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Instruction

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2. Put Thesis topic, supervisor's and your name in appropriate places on both English and Russian languages.

3. Put current year (last row).

4. Convert it to "title.pdf," replace the existing one in the root folder.

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Abstract

In this work, a complete design and implementation of the uni-axial force sensor has been present. This force sensor is based on an optoelectronic sensor which is known as a light fork. This design can be used for various robotics applications to measure the force. The simplicity of design and its low cost, make it more feasible to measure the force applied by different robots by the deformation of a properly designed mechanical structure integrated into the actuation module. This force sensor provides good linearity and sensitivity for applied force.The work contains the complete scheme of electronics schematics with PCB design.The electronics design contains the STM32f405 which has RAM memory to save the calibration data.The mechanical design is also described in this work with proper dimension and length to construct the obstacle and and case of the sensor.The design of sensor can be modified for calibration and integration with robotics module.The methodology of this work describes the basic working principle and also proper mechanism to measure the force applied at on the top surface of the sensor with arrangement of four optoelectronics sensors.

Chapter 1

Introduction

Nowadays, robotics systems and manipulators are used in many types of applications like medical systems and industries which are capable of adapting to the dynamic changes occurring in the environment. To measure these changes a number of features are required . Among these features, force and torque are primary measurements and also have importance in the design of wearable robotics devices like exoskeletons and prostheses.These devices require the efficient sensing scheme to control the forces exerted by an unstructured environment or by the robotics system on the humans or objects. The main purpose of the force sensor is to measure the force up-to maximum accuracy as much as possible. These measured force values are feedback to the robotic controller, so that it can adjust and control the force on a pre-defined scale.
In general, the force sensor contains the small transducer which measures the physical change due to force and then converts these signal into an electrical signal which can be converted into a digital signal using ADC(Analog to Digital Converter). This data is processed by the Microcontroller to calculate the magnitude of the force.The general working mechanism of the force sensor has

been shown in the fig1.1

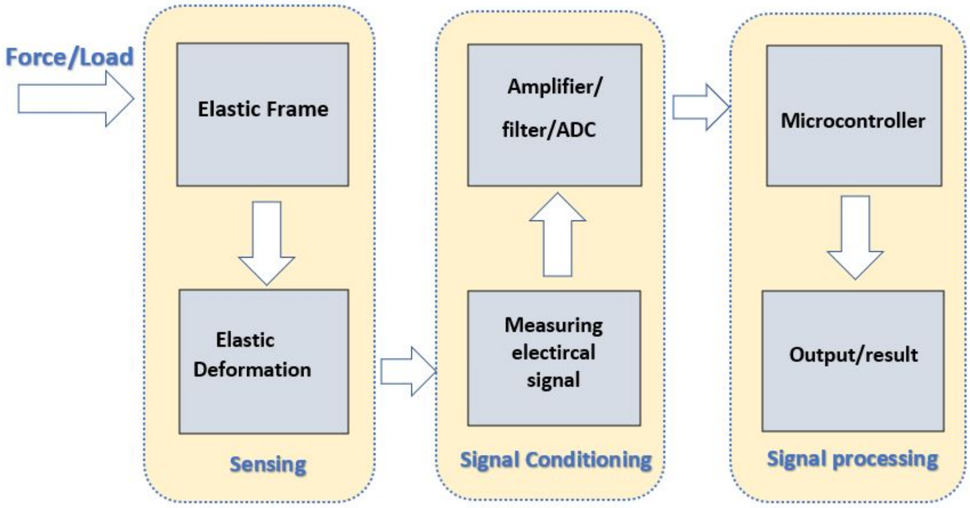


Figure 1.1: General design of Force sensor

1.1 Requirements and specifications

There are many commercial force sensor are available,that are used in different robotics systems. The price of these commercially available sensors is high, which make them expensive to use them in single robotics system.The objective of the work is to design the uni-axial force sensor with low cost and compare-able accuracy with industrial sensors .On the other hand Some robotics systems have different and complex mechanical structures.In these cases we need structure of force sensor in different shapes. For example in the legged robot, the shape of the sensor should be in spherical form to fit it in the joint . The main objectives are listed below for the design of this force sensor.

- Design of low cost sensor.
- Easy design of sensor to measure the force.
- Flexible mechanical design modified according to system requirements.

- Accuracy of the sensor in comparison with commercial sensor.

1.2 Thesis Outline

The Outline of thesis is organized as follow:

- **Chapter 2** contains the literature review about different type of the sensor like strain gauges,Piezoelectric and optoelectronics based force sensor.In this chapter,working of difference sensor and theirs advantage and disadvantages also discussed .

- **Chapter 3** This chapter describes the methodology strategy for design of force sensor.Mathematical model and working principle of proposed model has been explain in detail.

- **Chapter 4** Contains the three section of implementation.In first section schematics and PCB design of sensor is discussed .In second part mechanical design of force has been explained .In last section,process of calibration of force sensor is given.

- **Chapter 5** This describes about experimental setup and evaluation of the proposed force sensor to measure the force. There are various experiment has been performed to check result and validity of the sensor.

- **Chapter 6** Contains the conclusion of the proposed design of the sensor and possible future works to design multi-axes force sensor using the optoelectronics based technique.

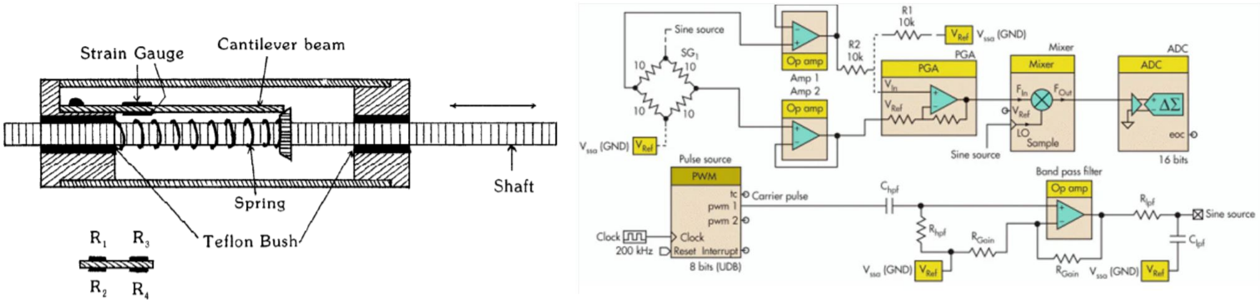
Chapter 2

Literature Review

There are many types of uni-axis and multi-axis force and torque sensors are available in the market.Their working principle and literature review has been discussed in the following sections.

2.1 Strain gauges-based force sensors

Most of the force sensors contain strain gauges-based structures which include the thin-film resistors or semiconductor components for sensing the force.When there is strain is induced in mechanical structure due external load,a change occurs in the strain guage material.These change cause to produce the electrical signal.The value of signal is proportional to applied load or force.by using calibration method,this signal is converted to force amount.So in this way,these strain gauge sensors measure the force[1] .Strain gauge based force sensor is shown in fig 2.1.Strain gauge sensors has some advantages that they have very good linearity but this system required the complex electronics design for signal acquisition, sensitivity to noise and temperature. electronics design is given in fig 2.1b further, the strain gauges based sensor requires a well and proper design for mechanical structures as given in fig 2.1a. This produced difficulty sometimes while integrating with the complex mechanical system of the robot. . So strain gauges based sensors have significant limitations in term of easy design. This brings the robotic designer to rely on some new sensors which have less complexity and feasible with the robotics system during integration.



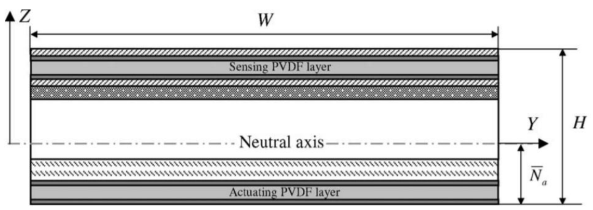
(a) Strain-guage based sensor design

(b) Circuit design for signal acquisition for strain-guage circuit

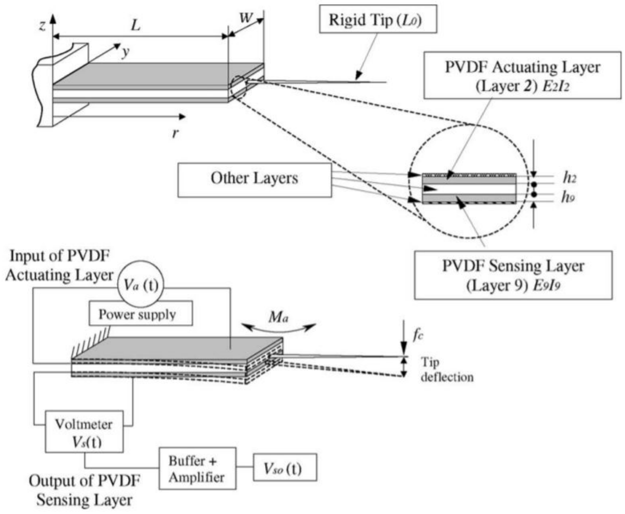
Figure 2.1: Strain gauge circuit design scheme

2.2 Piezoelectric based force Sensor

The work related to design of the force sensor using piezoelectric material has been represented in the article [2].The sensor has been developed by soft cantilevered beam structure and using piezoelectric material which is polyvinylidene fluoride(PVDF) for sensing layer which has been symmetrically embedded in composite sensor beam shown in fig 2.2.The working principle is that when external force is applied its produce the deformation in the soft layer. This deformation due force is recorded by PVDF, using feedback controller these changes measured through electronics circuits.Then these electrical signal are used to calculate the force in calibration process.The sensitivity of this sensor is extremely good, but there is difficulty to design the sensor is need of special labs for piezoelectric material and very care is needed for proper design of these type of the sensors.



(a) Soft cantilevered beam structure using PVDF

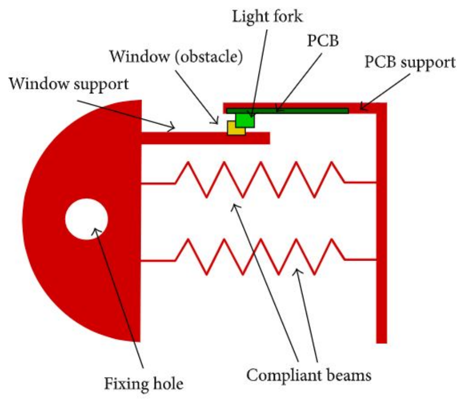


(b) General Piezoelectric based sensor design

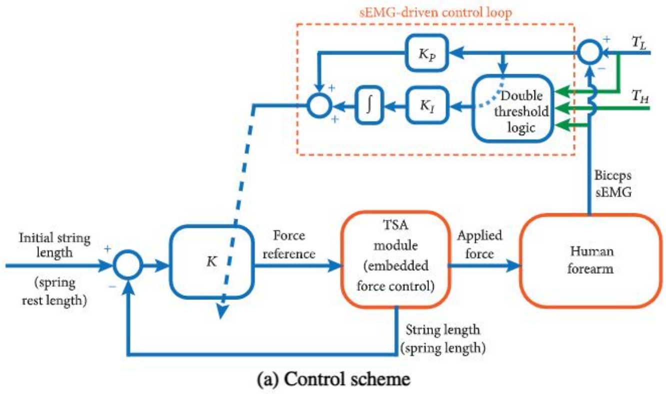
Figure 2.2: Piezoelectric sensor design

2.3 Optoelectronics based sensors

Optoelectronics components are used in various application in the electronics like switching and isolation.Theoretically use of these sensors has been discussed by the several authors [3] [4] [5].The optoelectronics sensors exploit the reflection beam which is emitted by the source and received by the detector or receiver.This beam is disturbed by the external elastically coupled elements.so detector can able to detect this deformation by the complaint structure due to external force[6].There is force sensor in fig 2.3 ,which contain the discrete optoelectronics for the robotics hand to measure the tendon force at the actuator side for force control and to compensate the frictions[7].



(a) Structure of optoelectronics sensor for robotics hand



(b) Feedback controller for design

Figure 2.3: Optoelectronics based sensor design scheme

There optical micrometric based force sensor is discussed in the [8].This measure the differential of the light intensity using optoelectronics devices and a pair of fiber optics the highly accurate and with good sensitivity for two degrees of freedom has been calculated. There is another article [9] Which discuss the work on bases of calculating the coupling power of the optical devices between photodiode and surface-emitting which is separated by a deformable transducer layer.when force is applied the transducer layer changed which receive the power less from transmitter so this change in power is used to calculate force. In this article [3], an optoelectronics sensor is built on the compliant mechanical structure to measure the force for human-force interactions.The working principle was that when force is applied then displacement of the handle piece inside the is measured using the infrared “reflective object ” sensor elements. These sensors are mounted on a PCB board and attached with the inner side of the sensor. There is 6-axis F/T optical sensor is design using a 2-axis photo-sensor which measure the deformation caused by external force or load on the complaint structure[10] .This sensor is 6-axis measurement but the manufacturing and design of the sensor is complex.There is more accuracy is needed to design for calibration.

Another work done on the two types of the sensor(3x3) arrays which are built using fiber Bragg gratings(FBG) and transducers for tactile sensation[11]. Which used to measure the normal force applied on the array of the sensor.This sensor has good sensitivity and spatial resolution.The transducer is designed in such a way that it is not affected by the light loss. There is another work related to optoelectronics based force sensors which work on CCD or CMOS cameras to measure the deformation which is caused by the external force [12]. In this work There is a rectangular box of transparent silicone rubber with dimensions of 10 $\times$10 $\times$4-cm is fixed with an acrylic board. We printed the collection of Different color markers with height of 0.6 mm in diameter are placed inside the box a CCD(color charge-coupled) camera is placed 15 cm below the marker.When force is applied the camera measures the displacement, this displacement is used to calculate the amount of the force.

This tactile based sensor contains the urethane foam and array of IR emitter and detector which are surfaced mounted [13].the foam layer creates the optical cavity above the emitter detector layer. The optical devices mounted below the polymer surface.when the force is applied on the cavity it deforms the optical properties. This change in the properties is used to measure the force which created these changes.

Another optical tactile based sensor has been proposed in [14].This use the LED phototransistor couples and there is deformable elastic layer is placed above the optoelectronics devices.These optoelectronics components are organized in form of matrix .LED illuminates the reflecting surface of the bottom side of the deformable layer.This deformation is occur due to external force which has been applied .due to this the reflection of the LED is changed which produced the variation of the current on photo detector. Which may be positive or negative .So these changes used to calculate the amount of the force. There is a 3D structure based tactile sensor that is discussed in [15]. The main working principle of this sensor is that it measures the force with three separate photodiodes.Three sensors are used to measure the three directional forces imposed on the sensor shown in 2.4.The LED through the light on the inner surface of the dome,each sensor works independently . each side only produced the reflection on the specific region. So this reflection is used to measured the force from all three sides of the sensor.

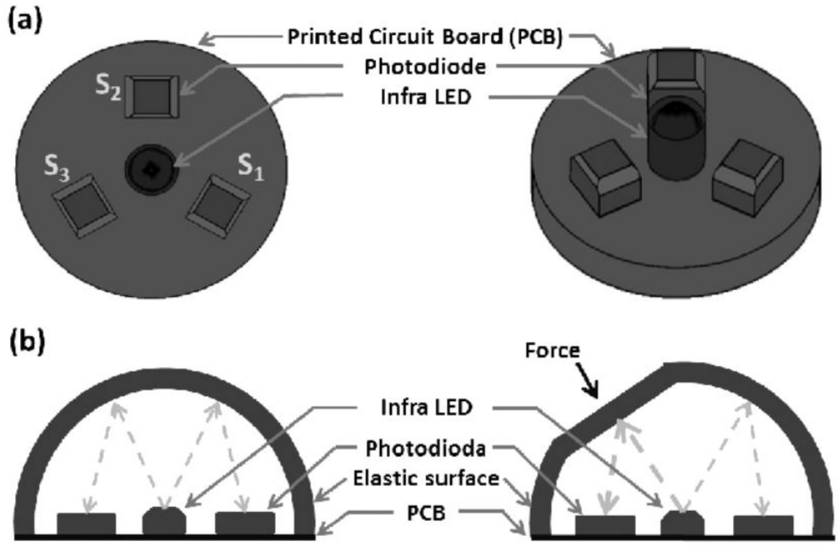


Figure 2.4: 3D structure based tactile sensor

Another alternative solution using fiber optic has been proposed in the in[16].This contained on Fabry-Perot strain interferometer.These contains the two flat semi transparents mirrors. Light propagates between them by reflection. There is some light transmitted and some light reflected .The distance between these two mirror fibers is usually in nanometers. When force is applied and this distance changes, the reflection angles and strength are changed. These changes are used to measure the amount of the force applied on the surface of the sensor.These types of sensor are compatible in high field magnetic resonance imaging (MRI). The machine learning techniques are investigate the sensors describe in the [17].this LIM(light intensity modulated) force sensors are widely used in the field of flexible system and surgical robotics.In this article there are three LIM force sensor are fabricated and machine learning regression techniques for compensation of temperature and ambient light sensitivity using on board environmental sensor data. These number of design and implementation of force sensor provide the importance and use of the optoelectronics devices in sensor.

Chapter 3

Methodology

Theoretical background for the design of the force sensor has been described in the previous chapter, where we have studied the different methods to design the force sensor. For effective measurement of the force, the transducer should need repeatability, accurately and predictably characteristics. In this work, our main focus is to design the cheap and easily manufactured uni-axial force sensor for different robotics systems. Method of design and mathematical model has been described below in subsections

3.1 Optoelectronics Devices

Optoelectronics devices are a major field in electronics. These devices used to measure the light intensity and convert them into an electrical signal, Value of the output depends only on the intensity of the light received by the receiver of the optoelectronics device. There are many sensors that work on the principle of optoelectronics devices. In general, the optoelectronics sensors contains LED(Light-emitting diode) which act as transmitter for light whereas PD(photodiode) act and receiver, when LED transmit the light and PD receive the light on its surface, its start to conduct the electrical signal depending on the amount of light. There is no physical connection between LED and PD. The basic mechanism of optoelectronics sensor has been shown in 3.1

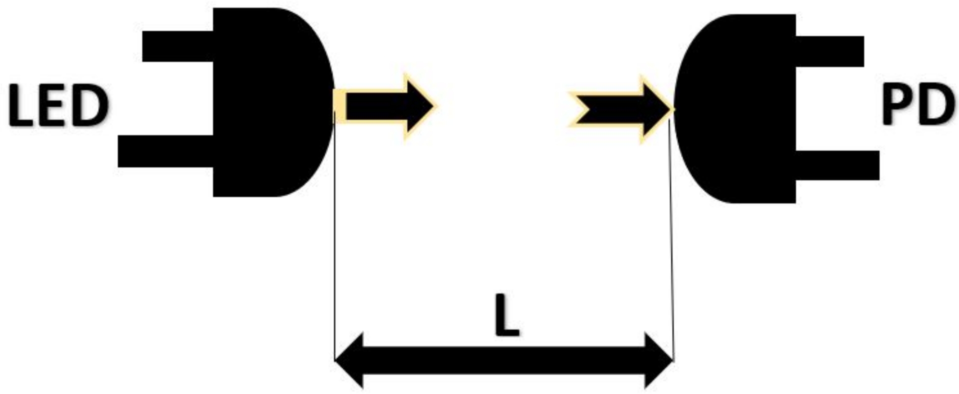


Figure 3.1: General Design of optoelectronics sensor

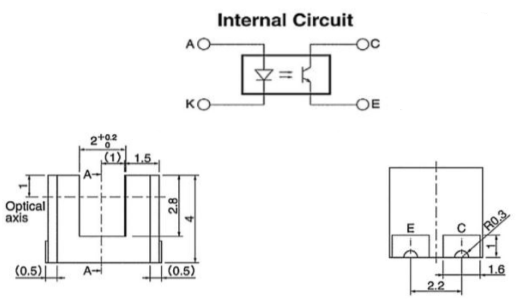
3.2 Photo-micro-sensor (OMRON EE SX1108)

There are many Photomicrosensos available.But for this design, the OMRON EE SX1108 has been used. Here it is called a light fork due to its forked structured. The main properties of this sensor has been listed below .

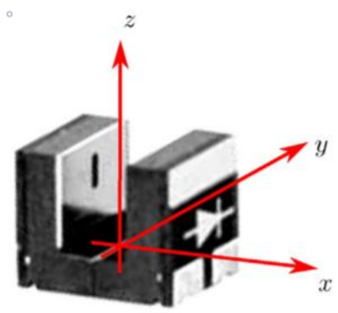
- It is more sensitive compare to the other sensors
- Both LED and PD are embedded together in a compressed structure and precise relative position.

- Both an LED and a PD face each other and provide a thin window that restricts the light cone coming from the LED to the PD just focused on a specific region.
- Produce output with high resolution and accuracy in response to the input

Details of the sensor design have been reported in fig 3.2 Particularly light fork sketch, dimension, and the internal circuitry is given in fig 3.2a and component has been shown with reference frame in fig 3.2b.This detail is given in datasheet of OMRON EE SX1108.



(a) Sketch and Dimension



(b) 3D view with reference axis

Figure 3.2: OMRON EE SX1108 sensor detail

The light cone of the light fork used in the proposed sensor design is well shaped, providing a very steep and linear transition. Region between the fully covered and the fully free light conditions and allowing a good sensitivity and linearity to be obtained.

3.3 Working principle of the sensor

The Working Principle of the sensor is based on the modulation of the current flowing through the PD. which is control by the mechanical component called obstacle. This obstacle used to partially intercept the path of the light emitted by the LED and received by the PD .When there is no obstacle present between them, its limits the light flow, and LED is considered as a source of point light and PD as the receiver surface. As depicted in fig 3.3.In this scenario current flow through the PD only depends on the relative position between PD and LED. From fig 3.3, Left point $\overrightarrow{A}$ represents the LED which is assumed as the point light source, on the right side the line $\overrightarrow{CD}$ represents the PD surface. Optical axes of both LED and PD are aligned and presented by the line $\overrightarrow{n_{led-pd}}$. point $\overrightarrow{B}$ represents the point of intersection of the optical axis and PD surface. from middle point B its represent the receiving angle of light on PD surface from a point source at distance $\overrightarrow{d}$.

When an obstacle is introduced in between LED and PD as shown in fig 3.4 . Some amount of light from LED is intercepted by the obstacle and optical power is measured in the form of P(sigma). The position of the obstacle is define by the variable which is from range o to 1. it means when the value is zero there is no occlusion and 1 means full occlusion .and no power transmitted. the equation when there is no obstacle is calculated by the following equation

$$P(\sigma) = K \int_{-\frac{\theta}{2}}^{\frac{\theta}{2}} I(\theta)R(\theta)\,d\theta \tag{3.1}$$

Where k is used to represent the device characteristics.$I(\theta)$ and $R(\theta)$ are used to represent he radiation pattern of LED and responsivity pattern of the PD. When there is obstacle came between them , equation of transmitted power is

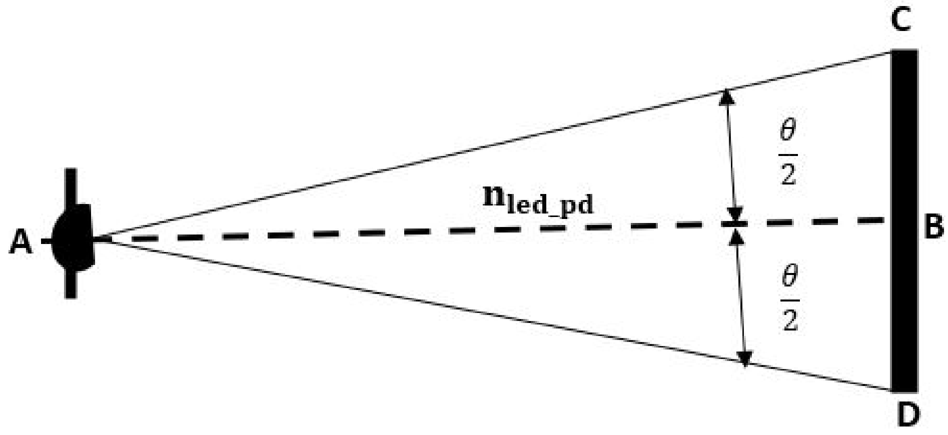


Figure 3.3: Representation of Intersection between LED and PD without obstacle

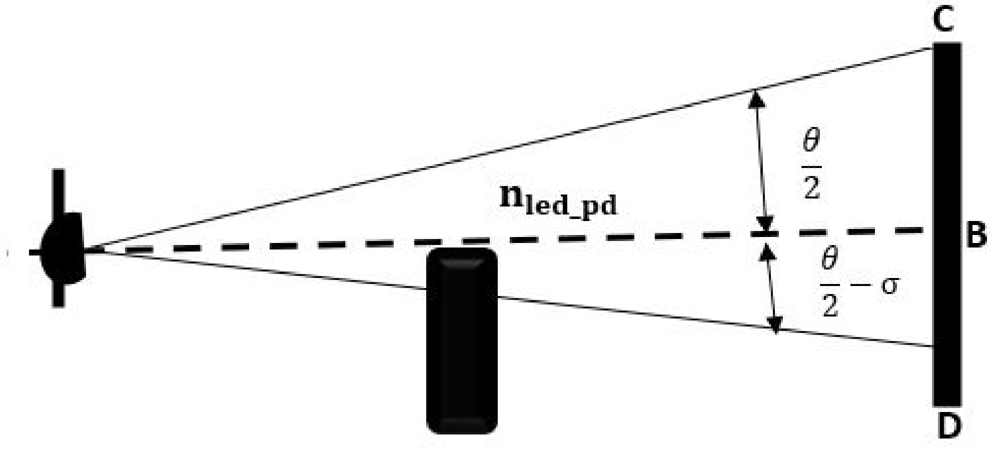


Figure 3.4: Representation of Intersection between LED and PD with obstacle

changed and represented by the following equation

$$P(\sigma) = K \int_{-\frac{\theta}{2}+\theta\sigma}^{\frac{\theta}{2}} I(\theta)R(\theta)\,d\theta \tag{3.2}$$

when σ =0 , then there is no occlusion,and $P(\sigma) = P_0$,but when obstacle moved between LED and PD and block the path completely then $P(\sigma) \longrightarrow 0$, and total occlusion is that $P(1) = 0$

As from the fig 3.4 , its shown that optical axes of light fork of LED and PD n_{LED} and n_{PD} are well aligned and theirs respective angle α and β are zero another relation between relative light current and I_L and transmitted power $P(\sigma)$ can be relate using following relation

$$I_L = K_1 P(\sigma) \tag{3.3}$$

where K_1 represent the characteristic of PD.Similarly the output voltage V_0 of the sensor can be calculated by from

$$V_0 = R_{PD} I_L \tag{3.4}$$

When changes occurs in light power receive by the PD can be acquired by measuring output voltage V_0 the circuit is shown in the figure 3.5.where given voltage is V_{cc} .The maximum out voltage V_{max} will be selected to avoid from saturation of the PD of the sensor. The maximum displaced of the obstacle can be limited to σ_{max}.

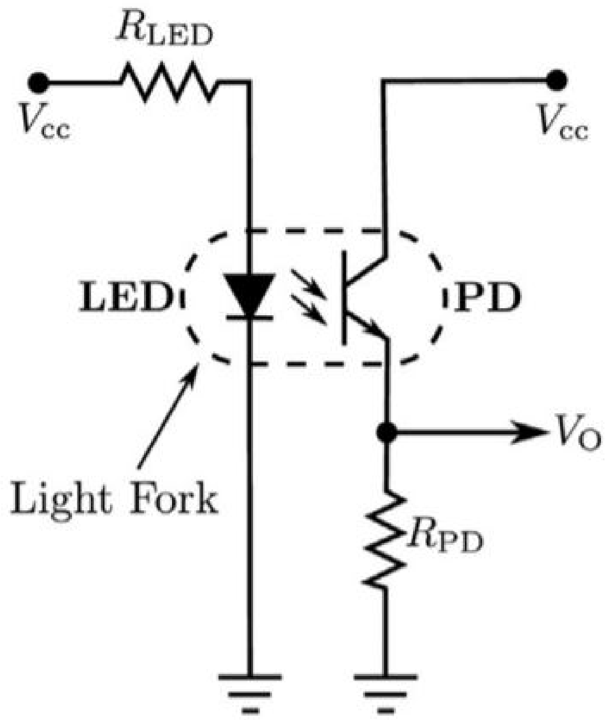


Figure 3.5: Electrical circuit presentation with V_{cc} voltage

The load resistance R_{PD} can be calculated from above equation

$$R_{PD} = \frac{V_{Omax}}{k_1 P(\sigma_{max})} \tag{3.5}$$

The light fork of the sensor is proposed in design with well shape.This provide linear and steep transitions of the region for fully covered and fully free light conditions, which allow good sensitivity and linearity with movement of the obstacle.So when we move the obstacle inside the sensor its give linear relation with voltage value, these voltage value used for calculation of the force.

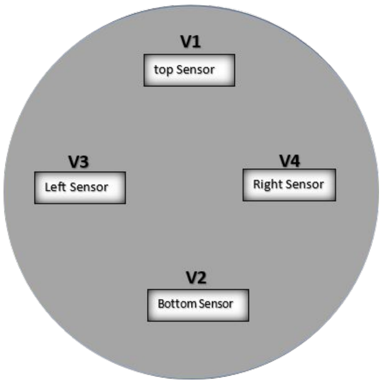


Figure 3.6: Four optoelectronics sensor based design

3.4 Four optoelectronics sensor based design

In the previous section, we have discussed the working of a single OMRON EE SX1108 sensor, which shows the linear relationship for output voltage, when an obstacle is introduced inside it. To measure the force from four sides left, right, top and bottom, to cover the whole 360 area, there are four force sensors that have been used as shown in fig 3.6. Which measures the total force .

3.5 Calculation of Force

There are four sensors used which generate the four voltage output. These values are used to measure the total force.To measure the force least-square method has been used.

3.5.1 Least square Method

The least-square is the method that is used to find the best value of the unknown variable in the large dataset which gives the best fit for the dataset by minimizing the error to satisfy expression with very small error.
As from above discussion we get the output from the sensors in form of volt-

age.So there are four sensors which produce the four voltage : At the start the known force has been used.

$$F_1 = \lambda_1 \; V_{11} + \lambda_2 \; V_{21} + \lambda_3 \; V_{31} + \lambda_4 \; V_{41} \tag{3.6}$$

$$F_2 = \lambda_1 \; V_{12} + \lambda_2 \; V_{22} + \lambda_3 \; V_{32} + \lambda_4 \; V_{42} \tag{3.7}$$

$$\vdots \tag{3.8}$$

$$F_n = \lambda_1 \; V_{1n} + \lambda_2 \; V_{2n} + \lambda_3 \; V_{3n} + \lambda_4 \; V_{4n} \tag{3.9}$$

These equations can be presented in to into matrix form below

$$\begin{bmatrix} F_1 1 \\ F_2 \\ \vdots \\ F_n \end{bmatrix} = \begin{bmatrix} V_{11} & V_{21} & V_{31} & V_{41} \\ V_{12} & V_{22} & V_{32} & V_{42} \\ \vdots & \vdots & \vdots & \vdots \\ V_{1n} & V_{2n} & V_{3n} & V_{4n} \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} \tag{3.10}$$

if we represent the force vector with F, voltage vector with V and unknown multiplier factors with B, then we can express them in following simple equation

$$F = VB \tag{3.11}$$

as F and V are already known we can calculate the value of vector B following equation

$$B = FV^{-1} \tag{3.12}$$

As F is applied known force and V's values are output voltage from all four sensors, these value are in large numbers and contain 1000s of values.Here, Least square method is used for calculation and give best value of the vector B which produces the minimum error and produce the most fit value which will satisfy the expression. after calculating the value of the vector B we can be able to calculate unknown force applied on the sensor.

$$F_{unknown} = \lambda_1 \; V_1 + \lambda_2 \; V_2 + \lambda_3 \; V_3 + \lambda_4 \; V_4 \tag{3.13}$$

Chapter 4

Implementation

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Chapter 5

Evaluation and Discussion

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Chapter 6

Conclusion

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Appendix A

Extra Stuff

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Appendix B

Even More Extra Stuff

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.