Enhanced Position Sensing Device for Mobile Robot Applications Using an Optical Sensor

A.M. Harsha S. Abeykoon, Lanka Udawatta, M.S. Dunuweera, R.T. Gunasekara, M.Fonseka, S.P. Gunasekara

Department of Electrical Engineering,
University of Moratuwa,
Sri Lanka.

harsha@elect.mrt.ac.lk
lanka@elect.mrt.ac.lk
dunuweera_06@elect.mrt.ac.lk
gunasekarar_06@elect.mrt.ac.lk
fonseka_06@elect.mrt.ac.lk
gunasekaras_06@elect.mrt.ac.lk

Abstract— **This paper introduces a low cost method of sensing position using a optical sensor. Main objective of this study was to overcome the shortcomings associated with the conventional contact type of position sensors using a low cost device. In a slippery terrain, rotary encoder based data often produce erroneous results, whereas, if optical based method is used it would be preferred. For this study, PAN 3101 type low cost CMOS optical sensor is used. This sensor is often used for making computer mice. Built device comprises of a PAN 3101 sensor, lens assembly, illuminating components and a microcontroller based interface. Lens assembly comprises of the convex lenses. PAN 3101 sensor processes the images that are taken through the lens assembly and gives the position in terms of relative distances traveled in vertical and horizontal directions. Microcontroller based interface handles the communication between PAN 3101 sensor and the main application that utilizes this technology. So this module can be used in applications that needs smooth position detection capabilities. Built device was attached to a mobile robot so that the robot can be driven from the position information of the rotary encoder and the new optical position sensing device. Results from both rotary encoder and optical device are presented to validate the applicability of the proposed concept.**

Keywords— **Optical position sensing device, encoder, mobile robots**

I. Introduction

Many people see technology as a solution to some of the problems that exist on our planet. Today, robots can be found virtually in every field, from medical to transport, industrial to recreational. They are slowly becoming part of the background furniture of the modern society without most people realizing it.

In almost all robotic devices, require its position or joint angles to be measured or sensed for controlling. The mechanism of position detection varies according to the nature of the application as well as the environments. Some of the researches carried out for developing position sensing mechanisms, were succeeded. As mentioned earlier, lot of methods such as research of Michio Kondo and Kouhei Ohnishi [1] has focused on few areas such as position detection of slippery situations. But this new technology covers lot of areas such as position detection in different terrains, position detection with different image qualities, with different speeds of the application and different heights to the surface from this module.

A. Position Sensing Using Rotary Encoders

Rotary encoders are sensors that generate digital feedback signals in response to movement and convert that movement of a mechanical position of a tool or signal into an electrical signal that is measurable. Rotary encoders can be used to measure rotary angles, linear movement, speed, velocity, distance and position [2].

B. Position Sensing Using Global Positioning System

The Global Positioning System is a space-based global navigation satellite system provides reliable location and time information in all weather and at all times and anywhere on or near the Earth when and where there is an unobstructed line of sight to four or more GPS satellites. It is maintained by the United States government and is freely accessible by anyone with a GPS receiver.GPS consists of three parts: the space segment, the control segment, and the user segment [3].

C. Other Position Sensing Methods

Apart from the above mentioned two methods, for position detection by following methods is used. Infrared, ultrasonic [3], and Charge Coupled Devices (CCD) [1] are some of them.

D. Advantages of Optical Position Sensing Device Over Other Methods

Mostly for mobile robotic applications rotary encoders are used; as it has mechanical components, frequent mechanical failures can be observed when dealing with rotary encoders. Therefore maintenance cost will be increased and the life time will be reduced. The proposed position sensing device does not contain any mechanical parts. Thus problems associated with the mechanical components will be eliminated with this new proposal.

In the existing systems, the main problem is the tight dependence of the positional parameters on the rotation of the wheels. Therefore when the wheels slip or when there is no proper rotation, of the wheels, the calculations are not accurate.

On contrary GPS has a low accuracy around 1-2m and it cannot be operated in indoor environments [4]. The proposed sensing device could work especially in mobile robot applications where the wheel slip occurs as the sensing is done using a non – contacting method.

Most of existing position detection methods are very expensive. Proposed device can be made with a minimum cost.

When compare the complexity of this method with other existing methods, it can be seen that this technology is very simple and very easy to use and deal with it. Some position detecting methods cannot be used in harsh environments such as on heated surfaces but this technology can be used for position detection even in such environments since this module is not contacting with the surface. Therefore this method can be used for position detection where the soft and smooth operation is required.

II. Methodology

This device comprises of an optical sensing device (OSD), lens assembly with illuminating components and a microcontroller based interface.

A. New Lens Assembly

Position detection using OSD is done based on the surface images taken by the Complementary Metal Oxide Semiconductor (CMOS) camera which is inbuilt in OSD [5]. And in order to form an image on the camera surface should be illuminated.

Therefore to use this sensor for position detection purposes, an image of the surface has to be produced by the CMOS camera. OSD has a very low focusing length around several millimetres because the OSD has been originally designed to be used as the position sensing device for computer mouse.

1) Application of Convex Lens Theory To the New Lens Assembly:

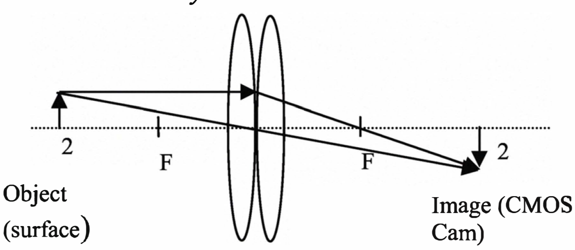

Fig. 1 Lens assembly

Formation of the image of the surface on the CMOS camera is given by Fig. 1. According to ray diagrams it can be said, when the distance of the object from the lens is twice the focal length of that particular lens, the image will be produced twice the focal length of that particular lens away from the convex lens.

In order to keep the distance between the surface and the convex lens 4cm, +50 Diaptor convex lens had to be used. Since the maximum power of the convex lenses available was +24 Diopter, in order to obtain +50 Diaptor convex lenses, a compound lens was made by combining two convex lenses. Above lens assembly is shown in Fig. 1 a compound lens was used. Compound lens theory is expressed by the following equations.

$$\frac{1}{f} = \frac{1}{f1} + \frac{1}{f2} \qquad (1)$$

Where f_1 and f_2 are the focal lengths of convex lens 1 and 2 respectively and f is the resultant focal length of the compound lens [6]. Eventually +48 Diaptor compound lens was obtained by using equation no 1.

Relationship between the focal length of a convex lens and its power is given by equation no 2.

$$\frac{1}{f} = D \qquad (2)$$

Therefore distance between the OSD and the surface could be increased by inserting compound lenses as shown in Fig 1. And distance between lens and the surface was increased by 4.1cm according to the above two equations. This is an essential requirement for mobile robot applications as the increased height from the surface (ground) to the robot would lead to greater flexibility in operation.

2) New Illumination System: Illumination system was basically provided to the system so that LED reflects light from the surface to the OSD. Illumination was provided using five blue LEDs and it was externally powered by providing +15V to the illumination system. Blue LEDs were the best among other colors of LEDs and high quality image could be obtained. Therefore blues LEDs were selected for illumination.

3) *Mounting Arrangement:* Lot of facts had to be considered in the physical development of the lens assembly. The casing was used to hold the lens assembly, Printed Circuit Board (PCB), OSD and the illumination system. The lense assembly was made movable so that different focal lengths could be achieved. This was done by mounting the lens assembly on a material which could be moved by rotating with an aid of a thread. Core was taken to ensure the lens assembly should be light weighted, durable, compact in size and could be fabricated with a lesser cost.

To carry out this task number of materials were available. Ebonite, Nylon, Wood, Plastic were some of the candidates. Nylon was selected among the available materials because it was conveniently fulfils all the aspects of design requirements.

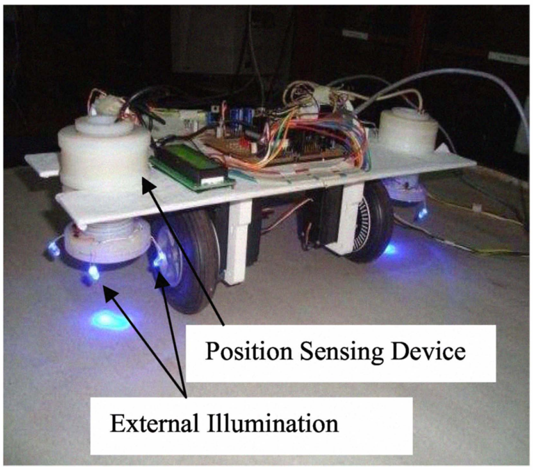

Fig. 2 Physical structure of the design after attaching to the robot platform

Fig. 2 illustrates the position sensing device attached to a mobile robot platform. The whole unit was made as a single unit so that it could be integratable with other components. This position sensing device can be used with independently. The total height of this cylindrical component is about 9cm and it has 2cm radius. And it is made by combining five cylindrical parts and connected to each other in order to vary the length of the holding tube.

B. Interfacing Between the Sensor of the Lens Assembly and the Main Microcontroller

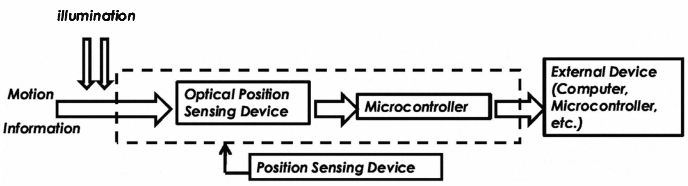

Fig. 3 Position sensing device

Fig. 3 shows the basic block diagram of the position sensing device. External device can be a computer, microcontroller or any other controller. Therefore a new interface was developed in order to keep the communication between the main microcontroller and the optical sensing device. 18F452 Programmable Interface Controller (PIC) was used to interface the OSD.

The minimum PWM frequency that could be obtained from the 18F452 microcontroller was 250Hz. But the PWM needed to drive the servo motor was 50Hz. To drive the servo motors frequency controller was developed to convert 250Hz to 50Hz and this interface was developed using mikroC 8.2 language.

1) Optical Sensing Device: OSD is a complete 2D motion sensor operates with single +5V power supply and uses a precise optical motion estimation technology. It is capable of high speed detection up to 21 inches per second (IPS) and it has accurate motion estimation over a wide range of surfaces. OSD has resolution up to 800 counts per inches (CPI). OSD consists of serial interface for programming and data transferring. A system frequency of 18.432MHz is needed for its operation and it has a frame rate of 3000 frames per second [5]. Oscillator was used to drive the sensor. A regulated power supply was given to the OSD by using LM7805C voltage regulator.

OSD comprises forty five 8 bit registers and these registers were not important for designing the optical position detecting module, therefore only few registers were taken in to consideration. Operation mode 1, Delta X, Delta Y, Configuration, Product ID1 and image quality registers were used to accomplish the task of position detection.

III. Results and Discussion

For data collection and data analysis, a mobile robot platform was used.

A. Analysis of the OSD's Performance in Contrast to its Encoder Counterpart

The final objective of this research was to develop an efficient and accurate position sensing component. Therefore it was important to investigate the deftness of the OSD against its other counterparts.

Developed OSD and its encoder version were forced to tracked different paths for a white colored cardboard. In this case the software XY plotter that was developed for data collection and data analysis. Then using the XY plotter software, the rotary encoder output (Distance travelled by the mobile robot) and the optical position detector output was plotted for both sides (left and right). Fig. 4 shows how the distance travelled by mobile robot 50cm was given by rotary encoder and the optical position sensing method.

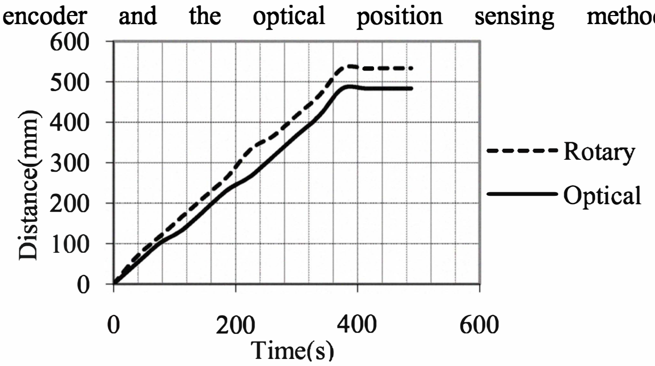

Fig. 4 Real time output of encoder and optical sensor vs time

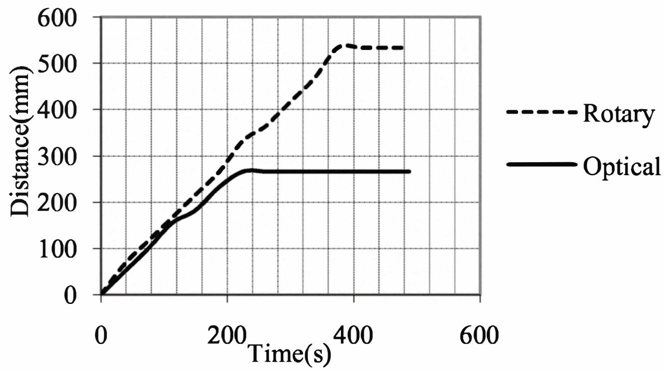

Fig. 5 Real time Output of Encoder and optical sensor Vs time in a slippery situation

Fig. 5 illustrates how the OSD and rotary encoder behaves in a slippery situation. In this test until 200s the mobile robot was driven without any slip. However after 200s it was put in to an artificial slippery situation. Both position sensing devices gave similar readings until it slips as shown in Fig. 5. After the slipping point it can be seen that the rotary encoder gives incorrect readings and the optical position sensing device gives accurate results. Therefore it can be concluded that this proposed device can be used for position detection in such situations.

B. Analysis of the Optical Mouse Sensor's Performance with Mobile Robot's Velocity.

OSD's output is measured at different velocities and this was repeated several times. The maximum variations of the readings are recorded for different velocities. To evaluate the performance of optical mouse sensor, a performance index, Y is defined as depicted in equation no 3.

$$Y = \left[1 - \frac{x_{max}-x_{min}}{x_{actual}}\right] \times 100\% \quad (3)$$

Where

x_{max} : Maximum read value from the sensor

x_{min} : Minimum read value from the sensor

x_{actual} : Actual distance travelled

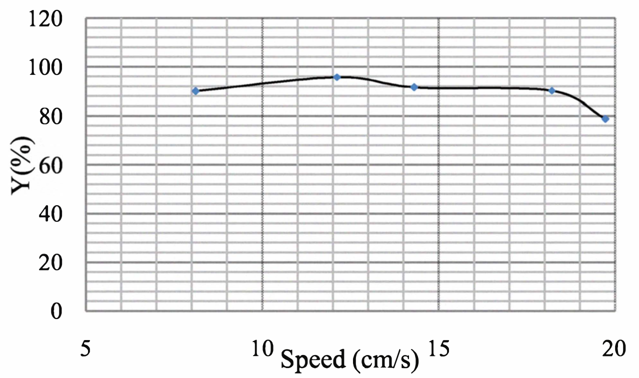

Fig. 6 Variation of Y of the optical mouse sensor over its speed

The Fig. 6 shows the variation of the measurements of the optical mouse sensor with respect to the variation of speed. It can be seen that the Y value is decreasing as the speed increases. Maximum Y is attained at 12 cm/s.

C. Lens Assembly's Performance Under Different Environments

Effect on the image quality by different surfaces was considered. Image quality is an output given by the optical mouse sensor in an eight bit register so that the value can be varied within the range of 0 to 255. Image quality of the sensor thoroughly depends on is the measurable microscopic patterns configuration of the texture. The data has been collected for different surfaces and following graphs shows its graphical representations.

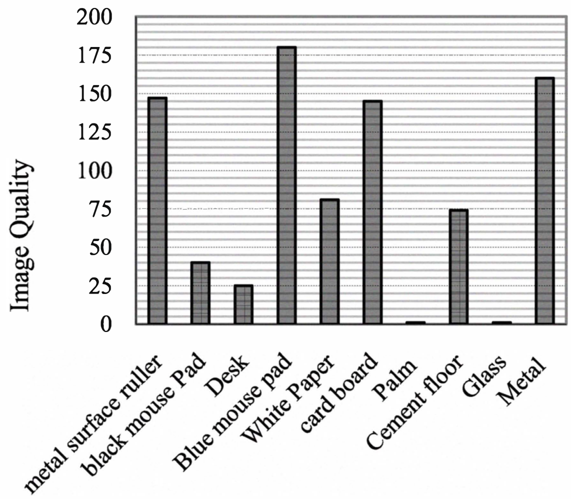

Fig. 7 Image quality for different surfaces of a typical optical mouse

Fig. 7 shows the variation of the image quality of a typical optical mouse with the change in surface. It can be seen that the highest image quality is achieved on the blue mouse pad. Optical mouse does not give accurate reading in glass surfaces and on palm. This is basically due to the reflections happens in the glass surface.

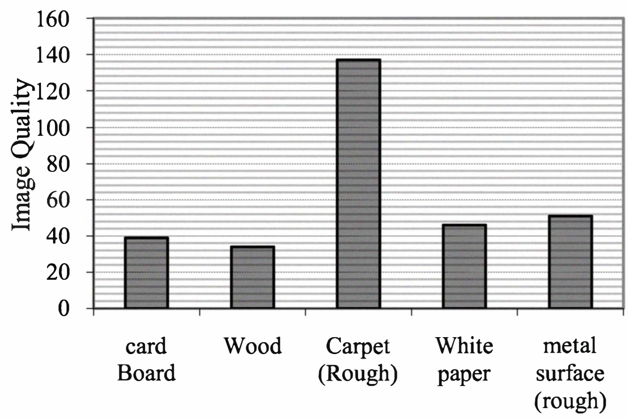

Fig. 8 Image quality for different surfaces

Fig. 8 shows the image quality variation of the sensor with different surfaces. When compared with the normal optical mouse, the image quality of the design is much low due to the errors occurs when focusing the lenses. However it has a higher image quality in carpet surface whereas the image quality is much low in other surfaces.

D. Variation of Travelled Distance of the Mobile Robot in Different Surfaces.

Optical position sensing device was programmed to move in a straight line for 1500 of mouse counters. Then the travelled distances of the mobile robot was measured in different textures in different circumstances. Following graphs can be used to show how accurately this optical mouse sensor can be used to sense its position in different surfaces.

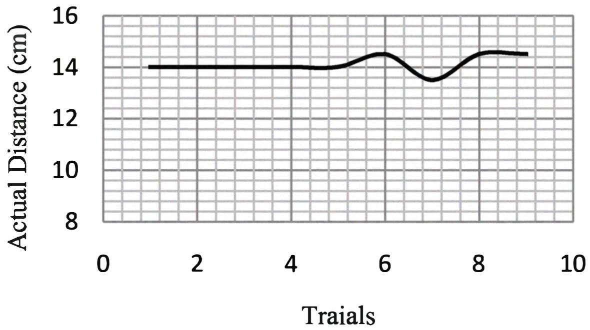

Fig. 9 Actual distance variation for different trials - cardboard

Fig. 9 illustrates how the actual distance varies in different circumstances for a pink colored cardboard. It can be seen that the mobile robot has been travelled all most same distance in different circumstances.

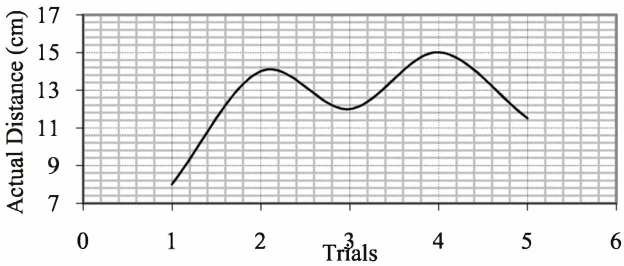

Fig. 10 Actual distance variation for different trials - carpet

Fig. 10 illustrates how the actual distance varies in different trials for a carpet. It can be seen that the distance travelled by the mobile robot, has been slightly varied in different circumstances.

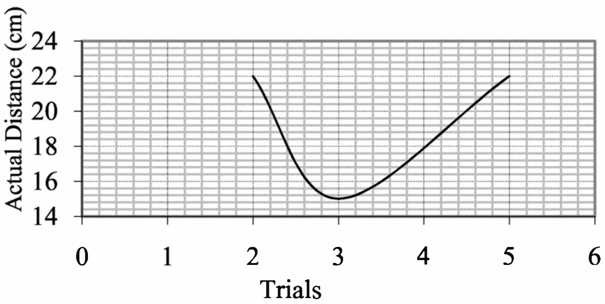

Fig. 11 Actual distance variation for different trials - wood

Fig. 11 illustrates how the actual distance varies in different trials for a wood surface. According to Fig. 11, it can be seen that the distance travelled by the mobile robot, has been slightly varied in different trials for a wood surface.

Out of those three occasions, the lens assembly measurement was all most similar in two times, on wood and carpet. And for pink colour cardboard the position sensing device has been worked accurately.

The other interesting observation is the variation of calibration of the developed optical mouse sensor from one surface to another. On this occasion number of counts (output pulses) produced for a unit distance for different materials is measured.

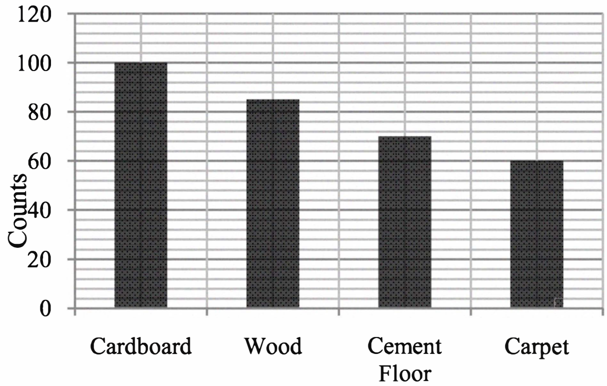

Fig. 12 Calibrations for different surfaces

Fig. 12 shows how the calibration is varying with the surface and it shows that the cardboard is having the higher calibration value. After analysing above data following data could be obtained.

According to the Table 1 it can be observed that the minimum distance which can be measured using this optical technology, is varying with the terrain type. The smallest distance which can be measured by the module is 0.01cm and it can be obtained on a cardboard surface.

TABLE I
MINIMUM DISTANCE MEASURED IN DIFFERENT TERRAINS

Terrain type	Minimum measurement that can be measured
Cardboard	0.01cm
Wood	0.117cm
Cement floor	0.014cm
Carpet	0.016cm

This indicates the accuracy of proposed sensing device in different terrains. The number of pulses per unit distance is higher on the surfaces that have more pattern orientations and which are not shiny. For different types of surfaces the calibration is different, therefore before using this design in a specific terrain, device has to be calibrated. There onwards the device can measure the distance in that specified surface.

E. Lens Assembly's Performance Under Different Illumination Levels

Another important factor that decides the quality of the image is the illumination of the surface. Illumination is provided externally as a peripheral service and in this experiment illumination was changed by varying the voltage and the current to the illumination circuit. Varying the illumination was done on different surface and the resulted data has been expressed in graphical ways.

Fig. 13 shows how the image quality of the optical position detecting device varies with the lux level on a white paper.

There should be a threshold lux level for a given surface in order to produce an image on the CMOS sensor. According to Fig. 13 it can be concluded that for a white paper image quality increase with the increase of lux level. However when the image quality reaches the value of 46 image quality get saturates and even the lux level is increased the image quality does not change.

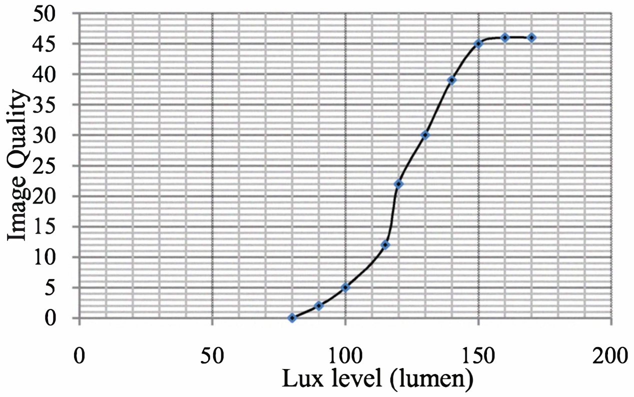

Fig. 13 Lux level vs image quality for a white paper

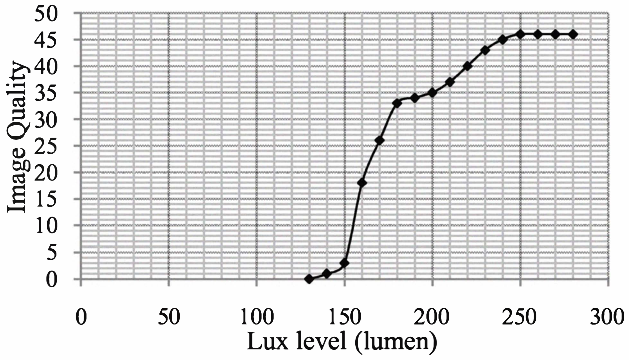

Fig. 14 Lux level vs image quality for a blue colour cardboard

Fig. 14 shows how the variation of image quality with the lux level in the blue colour cardboard. Same as the white cardboard the image quality of the blue cardboard is changing with its lux level. Other important thing that was noted out is the effect of the colour of the LED.

The extra factor that affects the quality of the image is the height from the surface to the lens of the design. The variation of this factor drastically affects the image quality and it is a must to keep the distance at the focal length in order to have a proper operation of the system.

Fig. 15 shows the variation of image quality of the CMOS sensor with the variation of the distance between the surface and the optical position detecting method by keeping the illumination level constant at each circumstance. According to the Fig. 15 it can be observed that for heights lesser than 5cm image will not be produced on the CMOS camera. Starting from 5cm when the height increases from the surface the image quality also increases. After a certain value of height (7.5cm), the quality of the image is decreasing. And when the distance between the lens assembly and the surface increases more than 13cm, no image will be produced on the surface.

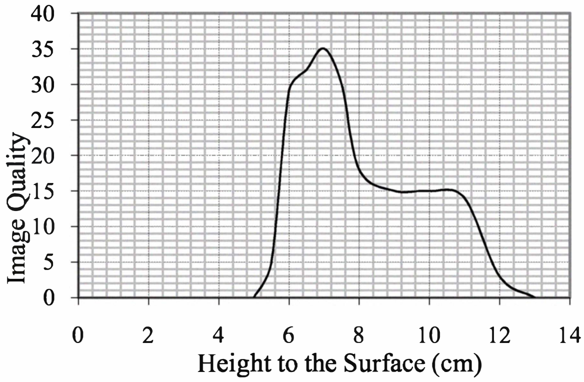

Fig. 15.Image quality variation with the height to the surface

IV. Conclusion

This position detection method is mainly developed for a mobile robotic application that needs high degree of accuracy in tracking its path. In fact, it does not mean that this concept can only be applied to robotic applications. The concept of using an "optical navigation method that involves a PAN 3101 sensor" can be engineered in order to use it in other applications where there is a relative motion as well as position detection mechanism that drives the application.

This position sensing method has lot of advantages when compared with the other position detecting devices. Giving accurate results even in environments. However this sensor has to be calibrated for the specific terrain before it is used. Results show the applicability of the proposed concept. This device can be further developed by introducing the auto focusing capability when the sensor's height is changed.

Acknowledgement

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