OPTOELECTRONIC SYSTEM FOR RELIABLE DETECTION OF DOCUMENT PRESENCE

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Abstract - *This paper presents the implementation of optoelectronic subsystem for reliable detection of document position in the system for scanning when strong light background and reflection are present. It contains analysis of commonly applied position sensing technology, descriptions of the subsystem concept, main functional blocks and control interface. Special attention has been paid to the optimization of detection parameters with accent on the reliability of detection. The subsystem for detection of document presence has been implemented and successfully integrated in the system for document scanning. This subsystem can be used for reliable detection of the presence of many other objects when it is required that it should be placed in sealed enclosure along with other parts of scanning system, separated by glass window from the object.*

Key words - *position sensor, proximity sensor, optoelectronic detector, IR light, phase-locked loop*

1. INTRODUCTION

Needs for position sensors are growing by leaps and bounds, and the sensing technologies used are as varied as the applications. Every commonly applied position sensing technology has its own characteristic benefits and limitations. Obviously, some of these technologies provide a better fit than others in different applications and environments and sometimes, specific requirements in applications demand for additional modifications of sensing techniques in use. Optoelectronic system for reliable detection of document presence, presented here, is one such example.

In a mobile system for scanning the contents of the document it is needed to detect presence of the document in exact position, so the scanning process can start automatically. Beside document presence, document absence also must be detectable to prevent multiple scans of same document. The system is in almost hermetically sealed enclosure, which shouldn't be changed, and the document is scanned through a glass window by means of the cameras, lights and radio waves. Before scanning, the document is slid over the window until its terminal position is reached. Position sensor needs to be reliable and its parts must not obstruct the view of cameras and lights. Since the system is battery operated, sensing system also must be low power consuming.

Use of standardized components with standardized footprints is preferable compared to integrated modules due to future availability and longevity of PCB design. Detection system is going to be designed as a peripheral module which is controlled with microcontroller already present in the system. It is also known that approximate range of document dimensions is from one third to double size of the glass window and that there are large variations of document thickness.

The goal of this paper is to present one possible implementation of optoelectronic subsystem for reliable detection of document presence in system for scanning (reading) the contents of the document.

Decision to use optoelectronic sensing technology is explained in the second section. In section 3 is presented the concept of new reliable system for document presence detection and its hardware implementation. Optimization of detection parameters and methods for increasing reliability of results are shown in section 4. In the last section are summarized achieved results and suggested possible future improvements.

2. SELECTION OF SENSING TECHNOLOGY

This section contains short review of position sensing techniques in use and, considering the requirements described in section 1, explains why optoelectronic method is selected for this application. Detailed information about position sensing techniques can be found in [1] and [2].

Position sensors provide position feedback. They detect a target object, a person, a substance or the disturbance of a magnetic or an electrical field and convert that physical parameter to an electrical output to indicate the target's position. Sensing of presence of material is known as proximity detection and it is often, directly or indirectly, used for position sensing. Position and inherently proximity sensors can be divided in two groups, contact and contactless sensors.

Some position sensors, such as limit switches, involve physical contact with the object being sensed. These are called contact position sensors. Contact position sensors often prove to be the simplest, lowest cost solution in applications where contact with the target is acceptable or physically possible. This method is useful only for objects whose mass is enough to operate the mechanism. Since microswitches are electromechanical contact devices, they are also prone to "wear-out" due to physical contact. Since all parts in the application must remain inside enclosure, contact sensors are out of the question for the application of interest.

Sensor manufacturers have employed a much wider variety of approaches and technologies to develop non-contact position sensors, which have no physical contact with target objects and don't "wear out" from repeated contact.

Magnetic properties can be used to determine position by detecting the presence, strength, or direction of magnetic fields. A Hall effect device derives its output from magnetic field strength. Hall effect position sensors are very affordable and accurate. When subjected to a magnetic field, a Hall sensor responds with an output voltage proportional to the strength of the field. The output signal is very weak and additional electronics is required for signal conditioning. These signal-conditioning electronics are combined with a Hall element on an integrated circuit (IC) to form a basic Hall effect sensor. Some of the advantages of Hall effect sensing devices include their long life and high speed. They operate with stationary input (zero speed), and have a broad temperature operating range. If Hall effect sensor would be used in the application, an object could be detected through enclosure walls, but external magnet would have to be used, what would be unacceptable, due to the technical requirements.

Ultrasonic sensors operate by exciting an acoustic transducer with voltage pulses, causing the transducer to vibrate ultrasonically. These oscillations are directed at a target and, by measuring the time for the echo to return to the transducer, the target's distance is calculated. Since the ultrasonic beam is a sound that propagates through the air, it is affected by air movement, air humidity and air temperature. Use of ultrasonic sensor in our application is not possible, since it cannot detect an object through the enclosure glass window.

Inductive proximity sensors detect all metals, ferrous metals only, or non-ferrous metals only. They operate on principle that the inductance of a coil is considerably changed in the presence of a metal core. The coil can be part of a bridge circuit or the inductor in a tuned oscillator. The presence of a metal close to the coil will thus cause a bridge output offbalance condition or a change in the tuned frequency that can be sensed. The use of light metal foils as contacts to a non-metal can make it possible to use inductive sensors in a range of applications for which they would at first sight be rejected. The sensitivity is quoted in terms of average sensing distance for an object of mild steel and, depending on the type of detector, this distance is of the order of 0.8 to 2 mm for mild steel. Other metals lower the sensitivity. This technique would have even more problems in the application than using Hall effect sensor. Beside the need for external part (a metal foil), sensor would have to be mounted very close to the enclosure wall, near the document, because of its low range. Since the document can be smaller than the glass window, detection must be done through it which would in turn obstruct the view of cameras and lights for scanning.

Capacitive sensors detect all materials. Capacitive sensing proximity detectors make use of the stray capacitance that exists between a metal plate and ground, a quantity that can be altered by the presence of non-conducting material as well as by either grounded or isolated conducting material. As before, a resonant circuit detection method can be used. A notable feature of capacitive proximity detectors is that the detectable range is much higher than it is for the inductive type. However, the ranges much depend on the size and shape of the object being sensed as well as on the material. If capacitive sensor would be used in the application, no external parts would be needed, but it would have to be in contact with the glass window obstructing view of cameras and lights for scanning.

Photoelectric sensors respond to the presence of all types of objects, be it large or small, transparent or opaque, shiny or dull, static or in motion. They can sense targets from distances of a few millimeters up to 100 meters. Photoelectric sensors use an emitter to produce a beam of light that is detected by a receiver. As a light source most often Light Emitting Diode (LED) is used. The light beam, which may be infrared, visible red or green, is switched at high currents for short time intervals so as to generate a high-energy pulse to provide long scanning distances or penetration in severe environments. Pulsing also means low power consumption. The use of infrared light is less likely to suffer from interference from other light sources. To protect the beam of light from the distortion, it is necessary to modulate LED excitation.

The receiver contains a phototransistor that produces a signal when light falls upon it. A phototransistor is used because it is more sensitive than equivalent photo diode, it has the best spectral match to the LED, a fast response, and is temperature stable. If much faster response is needed, photodiodes can be used instead, but they need more interface electronics. By tuning the receiver circuitry to respond to a narrow band around the LED pulsing frequency, very high ambient light and noise rejection can be achieved. Tuning the receiver to respond only to a specific phase of the pulsed beam can further enhance this effect. For building into new equipment, combined LED and photosensor units can be obtained at very low prices, allowing the designer to use whatever amplifying and relay system is preferred.

There are different scanning techniques available for optoelectronic position sensing system. Optical beam proximity detectors can use through-scan, with one source and one receiver aimed at each other, retroreflective-scan, with one combined source and receiver used with mirror and diffuse scan, making use of combined source and receiver with light reflected from the object itself. The through-scan and retroreflective types depend on the object breaking the beam, but the diffuse-reflection type can be used to sense the approach of an object along the beam (head-on mode) as well as cutting the beam (slide-by mode). Diffuse mode is used in cases where it is impractical to use a reflector, due to space considerations or when detection of a specific target is required. Because the reflected light is diffuse, a cleaner environment is necessary and scanning distances are shorter. The maximum scan distance of a diffuse-scan sensor is rated to a 10 × 10 cm white card. If the actual target is less reflective than a white card, the scan distance will be reduced and vice versa. The specified scanning distance for a photoelectric sensor is the guaranteed minimum operating distance in a clean environment. For retroreflective units, this distance is that obtained using a reflector of 100 percent efficiency. For diffuse units, this distance is that obtained using white Kodak paper with specified dimensions, usually 10 × 10 cm. Use of other materials affects the diffuse scanning distance (Kodak white paper 100%, Aluminium 120-150%, Brown Kraft paper 60-70%).

According to the requirements described in section 1, optoelectronic technique for detection of document presence best suites the application. Source and receiver of light can be mounted in place inside enclosure far below the glass window level not to obstruct the views of scanning cameras and lights. It is possible to detect the document through the glass window without any external part. Also, detector light will not influence scanning lights and imaging since detection and scan periods are successive, not overlapping.

3. SYSTEM IMPLEMENTATION

To gain the information of object (document) presence at exact position LED and photo-transistor have been positioned in such a way that reflections of the object (document) exist only when it is in its terminal position. For the purposes of higher reliability of detection and resistance to interference with other light sources modulation of light has been applied and an infrared LED has been selected. Arrangement of optoelectronic components is shown in Fig. 1.

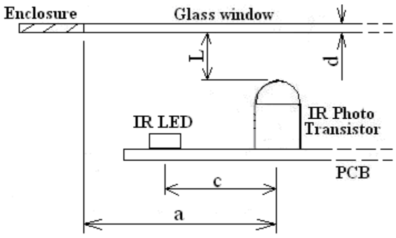

Fig. 1. *Mechanical configuration of the optoelectronic components*

IR LED is used as an emitter of light and IR phototransistor is used as a receiver. For the purposes of this application, both emitter and receiver are positioned in the corner of the glass window which is terminal position for approaching document. Beside their positioning, better precision is achieved using phototransistor with narrow angle of directional characteristic. According to Fig. 1, signal detected with IR phototransistor contains information about reflections from the inner and outer edge of the glass window, reflection from the object when it is present and external noise from infrared sources in surrounding. False reflections from the glass are expected, but it is presumed that they are of less power than the ones reflected from the object above the glass when it is present. Through the processing of received signal it is possible to distinguish reflections from the glass from the reflection of the object. Tests carried out on many typical document samples show that their reflectivity is higher than reflectivity of the transparent glass.

For the purposes of reliability of detection and resistance to external noise (such as sunlight, ambient light and from incandescent or fluorescent lamps), IR light is chosen for optoelectronic detector which is additionally frequency modulated. IR light is also pulsed, so low power consumption is achieved. Analog phase-locked loop (PLL) is selected as the core of the system [3, 4]. Tone generator of PLL is used as frequency modulator which pulses the IR light at selected frequency by the means of LED and its driver. LED driver provides proper electric current for LED so that intensity of light reaching phototransistor after reflection from the object is sufficient for circuit operation. Phototransistor with its load is essentially used for detection of IR light reflected from objects in its viewing area, but its secondary function is gaining information about background IR light. Block diagram of the detection system is shown on Fig. 2.

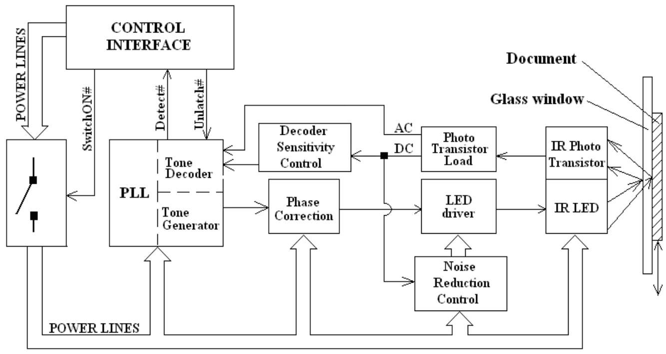

Fig. 2. *Block diagram of the system for detection of document presence*

Phototransistor provides signals of reflected modulated IR light (shown as AC in Fig. 2.) and of reflected background IR light (shown as DC in Fig. 2.). Tone decoder of PLL is used as frequency demodulator to detect only IR light with selected frequency same as of the tone generator and with amplitude which corresponds to signal reflected from the object. Amplitude threshold of tone decoder is adjusted by the means of Decoder Sensitivity Control circuit, which enables this detector to be very flexible in the sense of wide background light conditions and variable range of detector. Decoder Sensitivity Control circuit has three functions: determination of the exact distance between the sensor and the object at which the object is to be detected when it is present, to neglect signal reflected from objects other than expected (objects, such as glass window, with reflectivity lower than the one of the expected object, such as document) and cancellation of the effect of background light which tends to decrease the range of detector.

Noise Reduction Control circuit is used to further decrease the effect of background light noise on circuit operation, especially caused by artificial lights (incandescent or fluorescent lamps) and to further separate amplitudes of signal reflected from the object compared to one reflected from the glass window. Noise Reduction Control circuit acts as automatic gain control or feedback for the intensity of received IR light canceling or at least decreasing the effect of detected light noise. Although background light signal in Fig. 2. is marked with DC, it is actually low pass filtered from DC up to nearly 3 kHz which greatly cancels the effect of artificial lights having IR components of 100 Hz or 120 Hz. Frequency of tone generator is about 10 times greater than the upper limit of the filter.

Details about the effects of different background lighting on IR sensors could be found in [5]. Phase Correction circuit is optional component for alternative way to control sensitivity, but when omitted it is important that other components in circuit provide proper phase of signal propagating from tone generator to tone decoder. This issue is explained in [3]. Many of these blocks are integrated as one circuit, but for the sake of explanation clarity are shown separated.

Basic control flow of the detection system as independent peripheral is explained with time diagrams in Fig. 3.

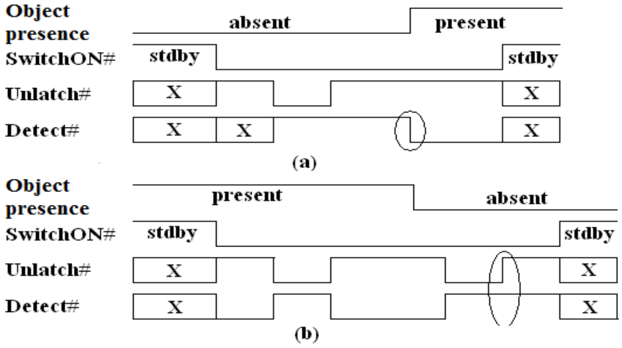

Fig. 3. *Basic control flow for detecting object: a) presence, b) absence*

After the device is turned on with SwitchON# going low, it should always be initialized with Unlatch# going low since state of status Detect# cannot be guaranteed. This procedure unlatches status Detect# (it is returned to logic one). While Unlatch# is in state of logic zero, Detect# is logic one regardless of document presence. After returning Unlatch# to logic one, device is ready for operation and status Detect# should be monitored for information of object presence. For the sake of energy saving, device can be returned to standby at the end of cycle. Basic control flow for detecting object (document) presence is shown in Fig. 3a. After initialization, status Detect# should be monitored for information of document presence. While document is absent Detect# is logic one. When document is positioned in its place, Detect# is latched to logic zero. This moment of latching is circled in Fig. 3a. and control logic should conclude document presence after reading logic zero on status Detect#.

Basic control flow for detecting document absence is shown in Fig. 3b. After initialization, status Detect# should be monitored for information of document absence. Control logic must periodically unlatch Detect# and read its state since Detect# would stay permanently latched on logic zero otherwise. When document is removed and following unlatching is finished, Detect# stays logic one which states document absence. This moment is circled in Fig. 3b. and control logic should conclude document absence after reading logic one on status Detect#.

4. METHODS FOR INCREASING RELIABILITY AND OPTIMIZATION OF CONTROL PARAMETERS

Additional reliability improvement is achieved by extending basic control flow described in Fig. 3. with filtering or debouncing algorithm. This prevents false readings in case glitches occur on status signal Detect#. One example of such control flow is shown in Fig. 4. where object presence or absence is recognized only if same state is detected three times in a row. It is important to include at least ten pulses of tone generator in one debouncing period to enable PLL to lock.

System operation and its main control parameters can be described with inequalities (1) and (2) considering the electric currents at the point of the tone detector input which is the same as phototransistor (PHT) output.

$$i_{THRESHOLD} < i_{PHT_{OBJECT}}\ , \qquad (1)$$
$$i_{THRESHOLD} > i_{PHT_{GLASS}}\ , \qquad (2)$$

These inequalities must always be fulfilled to enable detection of the object presence (PHT electric current is of corresponding amplitude and at modulating frequency) and to neglect all other light noises.

Background light is expressed in (3) as normalized variable, where maximum value of I_{NOISE} represents intensity of background light at which phototransistor is saturated.

$$m = \frac{i_{NOISE}}{I_{NOISE_{MAX}}} \qquad (3)$$

By decomposition of the system sub-circuits, decomposition of inequalities (1) and (2) is done in (4) and (5), where g_{OBJ} and g_{GLASS} represent the amplification of electric current from LED to PHT when object is present and when it is not, respectively, s is the parameter of tone decoder selectivity circuit, n is the parameter of noise reduction control circuit, I_{LED0} is the maximum electric current of LED (current at dark, meaning no background light) and g_0 defines selectivity of tone decoder at the dark. Parameters s, n and g_0 are set by the user to optimize functioning of the detector.

$$g_0 \cdot (1 - s \cdot m) \cdot I_{LED0} < g_{OBJ} \cdot (1 - n \cdot m) \cdot I_{LED0}\ , \qquad (4)$$
$$g_0 \cdot (1 - s \cdot m) \cdot I_{LED0} > g_{GLASS} \cdot (1 - n \cdot m) \cdot I_{LED0}\ , \qquad (5)$$

As example, in the application, as first step, values of g_{OBJ}, g_{GLASS} are determined by the experiment at the dark as 0.0133 and 0.01, respectively and for g_0 is selected value 0.013 (with margin). At second step, only selectivity control is enabled (n=0) for determination of parameter s to compensate signal losses due to background light, by the means of the experiment which in case of this application is 0.437. In this case, after the second step, the system can be described with Fig. 5a. where it can be seen that there is a risk of detecting reflections from the glass window as the object when strong background light is present. This is compensated at third step by enabling noise reduction control.

While keeping the parameter s from the second step, range of possible values for parameter n can be found from inequalities (4) and (5) where minimum value suites the best if the goal is to make object detection at widest possible range of background light possible, but without accidental detection of reflections from the glass window.

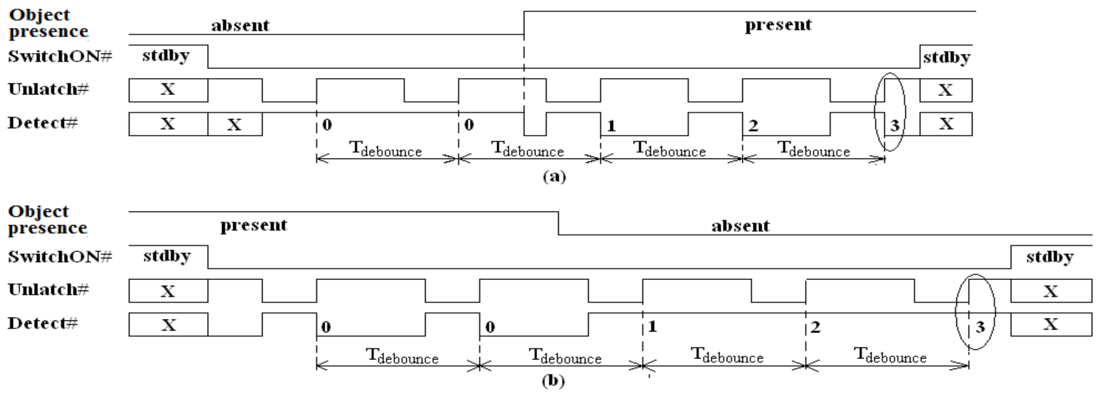

Fig. 4. *An example of suggested control flow with debouncing algorithm for detecting object: a) presence, b) absence*

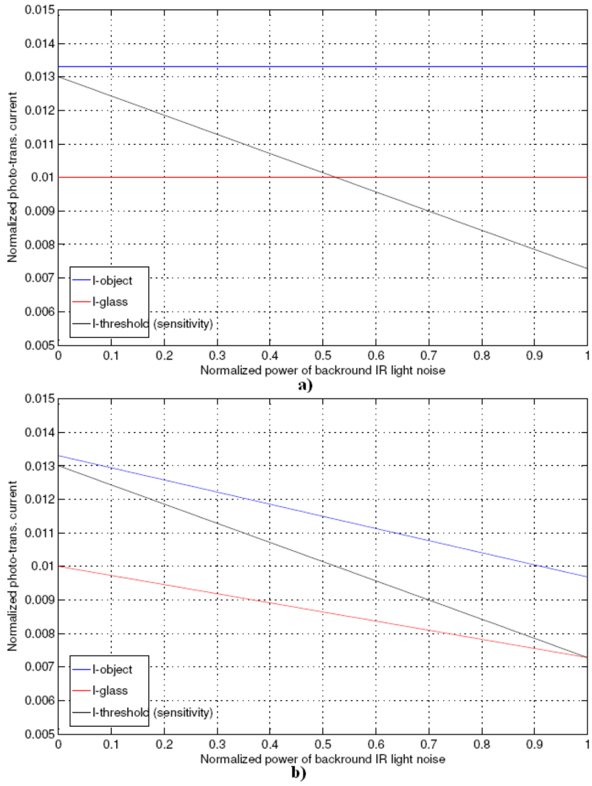

Fig. 5. *Device set and parameters optimized using: a) only sensitivity control, b) sensitivity and noise reduction control*

For *n* parameter value of 0.27 is used. After third step, system can be described with Fig. 5b. It is obvious that this narrows the range of background light intensities at which detection of the object is possible, but false detections due to reflections from the glass window are prevented at whole range of background light intensities.

5. CONCLUSION

Described system is tested and proved as functional and it is in use as a peripheral module of the document scanning device that has been developed.

Main advantages of the detection system are: high reliability of results; scanning through the glass window; design based on easy available, cheap and standardized components with standardized footprints; one time adjustment procedure during prototyping, no additional microcontroller in the system and its programming during production; and fairly low power consumption which is additionally improved with implemented standby function.

Main disadvantages are: used larger PCB area compared to a non-standardized integrated solutions; higher power consumption compared to complete digital solutions; and hardware adjustment to adapt to a new application.

Future development should be concentrated on exploring device possibilities and limits with further optimization of parameters to achieve best detection results at different background light conditions. It has to be mentioned that there are much complicated and advanced sensing technologies which could have been used, like accelerometers, but that would be much more expensive and much longer development period would be required that was out of the question [6]. As example, in case of accelerometers, one solution could be to recognize specific order of device movements when object approaching its terminal position for scanning.

The same design should be digitized and implemented on general-purpose microcontroller for the purpose of flexibility with future applications where this is not a constraint.

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