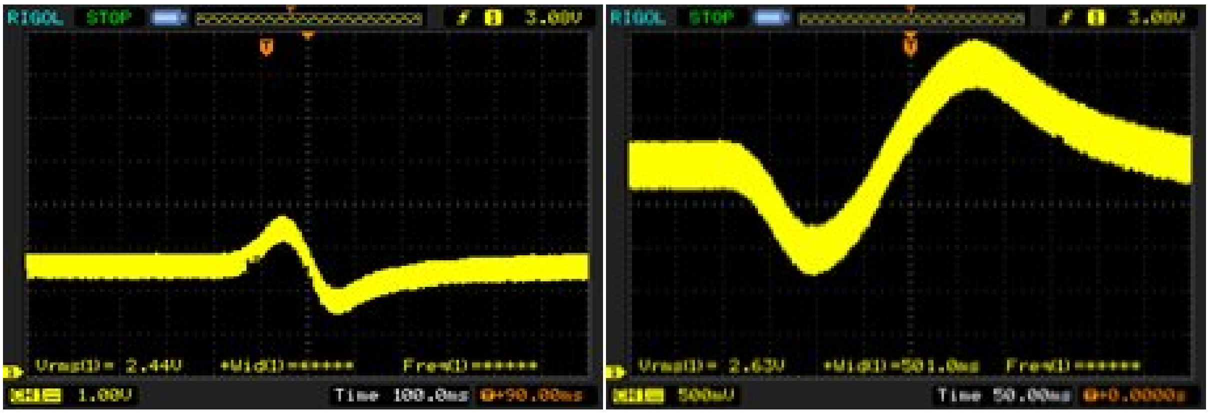

Fig. 5: Sensor activation a ~ b, (forward triggering), with positive first half cycle and b ~ a, (reverse triggering), with negative first half cycle.

Realizations

The PIR sensor is essentially split into its two substrates and in this configuration allows bi-directional reading plus two readings of radiation sensed (a positive followed by a negative) and is mounted on the vertical axis as in (Fig, 1). The second IR sensor input is static and used as a comparison to make certain assumptions. For example:

1. A bird flies across the path of both sensors. The result could be that the PIR sensor triggers, producing a photovoltaic reading of 20mV, however the IR Sensors reading is negligible, therefore the system does not register a trigger response
2. A large tree is swaying in the breeze, The PIR registers a thermal change across its substrates triggering a lesser response than example 1, say 10mV, however, again the IR Sensor registers none, no trigger.
3. The PIR registers a vehicle across its substrates with an amplified signal of 50mV, however the registered signal has produced a (ba) result, the IR sensor also register a 50 mV signal, however the system will not trigger because a (ba) signal indicates a vehicle departing the area.
4. The PIR registers a vehicle across its substrates with an amplified signal of 50mV, the registered signal has produced a (ab) result, the IR sensor also registers a 50 mV signal, the system will trigger because an (ab) signal indicates a vehicle is approaching the area.

Fuzzy membership model

The scheme required three variable in each of the four input arrays, with an output array, (Trigger_Event) having five variables for more accurate result. A use of linear, triangular functions were utilized in line with a requirement for simplicity in modification and high speed computation. The resultant Rule Block (Table I) consists of 405 individual rules enabling a suitably "smart" system. Three of the rules have been reproduced in (Table I) as an example of method used.

Table I: Selection from rule block

if	*and*	*and*	*and*	*operand*	*then*
PIR_Seq_AB.high	PIR_Seq_BA.low	mV_Pos.med	IR_Static.high	=>	Trigger_Event.high
PIR_Seq_AB.low	PIR_Seq_BA.low	mV_Pos.low	IR_Static.high	=>	Trigger_Event.low
PIR_Seq_AB.low	PIR_Seq_BA.high	mV_Pos.high	IR_Static.med	=>	Trigger_Event.low

Four sets of functions (Fig, 6) were created to express degrees of membership for the two sensors, having a membership from 0 to 1. The crisp values of the input functions are represented in millivolts in a range of 0mV to 100mV with an expected mean of 50mV. Currently with the completion of the latest prototype (Fig 7.), these original finding are proving to have less range with values from 0mV to 50mV indicating the system with its newer design is more evenly balanced across its substrates.

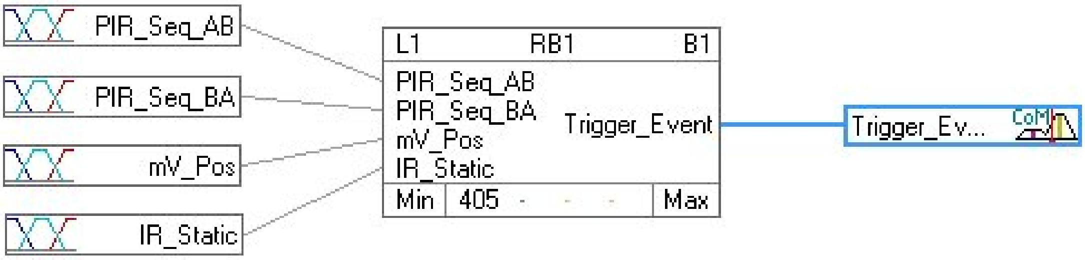

Fig. 6: Fuzzification, de-fuzzification at the output block.

Fig. 7: The most recent prototype displaying smaller form factor, advanced optics and an appreciatively increased sensitivity.

Results and conclusions

There has been no physical installation of the system as yet in a real world environment, all measurement as described herein are the results of hands on measurement of amplified signals, monitoring zoomed IR effects across a suitably wide courtyard, and along a neighbouring street. There has been some uncertainty in the Lens development with a wide range of sensitivities being recorded. This is due in the main to reliance on the use of stock lenses which are inexpensive and not task specific. Stage two of the project will involve development of the necessary suitable optics required. With that said, the system appears stable and robust and certainly worthy of further investigation as an iPM Device.

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