Design of a PIC Based Dual Sensing Motion Detector

Areej Alaa Hassen &, Abeer Fadhil Shamal

Received on: 20/ 10 /2005
Accepted on: 30 / 6 /2008

Abstract

Motion detectors are widely implemented in the design of intruder alarm systems. While these detectors in their raw state can have high detection sensitivity, this comes at the expense of generating higher false alarm rates. The most popular motion detection techniques implement either Passive Infrared motion sensors or Active Continuous Wave Microwave Doppler motion sensors. Motion detectors using Dual Detectors employing both Doppler Microwave (MW) and Passive Infrared (PIR) motion sensors provide a new performance level where the feature of both sensors are combined while avoiding the disadvantages of both. The sensors are combined through a microprocessor to provide "intelligent" motion detection system designed to greatly reduce or eliminate "single detector" false alarms. A Peripheral Integrated Controller (PIC) based on the popular 8051 device manufactured by Cygnal Corporation the C8051F020 has been chosen in order to reduce designed hardware complexity and utilize the improved features of this device to obtain better system performance. The PIR and Doppler Microwave detection systems are each designed as independent motion detectors. The PIC receives signals from these two sensors in addition to a third signal from a light sensor. The PIC compares the received signals against pre-stored values, double checking their existence in addition to dynamically selecting threshold detection levels depending on weather the motion detection system was operating in day light or at night. The result is a detector with a higher performance in terms of accuracy and detection certainty. The designed system has a large room for continued performance enhancements and features addition that can lead to designing a motion detection system that can fulfill every security system requiremen_

الخلاصة

إن كواشف الحركة تستخدم بشكل واسع في تصميم منظومات كشف التسلل و الإنذار. وبينما تتميز هذه الكاشفات بوضعها المبسط بامتلاكها حساسية عالية، فإن هذه الحساسية العالية تأتي على حساب ظهور منسوب عالي من الإنذارات الكاذبة. إن من أكثر كاشفات الحركة استخداما في منظومات كشف التسلل هي متحسسات الأشعة التحت الحمراء الخاملة العاملة على ظاهرة تغير الاستقطاب الكهربائي على بعض أنواع البلورات مع تغيّر (Passive Infrared Sensor) ، و أخرى فعّالة تعمل على مبدأ رادار دوبلر للموجات الكهرومغناطيسية الدقيقة ذي (Pyroelectricity)درجات الحرارة نمط الموجة المستمرة. عندما يتم دمج عمل هذين الكاشفين في وحدة واحدة باستخدام وحدة مسيطر دقيق متكامل بوحدات و ذلك لجعل المنظومة مدمجة بدرجة اكبر و الاستفادة من المزايا المتقدمة في *(Peripheral Integrated Controller)* هذين المتحسسين و تفادي مساوؤهما من اجل الحصول على أداء إجمالي أفضل. تم اختيار المسيطر المتكامل بالطرفيات وذلك لتقليل تعقيد الدائرة الإلكترونية و تقليل عدد القطع الداخلة في التصميم مع الاستفادة من (C8051F020)نوع المميزات المتقدمة في هذا المسيطر للحصول على اداء اقضل من المنظومة. إن وحدة تحسس الحركة بكشف الأشعة التحت الحمراء و وحدة تحسس الحركة باستخدام رادار دوبلر تصمم كل وحدة للعمل بشكل منفصل و تقوم وحدة المسيطر الدقيق المتكامل بالطرفيات استقبال الإشارات المنطلقة من كلا الكاشفين و تقوم بمقارنة الإشارات المستلمة مع قيم مخزونة بجداول خاصة، و يقوم بالتأكد من استمرارية وجود إشارة الكشف و انتقاء قيمة عتبة الكشف بصورة ديناميكية اعتمادا على كون عمل منظومة التحسس كان خلال النهار أو اليل لما يسبب ذلك تغير بخرج متحسسات الحركة. ينتج عن ذلك وحدة كشف حركة تتمتع بدرجة اداء عالية من حيث دقة و وثوقية إطلاق الإنذار .حيث يتم الاستفادة من مميزات كلا النوعين من الكاشفات مع تجنّب مساوؤهما. يتم جمع خرجي هذين الكاشفين باستخدام وحدة معالج دقيق يعمل ضمن منظومة استقطاب بيانات ليوفر الذكاء المطلوب في عمل منظومة كشف الحركة و يعمل على التخلص بشكل كبير من حالات الإنذار الكاذب المنطلقة من الكاشف المفرد. ان النظومة المصممة تتمتع بحيز كبير لتطوير الأداء و إضافة مميزات جديدة التي تؤدي إلى تصميم منظومة كشف تسلل قادرة على الإيفاء بكل المتطلبات المتنوعة لمنظومات الحماية.

1-Introduction [3, 7, 8]

Intruder alarm systems are designed to protect a certain location from intruders by providing it with the ability to detect the presence of unauthorized people in the vicinity of the operation field of the alarm system. They can perform several functions that are expected to detect the intruder or warn owners or guards in the protected zone.

These systems became more intelligent when microprocessors were implemented in them and a variety of operation options and modes became available with a wide range of complexity. This complexity ranges from simple sensors scanning and switching on a warning system, to a high degree of complexity where full protection and entry authorization using finger print, voice recognition, pattern recognition of entrant retina and/or face is used to verify the identity of persons entering the protected field. Figure (1) shows a generalized block diagram of the implemented system showing the main parts incorporated in it.

The implemented PIC has in addition to higher computational performance, more digital peripherals and is equipped with analogue peripherals as well.

This makes it suitable for highly integrated systems where no additional hardware is required in order to complete system design requirements.

This PIC has many additional features that make system realization, software and hardware debugging simple and fast. It is well supported by the manufacturing firm.

2- Hardware design

The main elements in the hardware of this system are the motion sensing elements, the light sensor, and the peripheral integrated controller.

The first of the motion sensing elements is a passive infrared motion sensor (PIR) that consists of a multi-element Fresnel lens focused on a pyroelectric sensor the RE200B [11.4]. The pyroelectric sensor is made of a crystalline material (Lithium–Tantalate "$LiTaO_3$") that generates a surface electric charge when exposed to heat in the form of infrared radiation. When the amount of radiation striking the crystal changes, the amount of charge also changes and can then be measured with a sensitive FET device built into the sensor [2, 7, and 8]. The sensor elements are sensitive to radiation over a wide range so an optical filter window is added to the TO5 package to limit incoming radiation to the 800 to 1400 nm range which is most sensitive to human body radiation. The RE200B sensor has two sensing elements connected in a voltage bucking configuration [11.6]. This arrangement cancels signals caused by vibration, temperature changes and sunlight. The PIR sensor works as follows; when a body passes in front of the sensor, it will activate the first one and then the other element, whereas other sources will affect both elements simultaneously and be cancelled. The radiation source must pass across the sensor in a horizontal direction so that the elements are sequentially exposed to the IR source. The multi-element Fresnel lens takes care of this situation and makes the sensor sensitive to motion taking place in any direction in front of its coverage area.

The second sensor is the microwave radar Doppler module [11.5]. This module incorporates the OM8960 X-band Doppler radar module is specifically designed for detecting movement of a remote target by detecting Doppler-shift in reflected microwave radiation.

The module contains a Gunn device (oscillator), which produces the energy to be radiated, and a mixer diode which combines the reflected microwave with a sample of the oscillator signal. The module is self contained and includes a voltage regulator and a preamplifier that provides an output for post processing circuits that will be added according to the requirements of the specific application.

Tests were carried out on the two sensors where the designed system makes use of them in setting the threshold and distance reference tables that will be compared against the received values in order to make the decision of activating the alarm with minimal chance of yielding false alarms. These values will be chosen depending on the indication of the light sensor. Figure (2) shows signals generated from the PIR and MW sensor modules at 1, 10 meters distance from an average human target, Table (1) shows the relation between sensor modules output signal magnitude versus target to sensor distance.

The next section in the system consists of signal conditioning circuits, these circuits are necessary to modify signals coming from the motion sensors in order to make them compatible with the analogue input of the PIC in use.

Firstly generated signals must pass through a band pass filter that will attenuate signal that are likely to be generated by non-human sources (wind moving tree bushes, motor vehicles passing by sensors coverage area, etc...) thus minimizing the likelihood of interpreting sensor signals as being generated by human figures which could lead the controller to falsely trigger the alarm indicators.

Both signals will be passed through a band-pass filter made by cascading a high-pass filter and a low-pass filter that are designed to pass the frequencies that are expected to be generated by the movement of a human figure.

As linearity is of prime importance in this application, the choice of Butterworth response is made as this filter is described to have a maximally flat response [1, 5, 6].

The filter design chosen is of second order response Sallen and Key type giving a slope of 12dB/Octave while using one op-amp [1, 6, 9].

For the Microwave Doppler module, Doppler frequency is calculated from[2, 11.5]:

$$F_D = \frac{2v}{\lambda} \qquad \text{................2.1}$$

Where F_D is the Doppler Frequency generated by a target moving at speed v, *and* λ is the wavelength of the Microwave generated by the Gunn oscillator in the Doppler module (10.6GHz gives a 0.0283m wavelength) [11.5]. The motion of an average adult human ranges from 1.8Km/H (0.5M/Sec) to about 24KM/H (17M/Sec) [5,8,11.5]. Applying these figures to equation 2.1 will result in calculating the frequency range expected from the microwave Doppler module.

Applying the lower speed index results in lower cutoff frequency:

$$F_D = \frac{2*0.5}{0.0283} = 35Hz$$

Applying the upper speed index results in the upper cutoff frequency:

$$F_D = \frac{2*17}{0.0283} = 1201Hz$$

The frequency range generated by the PIR motion sensor module is taken from the module data sheet and is a function of sensor and Fresnel lens geometry and the motion of an average human. The manufacturer recommends a lower cutoff frequency of 0.32Hz and an upper cutoff frequency of 7.96Hz [4, 11-6].

The low-pass and high-pass filter will be calculated using the following sets of design equations [1, 6]:

$$F_C = \frac{1}{2\pi RC} \text{............................2.2}$$

$$Rb = (2-\alpha)Ra \text{........................2.3}$$

$$A_P = \frac{Rb}{Ra} + 1 \text{............................2.4}$$

For Butterwort response [1, 6] α is taken from design tables to have the value of (1.414). Figure (3) shows the circuit layout of the Sallen & Key low-pass and high-pass filters.

Secondly, the filtered signal must be magnitude and level adjusted to suit the signal levels accepted by the ADC input.

the level shifter/ signal magnitude control circuit, this circuit is designed using a simple analogue adder/subtractor circuit for level shifting and a potentiometric circuit for signal level control. The output of the signal conditioning circuit is protected against having output levels in excess of 2.2Volts (which is the limit of signal swing for the ADC input thus keeping signal inputs to the ADC section of the C8051F020 to a safe limit.

The light sensor is designed using LDR (light dependent resistor) which has a dark resistance of ≈ 500KΩ. This resistance drops to ≈ 80Ω in day lit environment [5, 9]. The LDR is put in a voltage divider circuit coupled to the input of one of the C8051F020 comparators the hysteresis of each comparator is software-programmable via its respective Comparator control register (CPT0CN) for Comparator0. A hysteresis was programmed into the comparator control register in order to prevent comparator output chatter at switch over input values. The output of the comparator is polled main program software. The logic output of (0) indicates day and logic out put of (1) indicates night.

Figure (4) shows the circuit diagram of the interface circuit between the sensing modules and the PIC prototyping board.

The last part of system hardware is the Cygnal C8051F020 PIC [10.1, 11.4]. It is a new peripheral integrated micro-controller that is designed around the popular 8051 controller originally introduced by Intel Corporation but has many features that make it far more powerful than the original 8051 as it executes most of it instructions in one or two clock cycles. It is capable of delivering a 25MIPS performance figure when operated at 25MHz clock. In addition to higher computational performance it has more digital peripherals and is equipped with analogue peripherals as well. This makes it suitable for highly integrated systems where no additional hardware is required in order to complete system design requirements.

In the designed system the 8bit ADC (ADC1) was used in addition to the voltage comparator (comparator 0), one digital input port (port 0), and one digital output port (port 1). The digital input port is used to read user request to reset alarm system or arm/disarm alarm system by reading the push buttons status. The digital output is used to operate alarm indicators and sounders.

3-Intruder alarm system software: [10.1, 10.3, 11.1, 11.2, 11.3, 11.4]

Software for the dual sensing motion detection system was developed on the C8051F020DK development kit shown in figure (5). It provides all the hardware and software necessary to develop application code and performing circuit debugging with the C8051F020 PIC. The provided Integrated Development Environment (IDE) includes an editor, macro assembler, debugger and programmer.

The IDE's debugger and programmer interface to the PIC via its JTAG interface to provide fast and efficient in system device programming and debugging.

A configuration wizard helps user to setup all the I/O and hardware environment to suit a given application by choosing the required settings, then the wizard will complete the application program sections that are required to configure the C8051F020 peripherals to suit the required application.

Figure (5) shows the configuration wizard screen in the Cygnal IDE where the user can configure the I/O cross bar by inserting the proper values in the XBR registers.

The wizard forwards the registers in code that is well documented to assist user in putting the proper data in the control registers, thus no configuration error can take place.

The user can continue using the configuration wizard to configure all the supported peripherals by a given MCU.

The programs of the system software are explained in details with the aid of flowcharts. Programs were written in assembly language of the MCS 51 micro controller family.

The program was developed using Cygnal integrated design environment and its associated configuration wizard. The program is stored in the Flash ROM area for non volatile storage.

Lookup tables constructed from the tests performed on the two motion sensing modules are stored in Flash ROM too and compared against data received by the ADC (ADC1) for motion detection verification.

3.1-Description of main program

The main program is the heart of the designed system, it is written in a way so that false alarms can be minimized and their occurrence during alarm system operation can be avoided. Adapting a dynamic detection threshold for the pyroelectric sensor module and microwave Doppler module outputs does this. The detection threshold is selected according to data received from the light sensor (the LDR circuit) and the motion sensors after the main program calls the ADC data acquisition sub program. A detection threshold is selected in accordance with light intensity of the environment in order to minimize false triggering of the alarm.

In addition to that, the program checks the output from the motion sensors twice before switching on the alarm indicators thus reducing the amount of false alarms to a very small value.

Alarm system can be reset and disarmed and rearmed under software control. Figure (6) shows the flowchart of the main program of intruder alarms system software.

3.2-Description of analogue sensors data acquisition subprogram

This program is called from the main program in order to update data received from motion sensors and the light sensor for the main program to evaluate alarm condition.

This program selects the proper analogue channel thus coupling the desired sensor output to the analogue to digital converter. It then initiates an ADC cycle by toggling the SC (start conversion) input to the ADC then it waits for the EOC (end of conversion) signal from the ADC, after receiving the EOC the program reads ADC output and stores the result in the register designated for the selected sensor.

This cycle repeats until all existing sensors are scanned, afterwards the control is returned to main program.

Figure (7) shows the flowchart of the analogue sensors data acquisition program.

4-Results

The designed system was put under test for a period of one month; during this month the alarm system was tested several times in addition to intentionally triggering the alarm which was conducted in order to verify system functionality. The analogue inputs were populated with one pyroelectric module and one Microwave Doppler module as this system was built as a prototype for a false alarm free motion sensor for application in intruder alarm systems.

The analogue output of the pyroelectric sensor that is generated from the movement of an average person through the outer end of detection field (10 meters away from sensor) was about 320 µVolts (this voltage was generated from the movement of a 165cm 70Kg healthy male), after passing this signal through the built in 64dB amplifier circuit it became 0.33 Volts (this figure was larger than the calculated gain which was about 60dB while the given figure should have generated a 0.512 Volts output and was probably due to the tolerances found in resistors used in the design of the amplifier circuit).

This voltage was observed at the input of the ADC circuit that has generated a binary output figure of {1DH}. This signal was tested during day hours, at night the figure went below and the ADC generated a figure of {1BH} for the same person at the same distance. This figure was used as a detection threshold and the choice between these two figures was made by detecting the output of the light sensing circuit that produced a 2.63Volts output at night which corresponded to logic 1 from comparator output, in the morning, the output voltage from the light sensor dropped to 30 millivolts which corresponded to logic 0 output from comparator. It was decided that the switching between the two detection thresholds will be made as follows:

1. When the binary figure obtained from light sensor was logic1, the

{1CH} figure was used as a detection threshold for Doppler sensor and {19H} for Pyroelectric motion sensor.

2. When the binary figure obtained from the light sensor was logic 0, the {1CH} figure was used as a detection threshold for Doppler sensor and 1BH for Pyroelectric motion sensor.

Using these figures produced no false alarms throughout the test periods; the only incidents that have generated a false alarm were mains power failures that have generated the false alarms since the pyroelectric sensor produced random signals for a period of about 10 seconds. The Microwave Doppler module requires only 2 seconds settling time. This result has been put into system software and upon system startup a delay period of 12 seconds was generated in order to avoid these false alarms.

These figures indicate the time required by the sensing element circuits to reach steady state operation. Other than these incidents no other false alarms were detected

The output of the filter section of the signal conditioning circuit was tested over the desired frequency range and yielded results that were quite close to the values used in designing the filters stages regarding cutoff frequencies and response curve slope.

5-Conclusions

The designed system has been built around the infrared pyroelectric sensor and the microwave Doppler module that served as a motion detection sensor for intruder alarm systems applications, this dual sensing elements system is very effective in detecting moving objects within the operating field of the sensors. The performance of these sensors was improved by including an adaptive detection threshold and output verification function in the designed system. These improvements were reflected in the performance of the designed system in the form of improved alarm system reliability and the minimization of false alarms to a very negligible figure. The use of the selected PIC, the C8051F020 had a great impact on system performance in terms of system integration level as this PIC includes analogue peripheral devices like ADC's, DAC's, comparators and analogue multiplexers. This in addition to implementing most of its instructions in RISC technology makes it a better choice. Other PIC families like the 16F84 has implemented RISC technology in its design and has several digital peripherals but it has no analogue peripherals integrated into it. This will increase circuits complexity as analogue multiplexer circuits in addition to ADC must be added to circuit in order to accommodate for the analogue input signals received from the motion detection sensors.

When the system was put to test close to an environment polluted with electric noise for about one month period, no false triggering has occurred at all and detection of intruders was successful every time it was tested.

6-Suggestions for future work:

The designed system has plenty of room for future improvements and expansions. The following suggestion can provide a guide line for future work:

- The designed system can be integrated into a single package and using the serial bus feature available in the implemented micro controller can lead to higher system installation cost effectiveness by minimizing wiring requirements.
- Using larger look up tables to include al possible operation conditions.
- Adding a temperature sensor to the system will make it possible to select ideal detection thresholds to motion sensors output more effectively as sensor output can also vary to a certain degree depending on environment temperature.

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Tables:

Table (1.1a) MW Doppler Module Output in Daylight

Distance (meters)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Output (Volts)	9.4	7.9	6.25	4.6	4.1	3.6	3.35	3.1	2.6	2.1	1.6	1.2	0.9	0.7	0.45

Table (1.1b) Mw Doppler Module Output Variation with Object Distance at Night

Distance (meters)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Output (Volts)	9.1	7.5	5.9	5	3.8	3.5	3	2.9	2.7	1.9	1.5	1.2	0.91	0.65	0.5

Table (102a) Pyroelectric Motion detector Output Variation with Object Distance in Daylight

Distance (meters)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Output (Volts)	3.3	2.7	2.5	1.7	1.5	1.4	1.1	0.84	0.52	0.33	0.2	0.16	0.12	0.08	0.05

Table (1.2b)Pyroelectric Motion Detector Output Variation with Object Distance at Night

Distance (meters)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Output (Volts)	2.5	2.1	1.6	1.3	0.7	0.6	0.4	0.3	0.21	0.15	0.11	0.09	0.06	0.04	0.02

Feature of the C8051F020

- *HIGH SPEED 8051 μC CORE*
  1. Pipe-lined Instruction Architecture; Executes 70% of Instructions in 1 or 2 System Clocks
  2. Up to 25MIPS Throughput with 25MHz System Clock
  3. 22 Vectored Interrupt Sources

- *MEMORY*
  1. 4352 Bytes Internal Data RAM (256 + 4k)
  2. 64k Bytes In-System Programmable FLASH Program Memory
  3. External Parallel Data Memory Interface – up to 5Mbytes/sec.

- *DIGITAL PERIPHERALS*
  1. 64 Port I/O; All are 5V tolerant
  2. Hardware SMBusTM (I2CTM Compatible), SPITM, and Two UART Serial Ports Available Concurrently
  3. Programmable 16-bit Counter/Timer Array with 5 Capture / Compare Modules.
  4. 5 General Purpose 16-bit Counter/Timers.
  5. Dedicated Watch-Dog Timer; Bi-directional Reset.

- *ANALOG PERIPHERALS*
  1. 12-bit ADC

  ±1LSB INL

  Programmable Throughput up to 100ksps

  8 External Inputs; Programmable as Single-Ended or Differential

  Programmable Amplifier Gain: 16, 8, 4, 2, 1, 0.5

  Data Dependent Windowed Interrupt Generator

Built-in Temperature Sensor (± 3°C)

2. 8-bit ADC

Programmable Throughput up to 500ksps

8 External Inputs

Programmable Amplifier Gain: 4, 2, 1, 0.5

3. Two 12-bit DACs

Can Synchronize Outputs to Timers for Jitter-Free Waveform Generation

4. Two Comparators
5. Internal Voltage Reference
6. Precision VDD Monitor/Brown-out Detector

Figures:

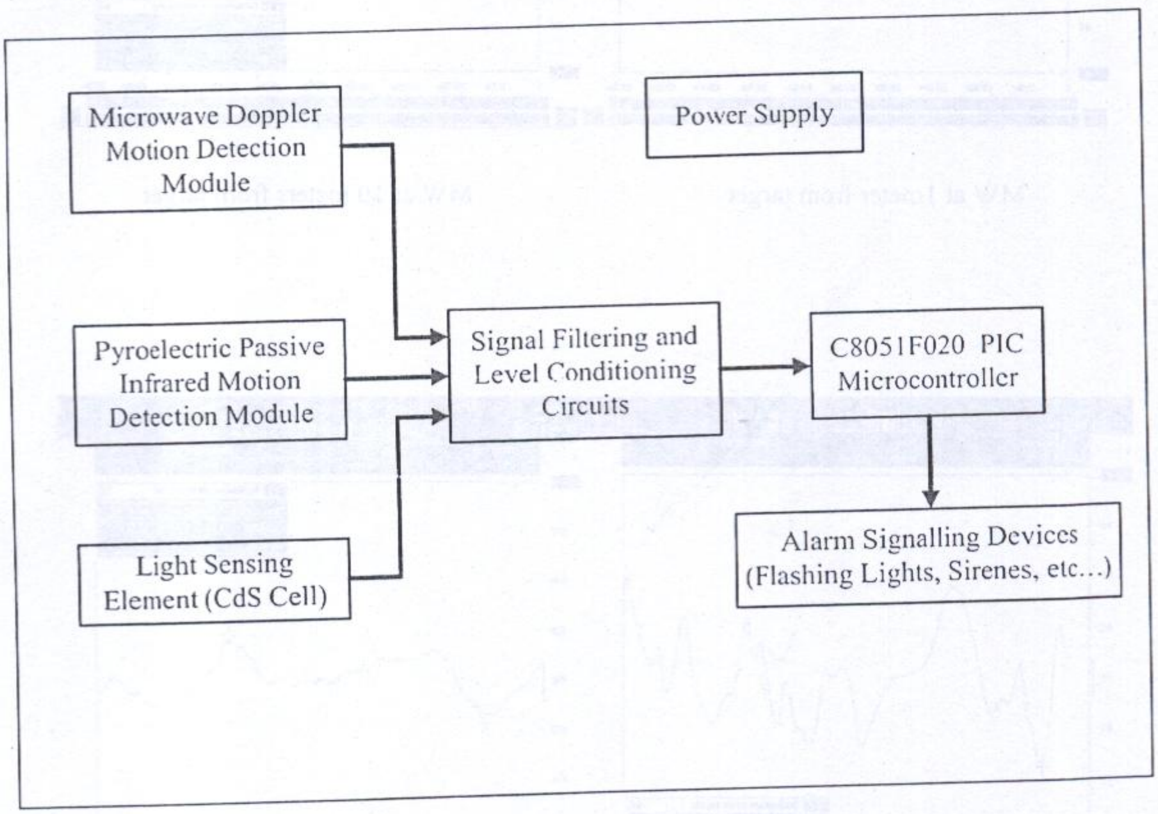
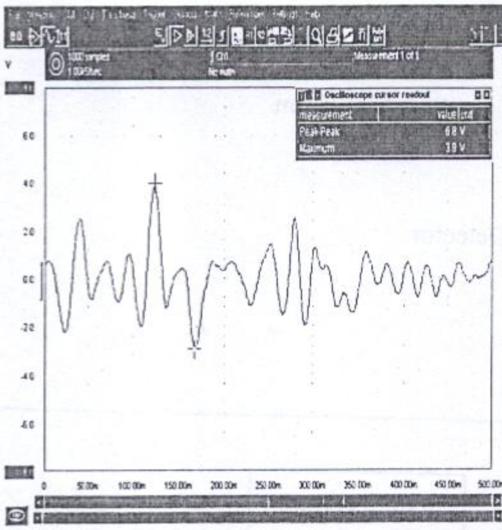
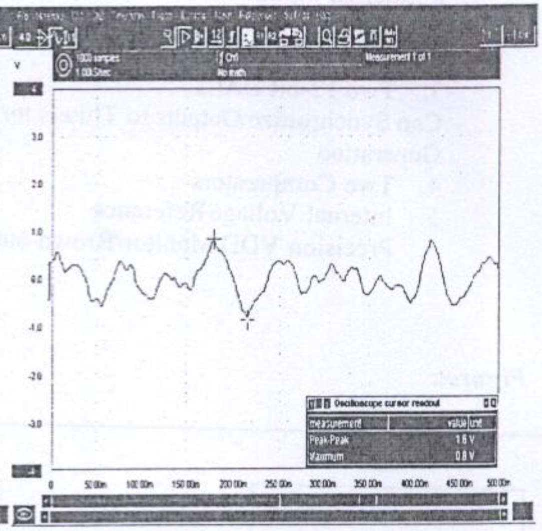


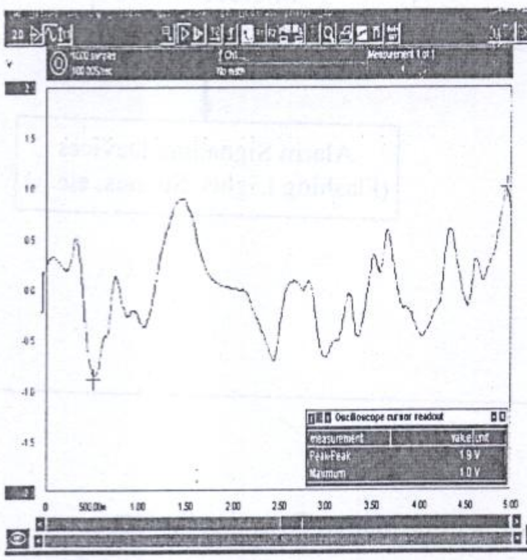
Figure (1): Block Diagram of the Dual Sensing Motion Detection System



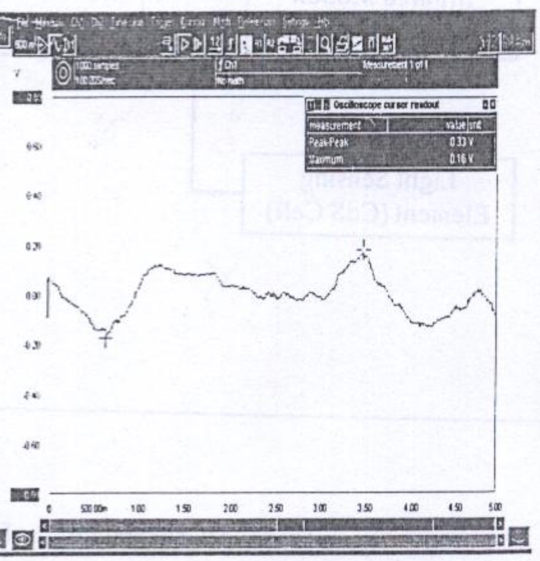
MW at 1meter from target



MW at 10 meters from target



PIR at 1 meter from target



PIR at 10 meters form target

Figure (2): Waveforms Observed At the Output of the MW and PIR Motion Detectors

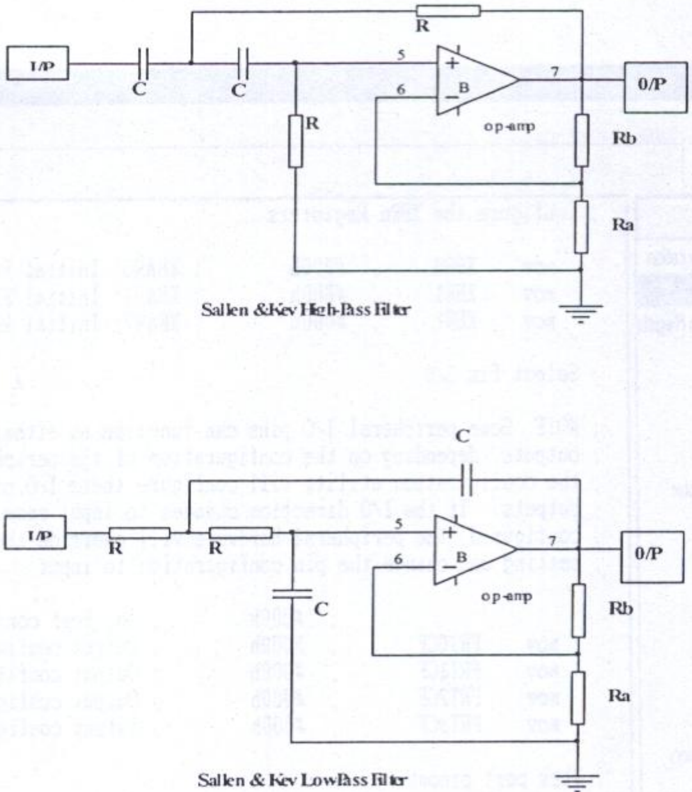


Figure (3): The Circuit Diagram for Sallen & Key High-Pass and Low-Pass Filters

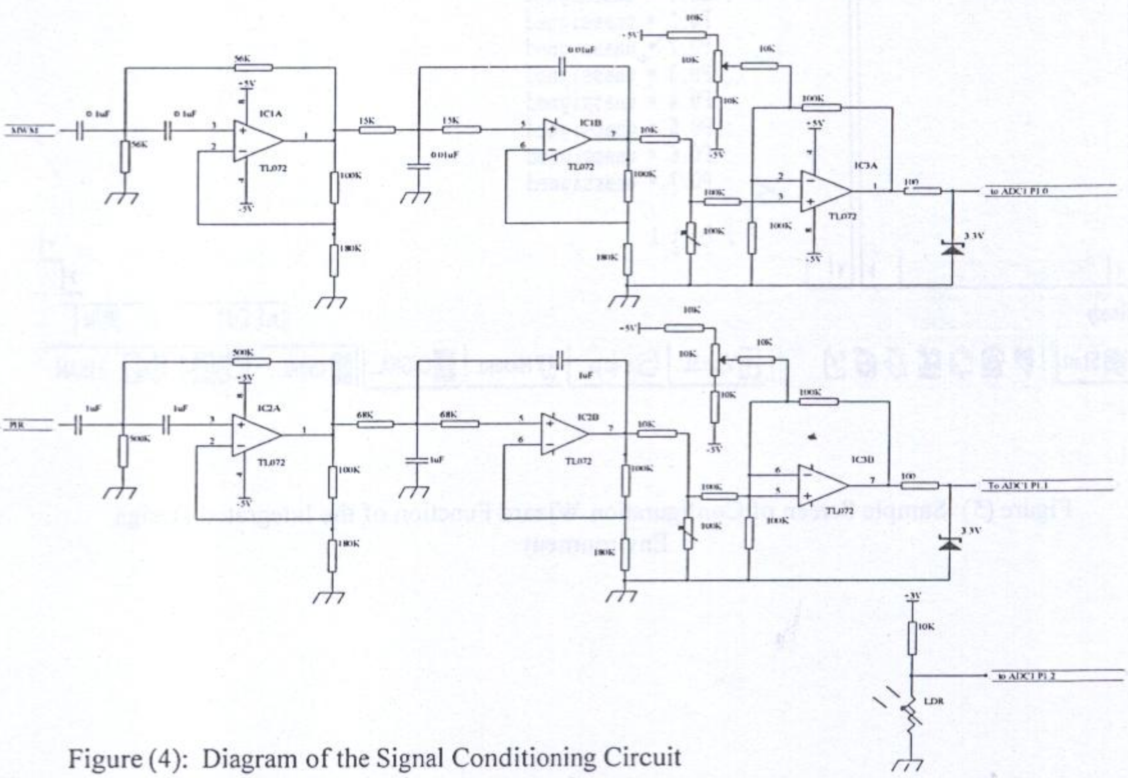


Figure (4): Diagram of the Signal Conditioning Circuit

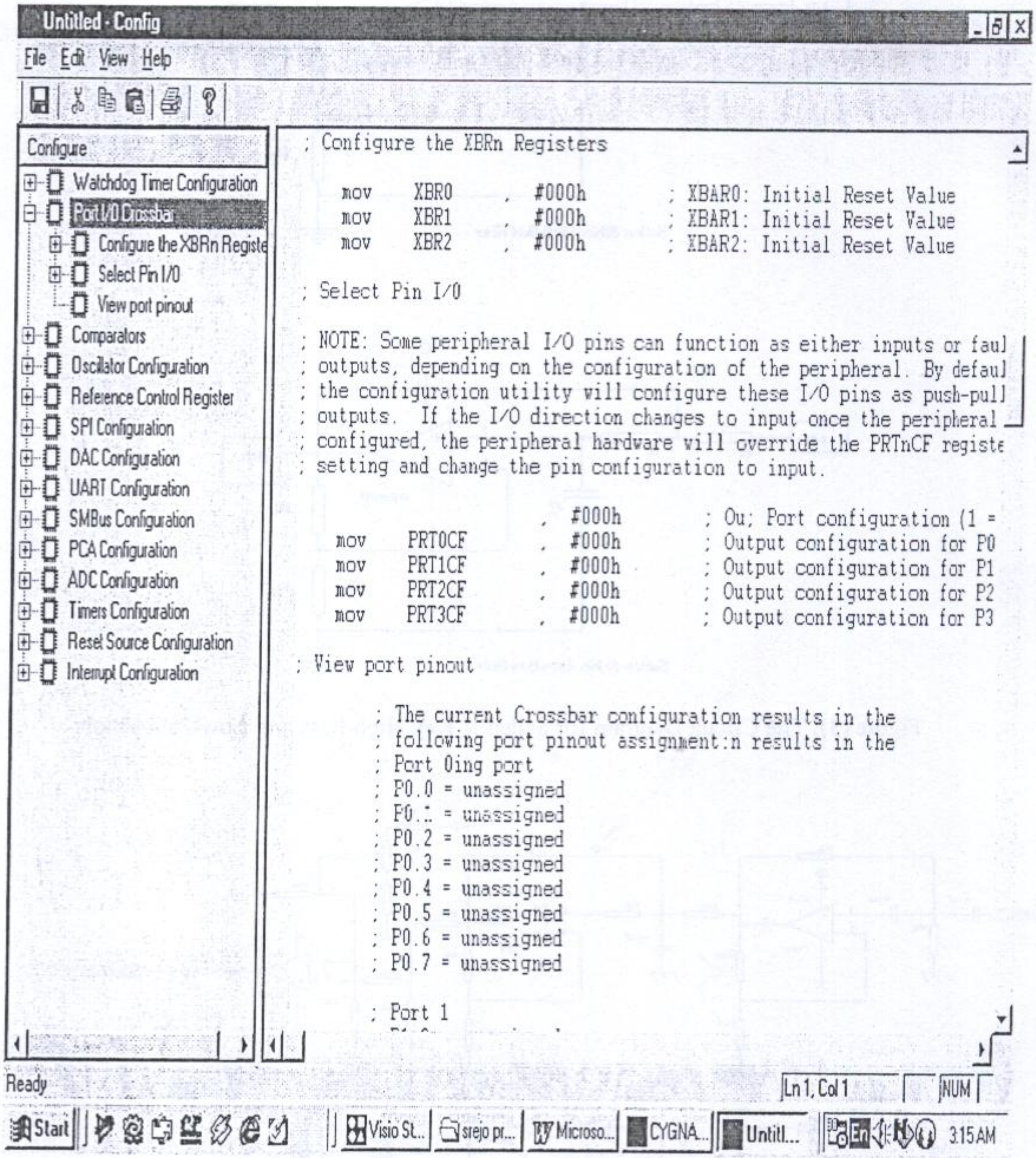


Figure (5): Sample Screen of Configuration Wizard Function of the Integrated Design Environment

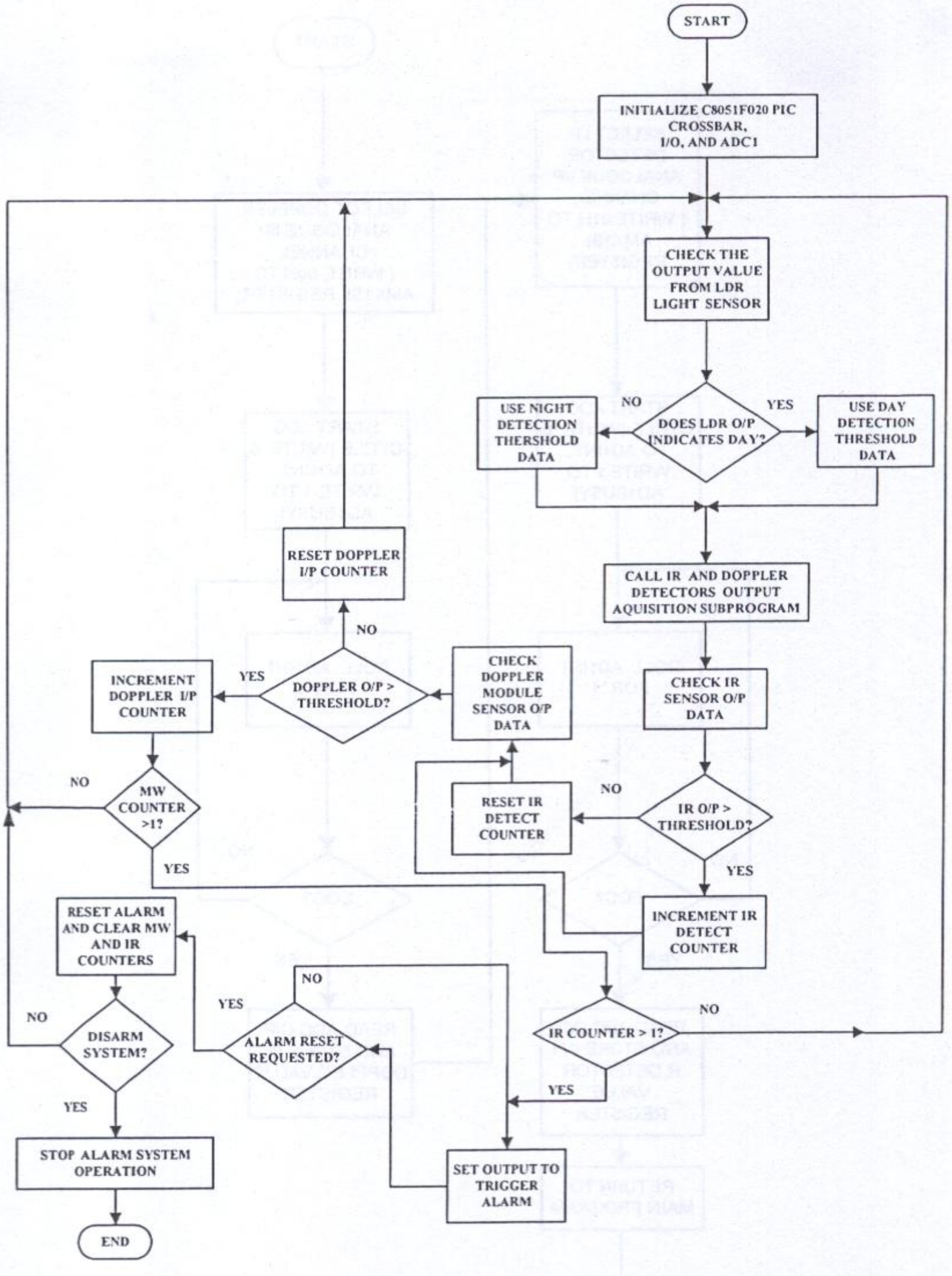


Figure (6): Flowchart of the Main Motion Detection Program

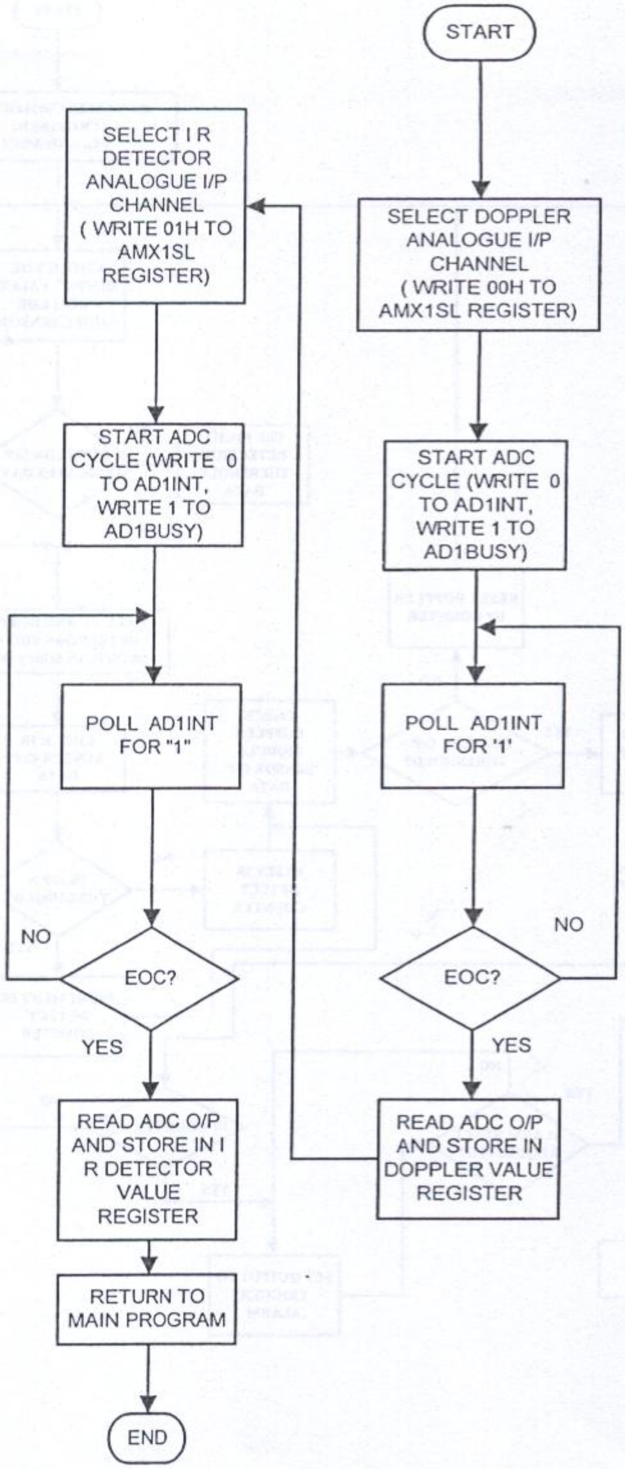


Figure (7): Data Acquisition Subprogram Flowchart