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MICROPROCESSOR BASED LIGHT BRIDGE SENSORS

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Modern photoelectric proximity sensors typically employ the use of a pulse modulated IR beam, a photodetector, amplifier, synchronous demodulator, and comparator to generate an output signal that indicates the presence of an object in the sense field (Figure 1). While these types of photoelectric controls generally work to acceptable performance levels at reasonable cost, they generally require a manual adjustment and high gain optics to achieve reasonable sensitivity and dynamic range. Adjustment is usually performed by setting amplifier gain; sometimes this is performed with an AGC circuit. The use of an amplifier gain adjustment has the drawback of limiting sensitivity and dynamic range under many normal operating conditions.

For example, a nearby background object in the path of the IR field normally requires the reduction of amplifier gain, whether manual or automatic. However, this very gain adjustment causes a reduction in differential sensitivity to less reflective or more distant objects to be sensed. High gain optics on the other hand invariably result in collimation of the emitted IR field and a corresponding restriction of the field of view of the photodetector.

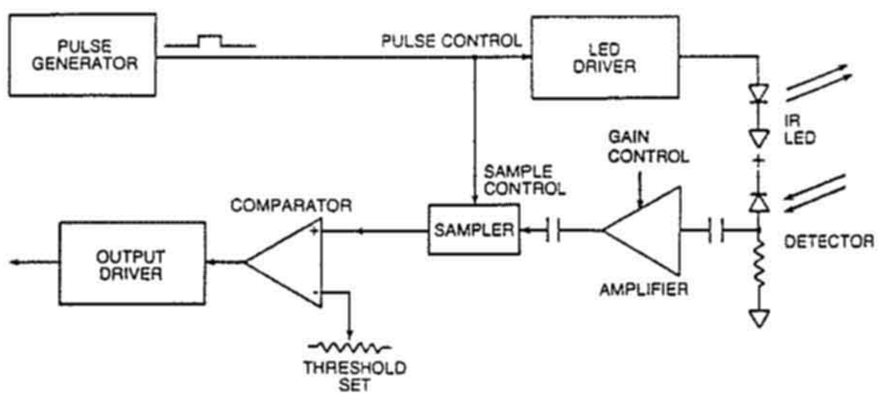

Figure 1. *Block diagram of a typical conventional photoelectric proximity sensor.*

While modern photoelectric controls employ modulated IR fields which can be easily discriminated from ambient light effects, modulating does not resolve the issue of detector nonlinearity, especially at low light levels and high amplifier gain settings. Changes in ambient light levels can alter photodetector gain, causing false detections to occur.

Modern photoelectric proximity controls thus have a very limited working dynamic range, i.e. a poor ability to discriminate small return signals from large background signal levels. They also have a restricted field of view, typically with sensing cone angles of only 1 to 5 degrees. There are many applications where very wide angle sensing would be useful. Modern photoelectric sensors also lack the ability to automatically adjust for changes in background reflections. If the static environment in the field of view of a photoelectric sensor changes, conventional sensors will not adapt, causing sensitivity shifts and/or false detections. Finally, conventional sensors are ultimately limited in sensitivity by detector nonlinearities in many situations.

1. DESIRED IMPROVEMENTS IN PHOTOELECTRIC SENSING

The desired objects of improvement in the state of the art of photoelectric proximity sensing thus include:

1. Increased sensitivity through high differential gain.
2. Lensless operation to permit wide angle sense fields.
3. Automatic background cancellation without reduction of differential sensitivity.
4. Automatic adaptation to background shifts on a continual basis.
5. Elimination of photodetector gain shift effects caused by ambient light.
6. Reasonable power consumption without undue component stress.

To achieve these goals, we propose a new form of sensor architecture, which we call a "light bridge". This form of sensor behaves very much like a Wheatstone bridge in the sense that at the photodetector, a null occurs just as in a Wheatstone bridge a null occurs across the meter when the two legs of the bridge are in balance. However, the light bridge is an AC system, whereas the Wheatstone bridge is a DC system (Figure 2).

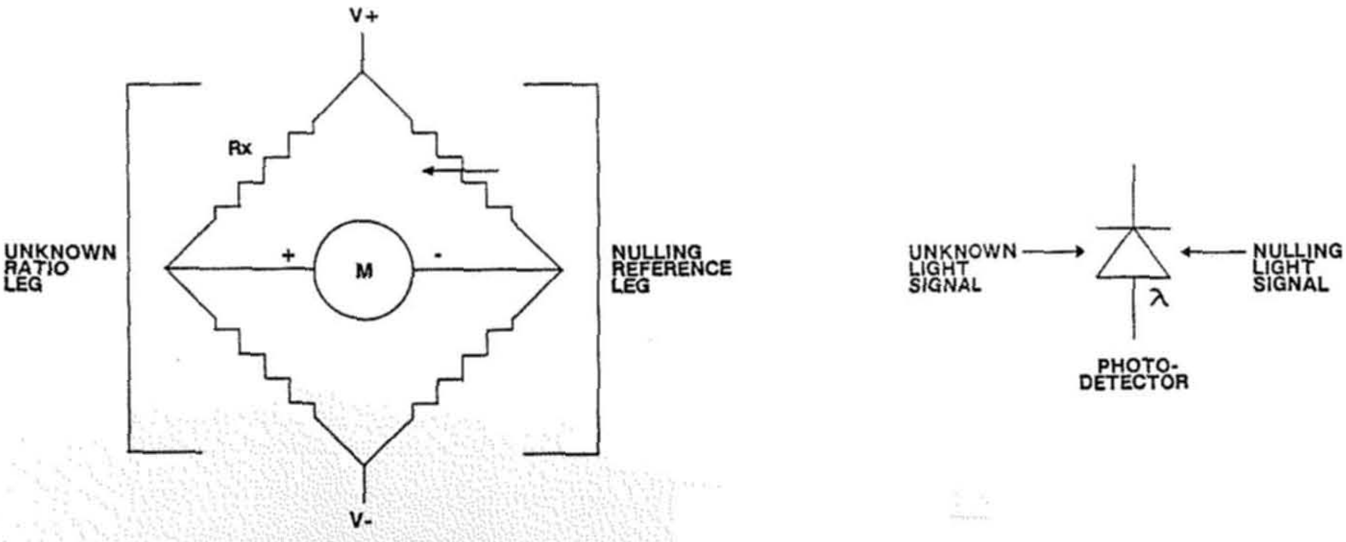

Figure 2. *Comparison of Wheatstone bridge to light bridge. Output of photodetector is AC coupled prior to amplification.*

2. OPERATION OF THE LIGHT BRIDGE PRINCIPLE

The output of the photodiode is AC coupled, amplified, and measured for further analysis. One unique aspect of the light bridge concept is that the nulling light signal is capable of cancelling even very high received signal levels, just as the Wheatstone bridge is capable of achieving a null with high resistance ratios. This results in high differential gain even at high absolute signal levels. This should be compared with conventional sensing technology where high signal levels require actual reductions in gain to achieve operation without amplifier saturation. The bridge concept allows the elimination of an AGC circuit entirely as will be shown. The nulling method permits the cancellation from view of large reflectances associated with background objects, while permitting full sensitivity to smaller, more distant, or less reflective objects (Figure 3).

The effect of nulling is accomplished by directing towards the photodetector a beam of light modulated 180° out of phase with the light emitted by the primary proximity field illuminator. In sensors built using the technique, the primary field illuminator emits 12 microsecond IR pulses; the nulling LED is normally on but is shut off for 12 microseconds coincident with the emission of the illuminator pulse (Figure 4). The photodetector acts as a summing junction to add the two signals. Since the signals are phased complementary to each other, the AC sum at the detector becomes the difference in magnitude of the AC components of the two signals. If both received signals are equal in magnitude, AC cancellation occurs and the resulting signal is merely a DC component easily blocked by a capacitor.

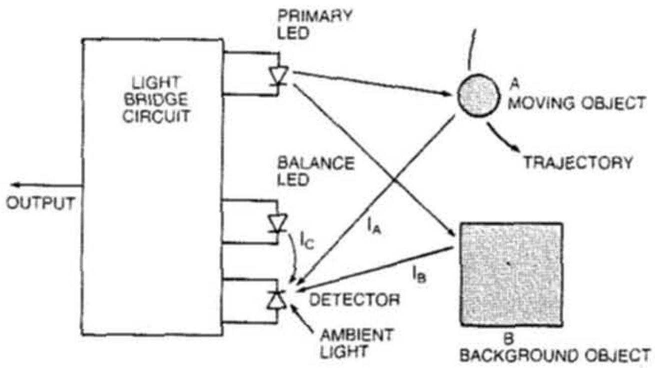

Figure 3. *A balance or nulling LED is used to cancel reflected signals which one desires to ignore, such as from a large stationary background object. Differential signals from smaller objects are easily detected.*

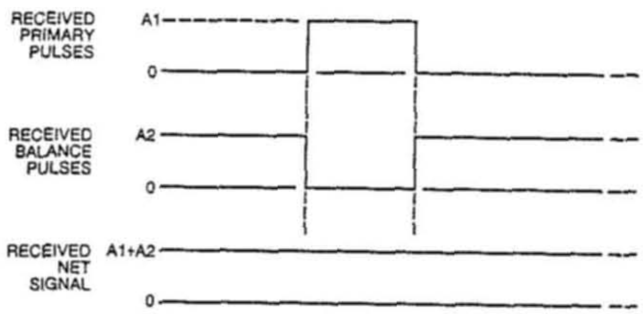

Figure 4. *Waveforms of light flux received from the primary LED and the balance, or null LED. When a null is achieved, the net signal shows no pulse component as shown.*

The resulting AC signal is amplified with a fixed gain of typically 95dB, and is subsequently demodulated by a synchronous pulse sampler to produce a DC signal that corresponds to the net detection signal (Figure 5). The DC signal may be further processed by digital filtering in a microprocessor to reduce amplifier and photodetector noise effects, and then thresholded to produce an output signal. An intriguing aspect of the nulling process is that two thresholds may be used, one above and one below the zero net signal level (Figure 6) to achieve detections if the net signal deviates either higher or lower. Four thresholds may be used, two above and two below the zero net signal level to achieve a hysteresis effect in both directions of possible signal change.

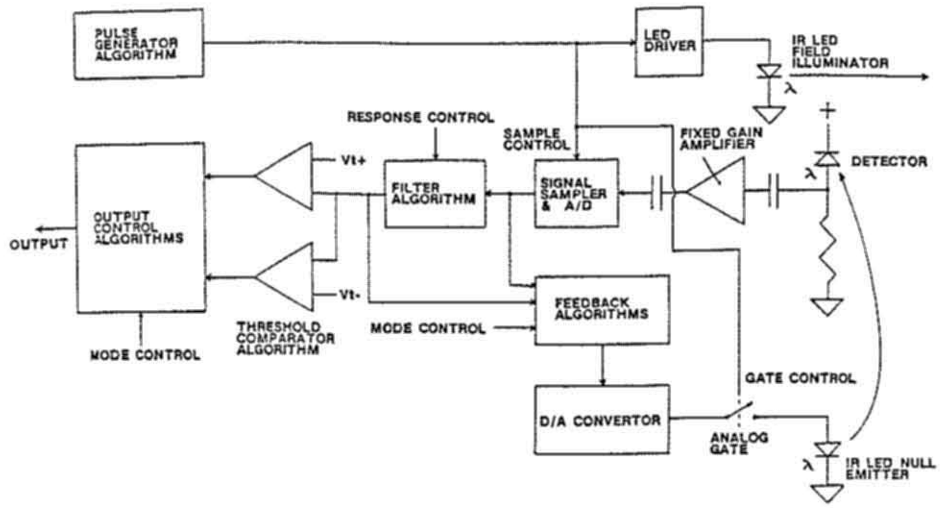

Figure 5. *Control flow diagram of a microprocessor based light bridge sensor. Diagram shows both hardware and software implemented functions. All elements shown as algorithms are incorporated into the ROM of a single chip microcomputer.*

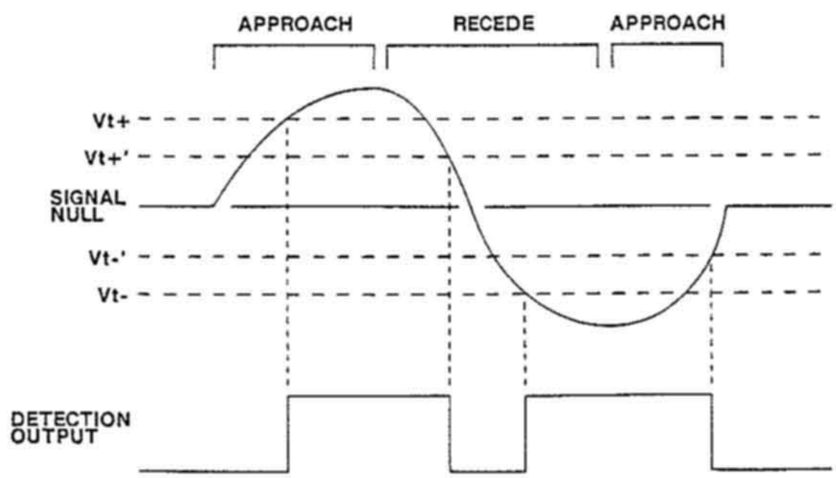

Figure 6. *Waveform of signal from a previously nulled object in the sense field that suddenly approaches the sensor, then recedes from the sensor, then returns to its original position. As signal levels cross the thresholds Vt+ and Vt-, a detection output is generated. Vt+' and Vt-' provide hysteresis for clean switching. All threshold comparisons are performed in software.*

Since nulling is accomplished at the photodetector itself, one of our goals, the elimination of detector nonlinearity effects, is achieved. This occurs because at the signal null point, the detector ideally sees no net signal at all. Nonlinearities can only have an effect when a net signal is present. Since there is no signal there is no change in signal amplitude when the photodetector's gain changes, for example due to low to high ambient light changes. Because of this, the threshold settings can be set very close to the zero signal level without fear of false detections.

Since amplifier gain may be held constant and may be set very high without fear of saturation, we achieve one of our other goals: high differential gain and hence sensitivity. This leads to the fulfillment of another goal: low power consumption, since the IR illuminator does not need to be driven hard to achieve respectable sensing ranges; typical average illuminator LED current is 30 milliamps for ranges to 3 meters, and 5 milliamps for ranges to two meters. High differential sensitivity also enables another goal: the permissible use of wide angle, lensless optics to enable volumetric detection patterns. The nulling process itself, if controlled through intelligent algorithms, gives us the final two goals: automatic background rejection and automatic adaptation to background signal level shifts.

The nulling effect is controlled by a feedback path from the detected signal level to the nulling IR LED (Figure 5). This path causes the amplitude of the nulling LED to be adjusted to achieve the cancellation effect. The feedback may be manipulated to achieve different sensing modes as will be described later. In the microprocessor implementation described here, the feedback is set digitally with an 11 bit digital to analog converter. The usable dynamic range of the cancellation effect is 63dB. Higher resolution D/A converters may be used to increase this range.

Signal detection, averaging, and thresholding is all accomplished internally in the microprocessor. Signal sensitivity is less than 1 nanoamp of photodetector current to cause a valid detection with a 20 millisecond response time. With no external optics, and using a very wide angle photodetector (Siemens SFH205), this translates into a usable range of 3 meters. Much larger ranges are possible with lenses.

3. OPERATIONAL MODES

The combination of the use of light nulling, high amplifier gain, and a microprocessor as an active signal processing and control element allows considerable flexibility in selecting different operating modes. The developed sensor incorporates two fundamental operating modes, motion and presence sensing, and several mode modification options.

In motion mode, the microprocessor acts to continually adjust the nulling feedback signal when objects enter or recede in the sense field. This forms a 'true' photoelectric motion detector, unlike most conventional detectors that simply provide a one-shot output. The sensor incorporates both upper and lower thresholds, so that detections may be registered on entry or exit of an object, or both.

In presence mode, the microprocessor acts to null background reflections when the sensor is powered up, and then 'locks' the feedback setting to prevent further feedback adjustment. When an object enters the sense field, an increase in signal that causes the upper threshold to be exceeded will result in a detection output. If a low reflectance object enters the field against a more reflective background, a net signal decrease may result, causing the lower threshold to be crossed. Again, either upper or lower thresholds or both may be selected. The nulling process may also be repeated after power up via an external control line.

This ability to detect any change in signal, either positive or negative, is a unique attribute of the light bridge concept that can be used in a variety of difficult sensing situations.

One sense option made possible by feedback locking is a 'learn' mode. If only the upper threshold is enabled, and an object is placed in the sense field prior to power up, a fixed comparison point is set at which output triggers will occur. For example, in sensing objects on a conveyor belt, if a sample object is placed a distance in front of the sensor prior to power up, the object will be cancelled from view and the feedback required to perform the cancellation will be permanently locked in place. Should a similar object come a small distance closer to the sensor the resulting increase in signal will cause a detection to occur.

If the background becomes dirty over time and its reflectance decreases, it would be desirable to alter the feedback to compensate for this in a transparent way. This automatic background adaptation is accomplished in the microprocessor with an algorithm that slowly adjusts the feedback level as the background changes, without causing a detection. There are many other real world situations where background shifts, IR LED illuminator aging, etc. interfere with photoelectric proximity detection and normally require manual intervention to correct. The light bridge concept coupled with intelligent algorithms is fully capable of automatically compensating for such phenomena.

4. SAMPLE APPLICATIONS

As an example of an application previously unsolvable by conventional photoelectric technology, consider an automatic sliding door as may be found in a grocery store or airport (Figure 7). Such automatic doors in the past have employed photoelectric safety beams which cross the door horizontally. A person standing in the door would normally break the beam and thus cause the door to be held open. In many situations this does not work, for example when a small child not tall enough to break the beam enters the doorway. In an actual application developed for a company and soon to be marketed, light bridge sensors positioned above the doorway and aimed down emit elongated, fan shaped safety sense fields on each side of the door. The emitted IR fields simply strike the floor. Because of the light bridge nulling effect, the floor itself is automatically cancelled from view; the sensor acts as though the floor does not even exist. Very slight disturbances in the fields will cause a presence mode detection and thus cause the door to hold open. If the floor changes reflectance slowly over time, for example due to dirt accumulation, the sensor will automatically compensate. If an object is permanently placed in the sense field, for example a new door mat with a radically different reflectance, a detection will occur but after a delay of 30 seconds or so software will cause a new null process to occur, and the mat will be ignored.

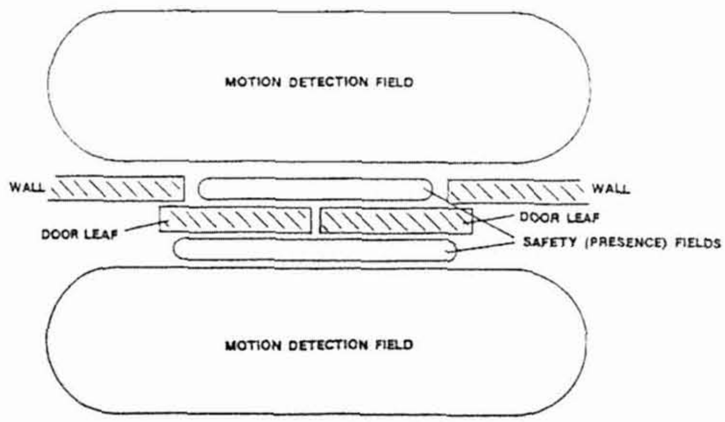

Figure 7. *Plan view of a dual leaf sliding door. Two light bridge sensors detect motion to open the door, and two detect presence to prevent the door from closing on people.*

Shown also in the figure are light bridge based motion fields used to detect oncoming traffic to cause the doors to open. These motion fields are considerably less expensive than existing microwave based sensors, require no government approvals, have better (i.e. wider) detection patterns, respond better to nonconductive objects, and have better environmental resistance. This application would not have been practical or economical without wide angle photoelectric sensing and without the characteristics and intelligence of the microprocessor controlled light bridge.

Another application for the light bridge is in fiber optic sensing (Figure 8). It is well known that optical fibers when bent will lose some of their light energy; in essence an entire fiber may be used as a simple displacement transducer. A practical sensor that operates over a wide range of fiber length and loss with consistent performance is relatively difficult to construct, especially if manual adjustments are undesirable. A light bridge can be used to intelligently sense fiber loss as a percentage of signal level, regardless of fiber length, automatically. The percentage of loss required to cause a detection may be selected by the user. If a fiber connector suddenly becomes lossy, a detection will occur due to the reduction in coupled light, but an adjustment in nulling feedback can quickly adapt to the new loss to resume normal operation, as though the lossy connector did not exist. Applications for such a device include intrusion security sensing, industrial motion sensing, pressure sensing, impact sensing, and many others. Currently under development is an inexpensive magnetically sensitive fiber transducer that can replace magnetic reed switches in a fiber loop incorporating many such transducers; these switch replacements will find use in security protection systems and industrial control.

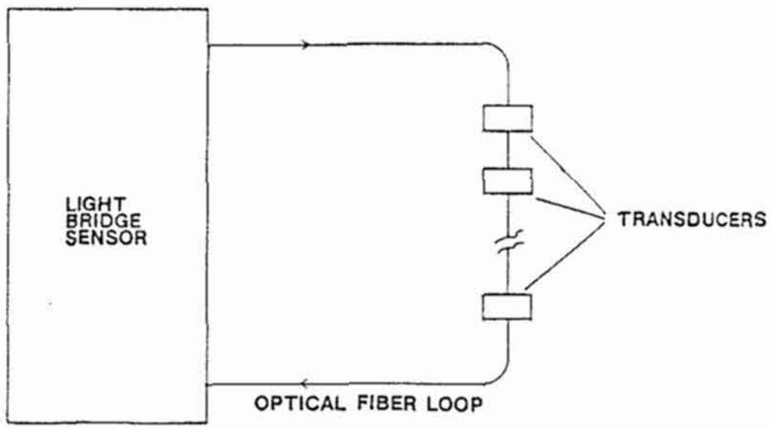

Figure 8. *Optical fiber sensor. The light bridge allows the sensor to automatically adapt to changes in fiber length, connector losses, etc. yet respond to very small changes in fiber attenuation caused by bending or special optical transducers.*

The light bridge technology is covered under U.S. patent 4,736,097, with other U.S. and foreign patents pending. Light bridge sensors can be manufactured for under $20 in commercial volumes of 1,000 pieces; some simplified versions can be made for under $12. We anticipate that the basic principle of operation will find use with other energy field types as well such as magnetic, capacitive, and RF sensing.