Chapter 4
Indigenous Development of Vision-Based Mobile Robots

Abstract. In this chapter we shall discuss how a low-cost robot can be indigenously developed in the laboratory with special functionalities. Especially, the development of two types of PIC microcontroller based sensor systems that can be integrated with a robot will be discussed in detail in this regard. One of them will be the development of an IR range finder system that can be developed with dynamic range enhancement capability. The second one will be the development of an optical proximity detector system which utilizes the principle of switching mode synchronous detection technique.

4.1 Introduction

In the phase of implementing the vision based algorithms with the KOALA robot (the version of KOALA that was procured by us), it was found that the KOALA robot operates under certain constraints, as given below:

- The communication between PC/Laptop and KOALA robot takes place by means of RS232. However, most of the present day PCs/Laptops do not have any serial interface and hence they require a separate USB-to-serial converter, to operate in conjunction with the KOALA robot.
- For a PC-KOALA combination, high-speed data transfer is not possible.
- KOALA I/O interface is limited.
- KOALA does not have any provision for USB interface.
- Low-cost USB webcam cannot be connected to KOALA directly.
- Image processing cannot be accomplished with KOALA's low-end processor. This requires a separate on-board Laptop or a PC with wireless camera interface. This makes the arrangement become complex and bulky.

Hence, a robot is developed indigenously in our laboratory, with an aim to overcome the above drawbacks and the functionalities and capabilities of this robot are described in detail in this chapter.

A. Chatterjee et al.: Vision Based Autonomous Robot Navigation, SCI 455, pp. 83–100.
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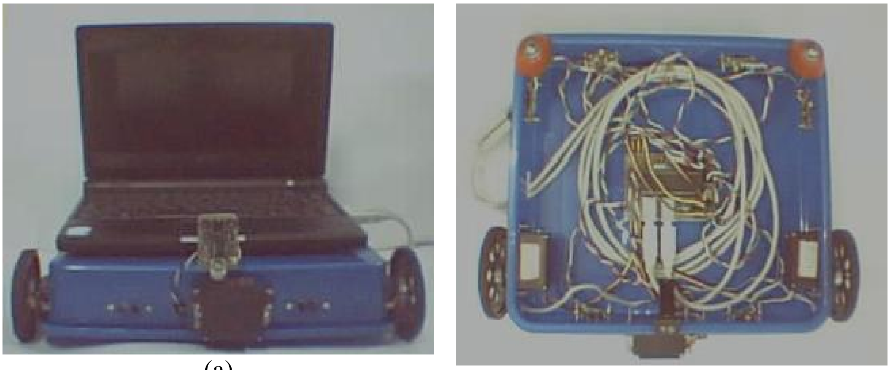
4.2 Development of a Low-Cost Vision Based Mobile Robot

As described in the beginning of this chapter, a mobile robot setup is indigenously developed, with an aim to provide a low-cost solution to the industrial community [14]. Figure 4.1 shows the actual robot in its front view and bottom view. Figure 4.2 shows the block diagram representation of the robot. The robot developed is a two-wheeled, differential drive system. The robot is equipped with six IR proximity sensors, one IR range sensor system, and a laptop. The proximity sensors provide Boolean signals, where each sensor gets activated if the robot is sufficiently close to an obstacle, or remains deactivated otherwise. The IR sensor based system adds a degree of freedom to the system as its angular position is controlled by a servo motor. This enables the IR sensor to scan the front and the side of the robot environment at eleven angular positions, from left to right. A laptop is mounted on the robot system so that the robot becomes a stand-alone, self-sufficient system. The laptop comprises 4GB solid-state HD, 1GB RAM, with Windows XP SP2 operating system. The laptop is free from any moving parts and it communicates with the robot base through a USB link. The robot base is energized (5V, 1A) from the laptop through two USB cables and no separate power source is needed for the mobile robot operation. All the RC servos employed are power controlled for energy saving. The left and right wheel encoders (4-pulses/rotation) are developed using hall-effect switches. The laptop camera with auto-focus serves as the mono-vision sensor of the robot system. The robot uses the webcam of the laptop as its mono-vision sensor. The IR range sensor system is specially developed for obstacle detection and avoidance, which employs a microcontroller (PIC 12F683) based system, also indigenously developed, with an aim to enhance the dynamic range of the range finder system. The system employs a Visual Basic based robot control program and navigation is performed using vision and IR range sensors. The system is also equipped with a Wi-fi link for wireless remote monitoring and supervision.



(a) (b)

Fig. 4.1. The mobile robot, developed indigenously, in its (a) front view and (b) bottom view

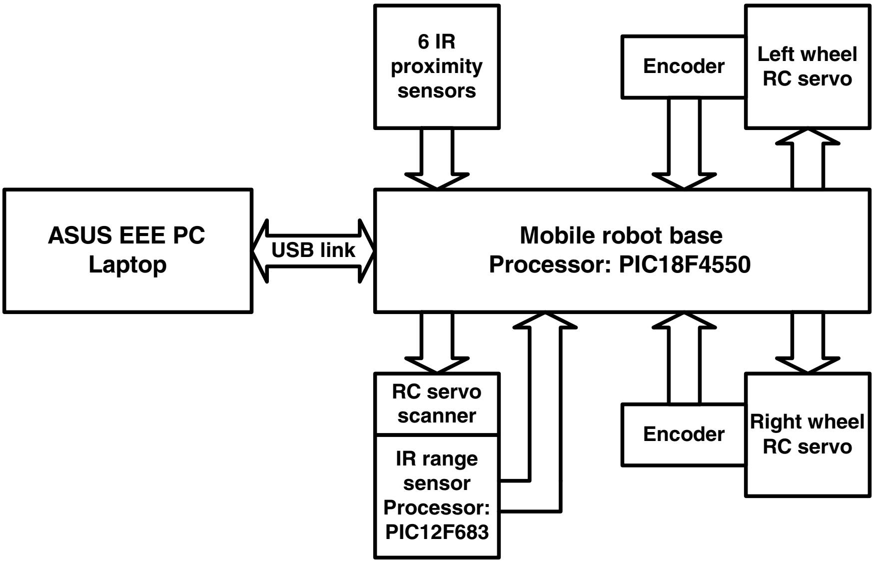


Fig. 4.2. The schematic diagram of the mobile robot

4.3 Development of Microcontroller Based Sensor Systems for Such Robots

This robot developed is made equipped with three special functionalities. The robot comprises two special types of sensor systems developed with indigenous concepts: (a) infrared (IR) sensors with the capability of dynamic range enhancement [2] and (b) optical proximity detectors using switching-mode synchronous detection technique [15]. These sensor systems are developed using PIC microcontrollers. In addition to this, the robot system is equipped with a sophisticated capability of intranet-connectivity where the laptop mounted on the robot, acting in a slave mode, can be suitably commanded by a PC, acting in the master mode, situated in a remote end.

4.3.1 IR Range Finder System with Dynamic Enhancement[1]

The robot system developed is equipped with an indigenously developed PIC Microcontroller based IR range finder system, with dynamic range enhancement capability [2]. Infrared (IR) range finders are overwhelmingly employed in robots for range measurement because of small size, ease of use, low-cost, and low-power consumption. In its conventional form, the Sharp make IR range finder

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[1] Section 4.3.1 is based on "A microcontroller based IR range finder system with dynamic range enhancement", by Anjan Rakshit and Amitava Chatterjee, which appeared in IEEE Sensors Journal, vol. 10, no. 10, pp. 1635-1636, October 2010. © 2010 IEEE.

finds extensive real-life use, which uses the method of triangulation [1]. Here, the angle of light reflected from the object depends on the object range. In our robot, the IR range finder system employed is developed using scattered radiation-based sensing, which attempts to reduce the influence of orientation of the plane of the object on the sensor reading obtained, as is the case in traditional triangulation-based approach. Usually the output voltage from an IR range finder system increases with decrease in range of the object, i.e. for a nearer object. However, the system can only be used beyond a *dead zone* because, for any range value within this dead zone, the voltage starts decreasing again, instead of increasing [1]. This is because, within the dead zone, probability of the narrow IR beam missing the sensor becomes significant. To increase the sensitivity of the IR sensor based obstacle avoidance scheme, the robot system, instead of utilizing a simple IR range sensor, is built with the PIC microcontroller based IR range finder system, developed in-house [2]. The system developed here utilizes an array-based approach where the burst frequency and duration of IR energy transmitted are progressively reduced. The objective is to reduce the dead zone, by utilizing the

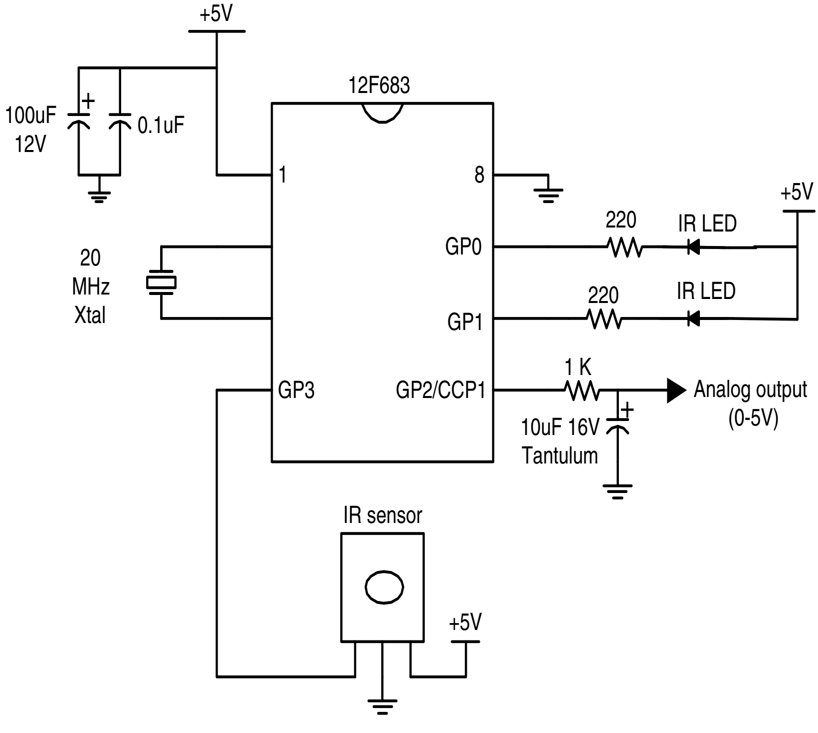

Fig. 4.3. The PIC 12F683 microprocessor based IR range finder system developed, for dynamic range enhancement (Reproduced from [2] with permission from the IEEE. ©2010 IEEE).

output from the IR sensor system to adaptively switch an IR LED ON/OFF. The system employs two IR sources on two sides of the IR sensor whose spatial separation helps to achieve the range enhancement.

Figure 4.3 shows the hardware system developed, in its schematic form, utilizing a PIC12F683 microcontroller [3]. The IR energy transmitted by two high intensity infrared LEDs (IR_LED1 and IR_LED2) is received by a SHARP-make IR sensor system (IS 1U60), called IR_Sensor in Fig. 4.3. The internal block diagram of the IS 1U60 system [4] shows that, when this receiver receives IR energy input, the sensor output goes low and vice versa. The center frequency of the bandpass filter is f_0 = 38 kHz. The relative sensitivity is maximum around the carrier frequency of 38 kHz [4], utilized for frequency modulation purpose. In the nominal case, burst wave signals of 38 kHz frequency, with a 50% duty cycle, are transmitted, for a duration of 600 μs [4].

Algo. 4.1 shows the main routine implemented in the PIC microcontroller. Algo. 4.2 shows the real-time interrupt routine developed, enabled on Timer1 overflow, that works in conjunction with the main routine. We introduce two arrays: (*i*) the *Burst_Freq_Array* for controlling the carrier or burst frequency of IR_LEDs and (*ii*) the *Integral_Cycle_Array* which determines how long the IR_LEDs should transmit in one sweep. In conventional systems, the burst frequency is 38 kHz, with a 50% duty cycle, the transmission duration is 600 μs, and the sensors produce sensitive results for a narrow width of relatively large ranges. We intentionally manipulate these two variables so that the IR_SENSOR receive some amount of IR light energy, reflected back from the object, for several or a few of these burst frequency durations during one sweep, depending on the distance. This information (*Range_Count*) is exponentially averaged to prepare a steady PWM signal. For a reasonable sensor speed, we can only build these arrays of finite lengths, that gives rise to "range quantization" or finite resolution of the system developed.

```
BEGIN
    1. Initialize IR_LED1 and IR_LED2 in OFF mode.
    2. Prepare Burst_Freq_Array and Integral_Cycle_Array.
    3. Prepare Timer1 register pair for Timer1 interrupt.
    4. Program suitable PWM carrier frequency.
    5. Receive Range_Count info. from interrupt routine.
    6. Scale this info. suitably for PWM generation.
    7. Generate PWM signal using exponential averaging.
    8. Go to step 5.
END
```

Algo. 4.1. Main routine in PIC microcontroller

```
BEGIN
 1. Prepare for interrupt using Burst_Freq_Array[i].
 2. Set Count1_max = Internal_Cycle_Array[i].
 3. IF (Count1 > Count1_max),
          Toggle Burst_Duration_flag and Reset Count1.
          IF (Burst_Duration_flag == 0),
               Increment i by 1.
               IF (SIGIN == 0),
                         Increment j by 1.
               ENDIF
          ENDIF
          IF (i reach last entry in Burst_Freq_Array),
               Range_Count =j; Reset i and j;
          ENDIF
   ENDIF
 4. IF (Burst_Duration_flag == 1),
          Put IR_LED1 ON if Burst_Freq_flag = 0.
          Put IR_LED2 ON if both  Burst_Freq_flag  = 0 and SIGIN = 0.
                    ELSE
                              Put both IR_LED1 and IR_LED2 OFF.
                    ENDIF
 5. Toggle Burst_Freq_flag.
 6. Clear Interrupt_flag.
END
```

Algo. 4.2. Interrupt routine

4.3.1.1 The Dynamic Range Enhancement Algorithm

The objective of dynamic range enhancement is achieved by utilizing the output from the IR_SENSOR as a feedback signal (SIGIN) to the microcontroller, which adaptively turns IR_LED2 ON/OFF. Algo. 4.2 shows that the blinking of IR_LED2 is controlled by the states of both *Burst_Freq_flag* and SIGIN. In a conventional IR range finder, within the dead zone, most IR energy reflected back from the object cannot be sensed by the IR_SENSOR. In our system, for distant objects, mostly only IR_LED1 blinks. As we approach the dead zone gradually, IR_LED2 starts getting activated often, as there is a higher probability of SIGIN being low. This intelligent scheme adaptively puts IR_LED2 ON more often with decreasing range, in an intelligent manner, which helps to reduce the length of the dead zone and achieves the required dynamic range enhancement. This is in stark contrast with the working principle of a conventional IR range finder, where, within the dead zone, most of the IR energy reflected back from the object cannot be sensed by the IR_Sensor.

4.3.1.2 Experimental Results

We carried out an experiment in our laboratory, where, for the system without range enhancement, we do not utilize the feedback signal SIGIN to control IR_LED2 in our interrupt routine. Figure 4.4 shows the output voltage vs. range variations for these two cases. For each range/distance, the output voltage computed is the average of ten readings taken, for both with and without range enhancement case. For the system without dynamic range enhancement, the usable range is 25-50 cm and below 25 cm the dead zone arrives. It can be seen that our proposed system could reduce this dead zone and the dynamic range was enhanced with the usable range being 10-50 cm.

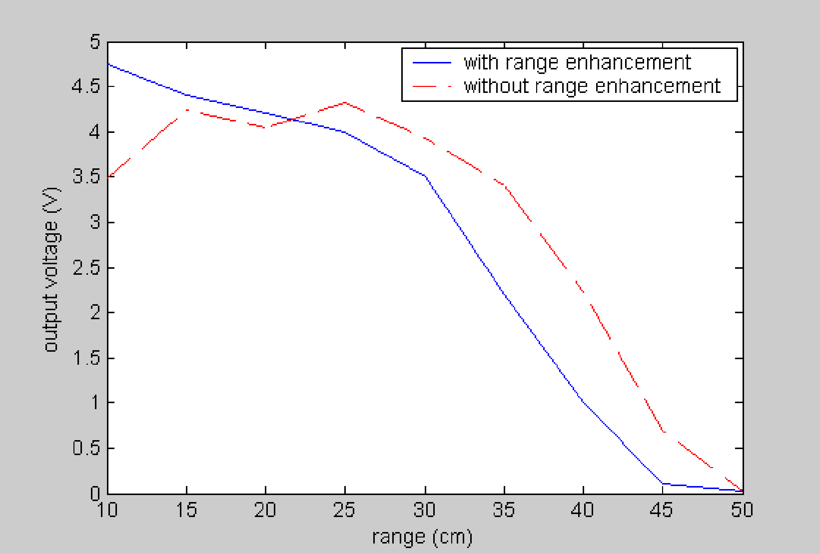

Fig. 4.4. Output voltage vs. range curve for IR sensor system. (Reproduced from [2] with permission from the IEEE. ©2010 IEEE.).

4.3.2 Optical Proximity Detectors Using Switching-Mode Synchronous Detection Technique[2]

The indigenously developed robot system is also equipped with optical proximity detectors which are developed utilizing the theory of switching-mode synchronous detection in a PIC microcontroller based application [15]. Microcontroller based systems have been widely used, in recent times, to develop such low cost robotic

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[2] Section 4.3.2 is based on “A microcontroller based compensated optical proximity detector employing switching-mode synchronous detection technique”, by Anjan Rakshit and Amitava Chatterjee which appeared in Measurement Science and Technology, vol. 23, no. 3, March 2012. Reproduced with kind permission of IOP Publishing Ltd. [Online]: `http://m.iopscience.iop.org/0957-0233/23/3/035102`

sensors systems [2] and also several intelligent instrumentation systems [5-7]. In this section we describe the development of a PIC microcontroller [3] based optical proximity detection sensor system which is developed using switching mode synchronous detection technique, an efficient strategy used to extract fundamental component of a signal heavily corrupted with noise. Such synchronous detection techniques have been popularly employed in AM radio receivers, in ac-biased strain-gauge bridge circuits, in pyrometer systems [8], in mechanical vibration measurement [9], in synchronous phase to voltage converters [10], in fiber optic sensor-based measurements [11], etc. The objective here is to develop a low cost yet powerful robot sensor that can provide accurate proximity indication of obstacles, even with a wide variation of ambient illumination conditions. This system is developed using two white LEDs which emit light to determine proximity of an obstacle. An electronic circuit using a light dependent resistance (LDR) [12] in conjunction with a transistor determines whether an obstacle is in close enough proximity or not. The system is developed with external threshold variation flexibility so that the maximum obstacle distance causing activation of the sensor can be suitably varied for different working conditions. The sensor system developed has an additional important merit that it has dynamic compensation capability so that the sensor performance is designed to be almost independent of ambient illumination conditions.

There are some important factors that influence the performances of such proximity sensors. The detection of an object will essentially depend on the detection of the radiation reflected back from the surface of the object and, hence, for the same closeness or proximity of an object from the sensor, the amount of radiation reflected back will depend on the reflectivity of the object. The reflectivity of the object varies between 0 and 1. A highly reflecting object will have a reflectivity close to unity and vice versa. Another important factor of influence is the condition of the surface i.e. how smooth (or rough) the surface of the object is on which the light energy from the white LED sources are incident. It is known that, if the reflecting surface is large enough to encompass the entire spatial distribution of the light emitted by the two LEDs, then, for dull objects, the sensor's analog signal can be used to determine the proximity distance, if the surface reflectivity is known. However, in most practical situations, the robot sensor does not know the type of object it is going to encounter during its navigation, and hence, the numerical values of their reflectivities will not be known *a priori*. To consider such situations, we have conducted experiments for a set of objects having wide variations in reflectivities and hence the suitability of the sensor developed is extensively tested and verified.

4.3.2.1 PIC Microcontroller Based Optical Proximity Detector

Figure 4.5 shows the PIC 12F675 microcontroller based system developed. This system has two digital outputs (pin 3 and 5) connected to two white LED drives (LED1 and LED2), two analog inputs (pin 6 and 7) and one digital output (pin 2) to turn an LED (named PXD_LED) ON/OFF. The pin 7 input is obtained from the collector of a P-N-P transistor whose emitter circuit contains a light dependent resistor (LDR) [12], whose resistance varies with the illumination. The system is designed with an external preset potentiometer at input pin 6, to adjust a threshold voltage (*THLD_val*), essential for preventing any spurious activation of PXD_LED. Each white LED is driven by an identical rectangular pulse, turning them simultaneously ON/OFF for a chosen time duration.

Algo. 4.3 shows the main routine implemented in the PIC 12F675 microcontroller. Algo. 4.4 shows the real-time interrupt routine developed in conjunction with the main routine and it is enabled on Timer1 overflow. The system is so designed that each time interrupt is generated at an interval of 1 ms. At each such interrupt generation, the value of a counter, named as *count1*, is incremented by 1. According to the design philosophy chosen, the ON and OFF durations of the rectangular pulse driving each white LED are unequal and the ON time duration, in each cycle, is controlled by a designer chosen parameter, *Count1_on_max*, and the OFF time duration, in each cycle, is controlled by a designer chosen parameter, *Count1_off_max*. In each cycle, as long as the value of *count1* remains within *Count1_on_max*, both LED1 and LED2 remain ON. For the time duration when the value of *count1* remain within the band [*Count1_on_max*, *Count1_off_max*] both LED1 and LED2 remain OFF. When both these LEDs are ON, they emit optical radiation. The proximity of an object is determined on the basis of the amount of optical radiation reflected back from a nearby object and this is determined in terms of the voltage signal received at input pin 7, from the output of the LDR-transistor combination. For each such acquisition of an input signal, it is always carried out towards the end of the duration of an ON/OFF time period. This is done to allow analog signal stabilization before any measurement is actually carried out. Hence any such signal acquisition is carried out at those instants when (*Count1* == (*Count1_on_max*-2)) or (*Count1* == (*Count1_off_max*-2)).

Each such signal acquired is subjected to three-point median filtering to eliminate any spurious high frequency component, especially impulse natured signals, which may have contaminated the original signal. The signal acquired at pin 7 and then median filtered is called *LDR_on_val*, when this is acquired during ON time of the white LEDs. The identically acquired and processed signal is called *LDR_off_val*, when this is acquired during OFF time of the white LEDs. One can easily appreciate that, if there is a sufficiently close object/obstacle, then *LDR_on_val* will be significantly higher than the *LDR_off_val*. Hence, ideally speaking, a higher value of (*LDR_on_val* - *LDR_off_val*) means a closer object and if this (*LDR_on_val* - *LDR_off_val*) exceed a threshold value then the output PXD_LED will be turned ON, indicating the activation of proximity detection sensor. However, depending on different environments, there are possibilities that, if this threshold value is made a fixed one, then, in certain situations, PXD_LED may get turned ON, even when the object is not in near proximity. Hence, to avoid such spurious activations, the user is given the flexibility where they can externally set a POT using which they can regulate the threshold value chosen

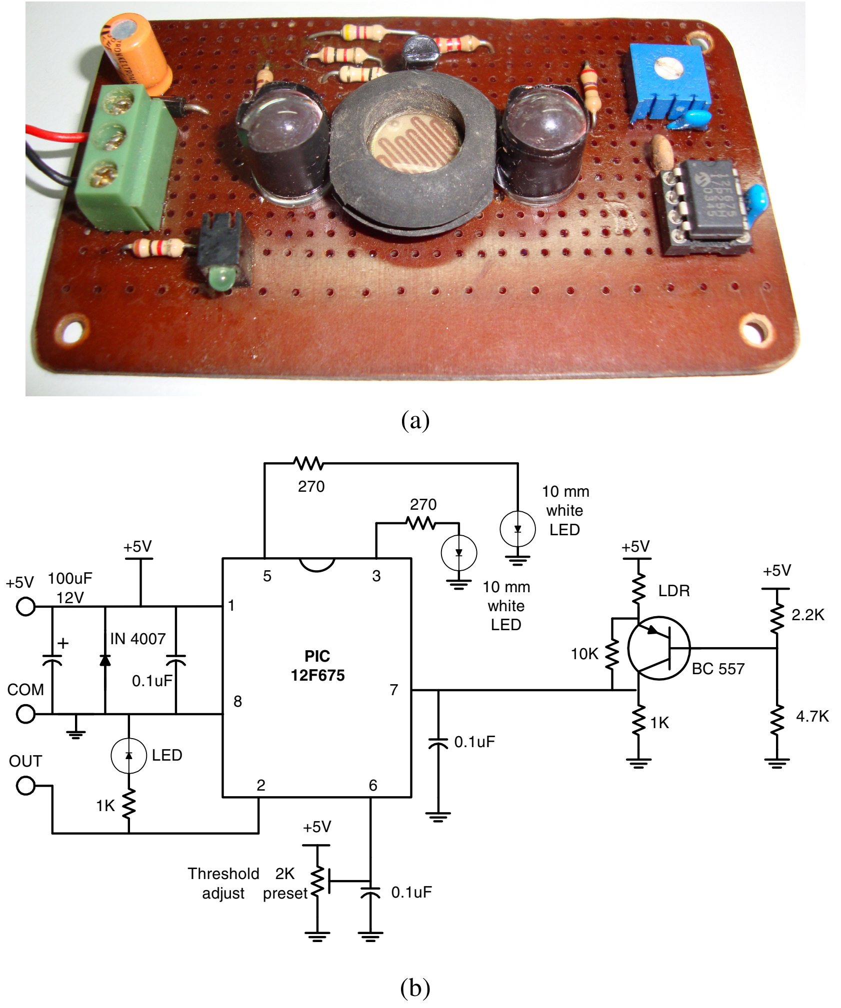


Fig. 4.5. The optical proximity detector system developed: (a) the hardware system and (b) the schematic diagram

(acquired, processed by median filtering and named as *THLD_val*). From Algo. 4.3, if (*LDR_on_val* - *LDR_off_val*) exceed *THLD_val*, then one can conclude that the proximity sensor is close to an obstacle and the output PXD_LED will be turned ON, otherwise it will be OFF.

The developed system also employs a smart compensation scheme that can dynamically cope with ambient illumination variations. The design of the LDR-transistor combination circuit has been so carried out that the transistor always maintains almost constant voltage across the LDR to ensure same signal level, independent of different ambient illumination conditions. Hence an approximately constant signal level is ensured for the two extreme cases of both weak and strong ambient illuminations. This ensures almost linear sensitivity of the sensor i.e. an almost constant ratio of incremental variation in output voltage (i.e. input voltage at pin 7) to the incremental variation in the relative distance between the optical sensor and the obstacle i.e. ($\Delta V/ \Delta x$) value. This directly translates into a very important property of any sensor system designed i.e. provision for almost constant detector output voltage variation with the same change in primary measurand (in this case, distance between the sensor and the obstacle), in spite of variation in other secondary factors (in this case, ambient illumination).

```
BEGIN
  1. Prepare Timer1 for 1 ms Timer1 interrupt.
  2. IF (Count1 == (Count1_on_max-2)),
         Accept the input signal from LDR-transistor combination circuit at pin 7.
     ENDIF
  3. IF (Count1 == (Count1_on_max-1)),
         Median filter the 10-bit ADC converted analog signal in PIN 7 and store it as LDR_on_val.
     ENDIF
  4. IF ((Count1 >= Count1_on_max) & (Count1 < Count2_on_max)),
         Accept the THLD set as an input signal at pin 6.
         Median filter the 10-bit ADC converted analog signal in PIN 6 and store it as THLD_val.
     ENDIF
  5. IF (Count1 == (Count1_off_max-2)),
         Accept the input signal from LDR-transistor combination circuit at pin 7.
     ENDIF
  6. IF (Count1 == (Count1_off_max-1)),
         Median filter the 10-bit ADC converted analog signal in PIN 7 and store it as LDR_off_val.
     ENDIF
  7. IF ((LDR_on_val-LDR_off_val) > THLD_val),
         IF (Count2 == Count2_max),
             Reset Count2 to 0.
         ENDIF
         IF ((Count2 > (Count2_max-10)) & (Count2 < Count2_max)),
             Turn PXD_LED on.
         ENDIF
     ENDIF
END
```

Algo. 4.3. Main routine in PIC microcontroller

```
BEGIN
    1. Prepare for 1 ms timer interrupt.
    2. Increment Count1 by 1.
    3. IF (Count2 < Count2_max),
           Increment Count2 by 1.
       ENDIF
    4. IF (Count1 > Count1_on_max),
           Turn both LED1 and LED2 off.
       ENDIF
    5. IF (Count1 > Count1_of_max),
           Reset Count1 to 0.
           Turn both LED1 and LED2 on.
       ENDIF
END
```

Algo. 4.4. Interrupt routine

4.3.2.2 Switching Mode Synchronous Detection (SMSD) Technique

The synchronous detection is a popular signal processing technique used to extract fundamental component of a weak signal, embedded within a strong noisy counterpart. This technique is popularly employed in radio communication, in industrial scenario (where there is strong possibilities of encountering heavily noise contaminated or disturbed signals) etc. and this technique requires a reference signal with known frequency and phase [8]. A very popular application of synchronous detection technique includes design of superheterodyne receivers for AM radio. In traditional synchronous detection method, the reference signal employed is a pure sinusoidal signal or a harmonic signal. In a popular variation of this traditional technique, switching mode synchronous detection technique employs a square/rectangular wave as a reference signal. The core of a switching mode synchronous detector employs a phase sensitive detector. In SMSD technique [13], a periodic rectangular pulse train is employed as a reference $r(t)$ which is used to sample the noisy signal $x(t)$ and the output of the detector $x_m(t)$ is low pass filtered to recover the fundamental of $x(t)$, i.e. $x_f(t)$. In our scheme, we employ a modified switching mode synchronous detection technique, as shown in Fig. 4.6. Here, the rectangular reference $r(t)$ is used to sample the noisy signal $x(t)$ and this produces the output of the detector $x_m(t)$, identical to a conventional SMSD scheme. Then the output $x_m(t)$ is used to cause an activation of the output LED only when this $x_m(t)$ produces a high signal for a consistently long, continuous duration of time. This is similar to a conditional sample and hold operation and can be visualized equivalent to a low pass filtering action, because it avoids any spurious activation of the proximity detector caused by any high input impulse signal or a short duration input signal, acquired at input pin 7 of the microcontroller, which may have arose because of some unwanted, external interference. If this signal produces a high value for a continuously long time then

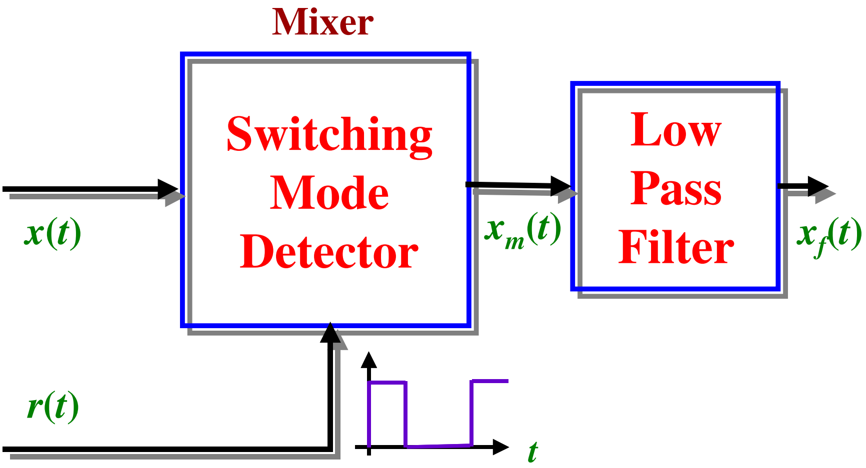


Fig. 4.6. The modified switching mode synchronous detector

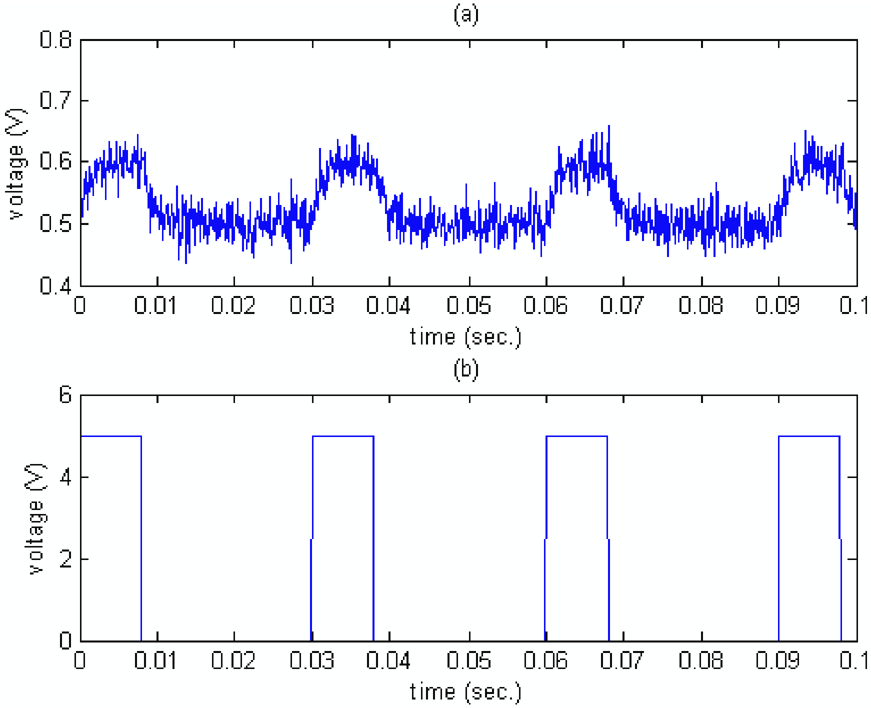


Fig. 4.7. (a) A sample real input signal $x(t)$ and (b) the reference signal $r(t)$

we can infer that it is definitely because of the presence of an object in proximity of the sensor and not because of any noisy signal acquired. Figure 4.7 shows a sample real situation for a given condition of an object in the proximity of the sensor. The input signal acquired at pin 7 of the microcontroller is shown as input $x(t)$ and the reference signal is shown as $r(t)$. It should be borne in mind that, in switching mode synchronous detection technique, the relative phase of the signal under consideration and the reference signal plays an important role [8]. For those frequencies in the signal whose phase do not match with the reference, the output reduces and a given frequency has zero contribution in the output of the switching mode detector, if its phase is at a 90° deviation from the reference signal. In our scheme, the transistor emitter signal output read at pin 7 is the signal $x(t)$ and the white LEDs produce the reference signal $r(t)$. In case of sufficient proximity of an object, the low pass filter produces a high output and for distant objects the output is low. The THLD signal is utilized on whose basis the proximity of an object is determined as a Boolean signal.

4.3.2.3 Experimental Results

The optical proximity detector designed is implemented in real life for detection of nearby objects under several case study conditions. Each time the sensor system showed satisfactory performance with a Boolean output i.e. the output LED (i.e. PXD_LED is turned ON for sufficient proximity of an object or, otherwise, turned OFF). However, as remarked earlier, if the relative distance between the sensor and a distant object keeps reducing, then the exact minimum distance of an object at which this change in Boolean output takes place, from OFF condition to ON condition, depends on various factors. Figure 4.8 shows the experimental results obtained in testing the effect of variation in the minimum distance of an object required to activate the proximity detector as a function of the threshold voltage (*THLD_val*), adjusted externally using a POT. As expected, with an increase in the threshold, the detector gets activated for a smaller minimum proximity, in general. For higher thresholds set, the system shows a near saturation effect, which indicates that there is an effective dead zone for minimum distance to activate the detector.

The experimental results are given for three types of objects in Fig. 4.8: (a) with moderately high reflectivity (p = 33%), (b) with medium reflectivity (p = 16%), and (c) with low reflectivity (p = 7.8%). These reflectivity values are obtained for wavelengths centered at 550 nm. The experimental determination of the reflectivity of each object used is carried out using KYORITSU make Model 5200 Illuminometer. These experimental results are obtained by maintaining the reflecting surface of each object normal to the optical axes of the emitting LEDs. It can be seen that, for highly reflecting objects, for a given threshold voltage set, the proximity detector gets activated at relatively larger distances. For same threshold voltage chosen, if this object is replaced by other objects with lower and lower reflectivities, then the proximity sensor gets activated at closer and closer proximities i.e. the minimum distance of separation required to cause activation of the proximity output LED will get smaller and smaller. For objects with small reflectivities, these proximity distances are quite small and the sensor reaches its dead band very fast, even for small values of threshold voltages chosen. For example, in our experiments, for object (c), this dead band is reached for a threshold voltage of 0.6 V and for a further increase in this voltage, the system cannot be effectively used for proximity detection. Hence, for effective utilization of this proximity sensor for robot navigation, the objects should be at least having medium or low-medium reflectivites so that the robot can safely avoid them, based on this sensor activation. Our experimentations have also revealed that the sensor system developed can be effectively utilized to detect objects of a minimum dimension of 6 cm × 8 cm or of bigger dimensions.

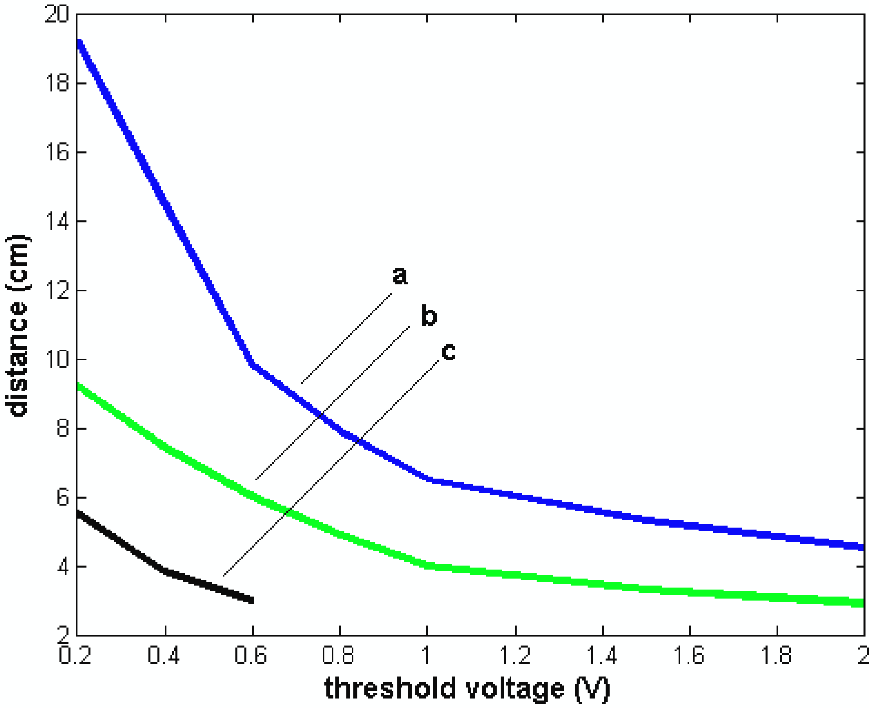
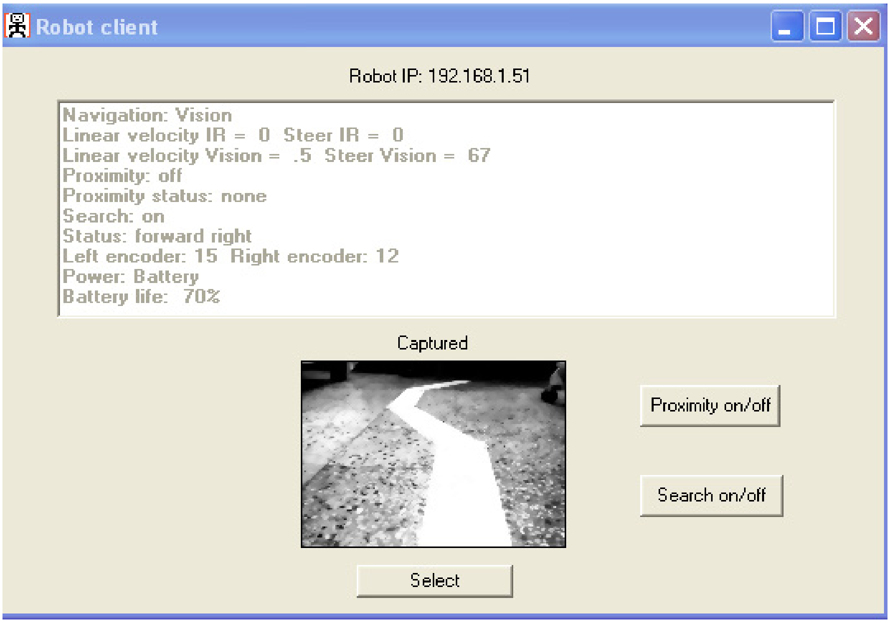


Fig. 4.8. The proximity detector performance curve for objects with (a) reflectivity p = 33%, (b) reflectivity p = 16%, and (c) reflectivity p = 7.8%

4.4 The Intranet-Connectivity for Client-Server Operation

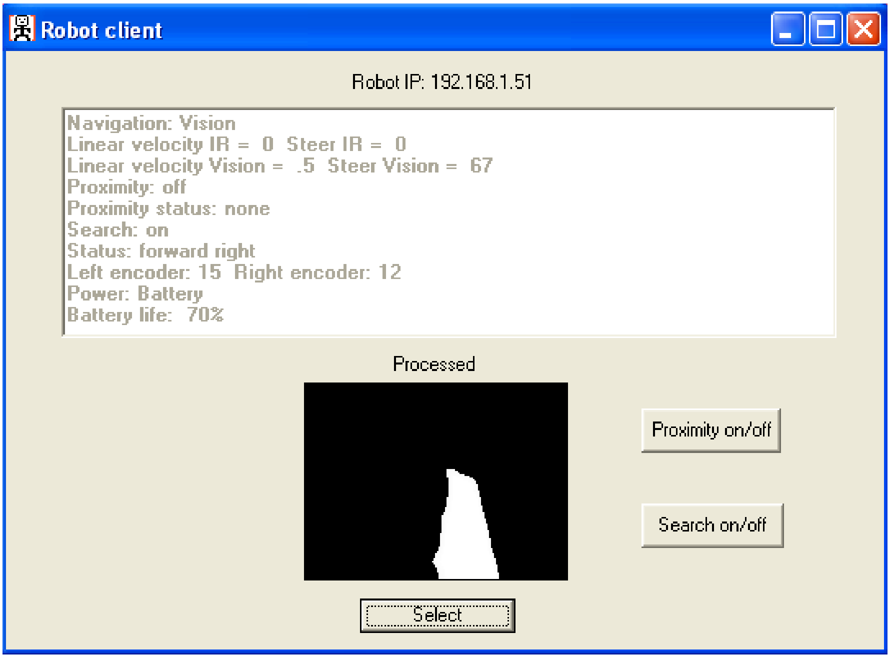
In addition to the two special types of sensor systems, the indigenously developed robot is also equipped with intranet-connectivity where data communication and control command exchange can take place between the laptop mounted on the robot and a remote end PC. In this client-server mode of operation, the robot acts as the server and the remote-end user acts as the client and the communication takes place using Windows based socket programming in TCP/IP protocol.



Robot IP: 192.168.1.51

```
Navigation: Vision
Linear velocity IR =  0  Steer IR =  0
Linear velocity Vision =  .5  Steer Vision =  67
Proximity: off
Proximity status: none
Search: on
Status: forward right
Left encoder: 15  Right encoder: 12
Power: Battery
Battery life:  70%
```

(a)



Robot IP: 192.168.1.51

```
Navigation: Vision
Linear velocity IR =  0  Steer IR =  0
Linear velocity Vision =  .5  Steer Vision =  67
Proximity: off
Proximity status: none
Search: on
Status: forward right
Left encoder: 15  Right encoder: 12
Power: Battery
Battery life:  70%
```

(b)

Fig. 4.9(a) & (b). The GUI-based view from the client-end, at a sample instant, during the robot navigation

The client end can select the robot functionalities like (i) whether the proximity sensors should be used in navigation or not and (ii) whether search mode should be ON or OFF. If the search mode is on, then the stored information for possible steering angle detour is used to guide the robot back to the path, in case the robot leaves the path/line. If the search mode is deselected from the client end, then the robot stops once it leaves the path/line. One can include more such functionalities to add more control flexibilities in remote operation, if it is so desired. The server end can also send both text and image data on receiving "data send_request" from the client. Usually image data is voluminous, and, on receiving a request, the server end first creates an array of all pixel values of an image matrix for transmission. However the entire array of data is not transmitted in a contiguous manner but it is sent in a series of data packets, managed by a low-end device driver. The client end system is also programmed in such a manner that they keep receiving the data packets until a complete image data array is received and then reconstruct the image for display at the client end. The system is developed with an interlocking feature so that the client is not allowed to send a new request, when it is in the process of receiving data packets corresponding to an earlier request. Figure 4.9(a) and Fig. 4.9(b) show an user interface developed in the client end, which show a captured frame and the path/line extracted from this frame, at the server end. As the GUI shows and as mentioned before, the system has the flexibility that, from the client end, one can activate or deactivate the IR proximity sensors, by clicking the button "Proximity on/off". Also one can click the button "Search on/off" which will signify, when the path vanishes from the field-of-view of the robot, whether the robot will continue to take turns in iterative fashion to re-localize itself on the path/line, or will it simply stop further navigation.

4.5 Summary

This chapter described how a low-cost robot can be indigenously developed in the laboratory with special functionalities. The robot system consists of two specially developed microcontroller based sensor systems and also the flexibility of intranet connectivity. Among the two specially developed sensor systems, a PIC microcontroller based IR range finder system is developed where dynamic range enhancement is achieved by adaptively utilizing the IR sensor output to switch one IR LED ON/OFF. This system utilizes an array-based approach to manipulate the burst frequency and duration of IR energy transmission, to enhance accuracy of range finding. Another microcontroller based sensor system designed comprises an optical proximity detection sensor system using white LEDs, an LDR-transistor based electronic circuit and an output LED for Boolean indication of ON/OFF. The scheme is developed using switching mode synchronous detection technique and to facilitate reliable functioning of this circuit under different working conditions, the system is equipped with an external threshold adjustment facility, which an user can advantageously use for fine tuning the performance of the system. Finally the robot is equipped with intranet connectivity for client server operation where the laptop on the robot acts in the slave mode and a remote end PC, in master mode, can command the robot from a remote location for suitable operations.

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