DESIGN AND IMPLEMENTATION OF SERVER BASED POSITION AND ANGLE MEASUREMENT AND CONTROL OF DC MOTOR

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List of Symbols

w_m	Calculated angular speed
w_{r}	Actual speed of the shaft
w_{fm}	Calculated speed by frequency measurement method
w_{pm}	Calculated speed by period measurement method
w_{crit}	Critical speed
θ_g	Graduation angle (angular step)
$\Delta\theta_p$	Physical resolution
θ_{max}	Maximun covered angle
N_{pr}	Number of pulses per revolution
N	Number of (counted) pulses
ΔQ_w	Quantization error
e_{fm}	Relative error for frequency measurement method
e_{pm}	Relative error for period measurement method
T_w	Time observation window (speed sampling time)
T_h	Time period of high frequency clock pulse
T_s	Sampling time
T_e	Incremental encoder pulse width
T_{eq}	New adopted time window for speed calculation
n	Number of periods of high frequency clock pulses

List of Abbreviations

ppr	Pulses per revolution
cpr	Counts per revolution
rpm	Revolution per minute
CCW	Counter clockwise
CW	Clockwise

Abstract

Motion control process requires highly accurate speed information with high bandwidth. Incremental Encoders are used as *rotary feedback position and speed sensors* that converts *motor position and speed information* into coded electrical pulse. Accurate speed decoding system is very important to extract necessary position and speed information from encoder output, which is further required by the motion control process. *Resolution of the encoder being used* and the *data processing technique* highly influences the level of accuracy and bandwidth. Topics of discussion – 1. Different Incremental Encoders; 2. Speed Decoding Algorithms.

Acknowledgements

First of all, we would like to bow earlier than ALLAH Almighty, the most Omnipotent, the Most Merciful, the Most Beneficial, Who bestowed us with such a lucid Genius that we may want to endeavor our services in the direction of this manuscript.

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We are very thankful to our family members for supporting us throughout our graduate study.

1. Introduction

1.1. Background

A typical motion control system has *a motor, a drive and a controller*. *Controller* performs necessary calculations to obtain desired motion in result. So, what does feedback devices, encoders do? They play a vital role to achieve high performance and accuracy. They inform the controller or drive with details about *actual position and movement of motor shaft.*

Different types of rotary speed sensors are there based on *Magnetic, Electromechanical, and Optical*.

Optical Incremental Encoders are widely used as speed sensors due to low maintenance, low cost and high noise immunity. Optical Incremental Encoders have disc with a circular graduation track consisting of transparent and non-transparent sequence of windows. These windows allow and restrict the optical beam from a source to reach the optical sensor periodically. 2 fixed optical beam sources are placed on one side of the disc and are shifted, while sensors are located on the other side. When the shaft of an incremental encoder is rotated, it generates 2 electrical pulse trains which are shifted by quarter of the angular step graduation. An angular step of graduation means the angular displacement starting from one non-transparent window to the end of successive transparent window. The shift between pulses is required to find the direction of rotation while the angular position of the encoder is directly proportional to the number of pulses produced.

Output pulses carry low level information which are then fed to decoding circuitry in order to calculate shaft position as well as its speed which is further required for control purposes.

To calculate speed, A speed decoding system is needed – 1. Compatible to the encoder being used. 2. Accurate 3. Provides Rapid Response 4. Suitable for wide speed range.

Accuracy of speed measurement depends upon resolution of encoder which is governed by the structural design of graduation of the encoder disc. *The design of the encoder* along with the *data processing hardware* or circuitry introduce quantization error in final measurement. Some estimation technique and signal processing methods are required in order to minimize the quantization error, and for obtaining a measurement which should not move from actual value and should be suitable for all speed ranges.

Quantization Error: Process of mapping input values from a large set of output values.

With two basic approaches: frequency and period measurement method, different speed calculation algorithms are presented here.

Frequency Measurement Method: One in which the number of electrical pulses from an encoder are counted inside a fixed time window. As the number of pulses is directly proportional to angular rotation of the shaft, the speed as well as angular position can easily be calculated. It introduces quantization error at low speeds where pulse duration is too long and thus makes it not suitable for low speed region. Main advantages of this method are – 1. Simple circuitry required for its implementation 2. Short time for processing that makes it possible to produce good results at high speeds.

Period Measurement Method: Measuring number of periods of high frequency clock pulse in one or more encoder pulses. The approach works better in low speed region, while at high speeds, the encoder pulse may be smaller compared to high frequency clock period, the pulse interval is not measurable. This also shows quantization error as it measures integer number of periods. Error is high at high speeds and provides accurate results in low speed region.

To be able to use both methods in the wide speed range, a combined way based on both frequency and period measurement methods, is discussed in the following thesis. The switching is done by matching the error level produced by the methods in such a way, which above certain level of speed, estimation of speed is done by using the frequency measurement method. Now again, below that level the period measurement approach is used, thus reduces the quantization error to an acceptable limit. Still the combined method is not useful to get the suitable measurements. So why does this happen? *It is because* *of intermittent speed feedback to the controller due to the low frequency of the encoder pulse.*

How to overcome this? A variable combined method based on frequency and period measurement is presented in this thesis.

Traditional combined method of speed estimation based on frequency and period measurement method requires the fixed sampling period. But in variable method, sampling time starts from the start of encoder pulse and ends with it, It has advantage in the low speed region, when the encoder pulse frequency is very low compared to sampling frequency, it turns to be period measurement method from start of one encoder pulse to its end, and produces the same relative error as in the period measurement method.

But when at higher speed, it combines the advantages of both frequency and period measurement approaches as the relative error is almost same for both of the methods.

1.2. Objectives

This thesis describes the cutting-edge speed estimation algorithms targeting incremental encoders, subject to accuracy, rapid response time, wide speed range application and simple design structure. These algorithms are theoretically explained, implemented in MATLAB Simulink and investigated through simulations and experiments. Main aim of this thesis is to analyze and compare each algorithm from its implementation to performing point of view and to highlight the main characteristics of each one.

2. Encoders

2.1. Overview

Encoders are mechanical to electrical transducers whose output is derived by "reading" a coded sample on a rotating disk or a shifting scale. The classification of encoders is considered by the following:

- Method used to study the coded element: contact or non-contact
- Output Type: Absolute digital word or series of incremental pulses
- Bodily phenomenon employed to produce the output: electrical conduction, magnetic, optical, capacitive

2.2. Contact Encoders

Contact encoders are those which rent mechanical contact between a brush or pin sensor and the coded disk. The disk carries a sequence of concentric rings or tracks which are thin steel strips joined at their base as shown in Figure 2-1. The 4 tracks shown in Figure 2-1 signify a binary code consisting of 2^0, 2^1, 2^2, and 2^3. The related contact sensors are identified at B_0, B_1, B_2, B_3, and encode the numerals 0 thru 15. As the disk rotates, the sensors alternately contact conductive strips and adjacent insulators, producing a sequence of square wave patterns.

Uniform and non-uniform disc patterns can be utilized relying on the application. Virtually any sample which can be produced photographically can be imaged on an encoder disc. The regular application is dimension of

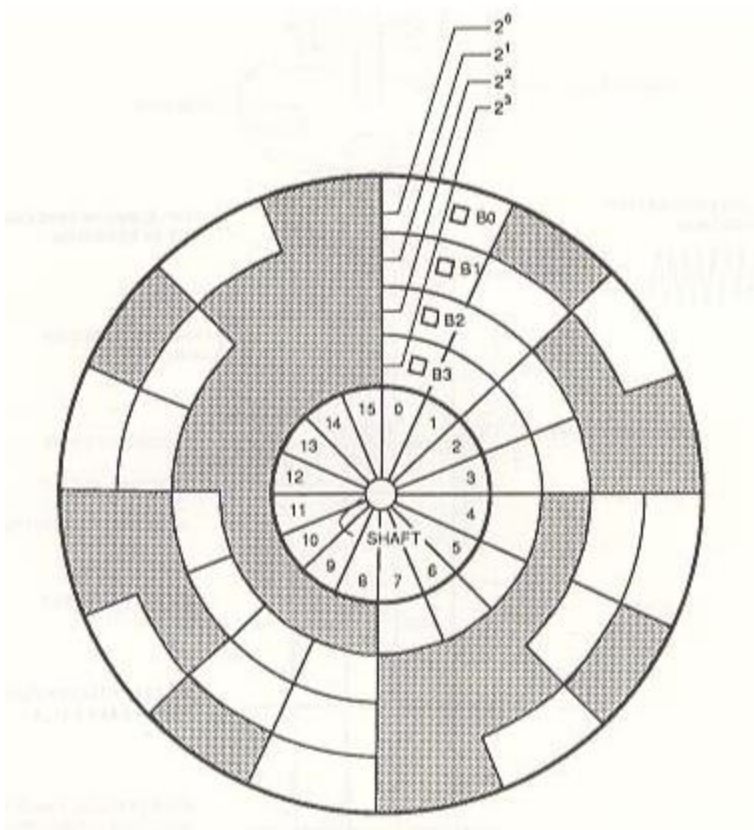


Figure 2-1: Absolute Contact Encoder Disk

Source:
http://irtfweb.ifa.hawaii.edu/~tcs3/tcs3/0306_conceptual_design/Docs/05_Encoders/encoder_primer.pdf

shaft function which utilizes a uniform pattern. Any non-uniformity in the disc is a source of error. Non-uniform segment spacing produces position error and eccentricity motives an error which is a sinusoidal feature of the shaft angle. Performance specifications are limited for factors such as, sensible segmenting limitations on discs, bridging of disc segments, and wear of contacts.

2.3. Non-Contact Encoders

Non-contact encoders are these which appoint physical phenomena different than electrical conduction to read the coded disc. The most common sorts are magnetic, capacitive, and optical.

2.3.1. **Magnetic Encoders**

Magnetic encoders had been developed to substitute contact encoders in applications restrained with the aid of rotational speed. Magnetic encoders function with the aid of detecting resonant frequency change, a magnetization change, or a magnetic saturation in an inductor. For each method, flux induction by means of the magnetically coded disc affects the change by using assisting or inhibiting a current state. Thus, for each principle, two regular states exist corresponding to a logical one or zero.

The resonant frequency type makes use of a tuned circuit, the frequency of which represents one logical state, and the detuning of the circuit representing the contrary logical state. In the magnetic saturation method, the inductor is both saturated and non-saturated. Alternately, the reluctance of the magnetic circuit is correctly translated to logical ones and zeros. Resolution is restrained by means of the size of the magnetized spot and difficult through interaction between magnetized spots on adjacent tracks. Magnetic encoders overcome the fundamental velocity problem of contact encoders and provide increased sturdiness by means of eliminating physical contact between disc and sensor. Also, magnetic encoders function properly in environments hostile to contact kinds where any of the magnetic scanning techniques can be efficiently employed. However, excessive ambient fluxes or radiation densities can smash the disc pattern or inhibit saturated core operation. Greater precaution against mutual electromagnetic interference is required when magnetic encoders are blanketed in the system. Figure 2-2 illustrates the principle levels of regular magnetic encoding.

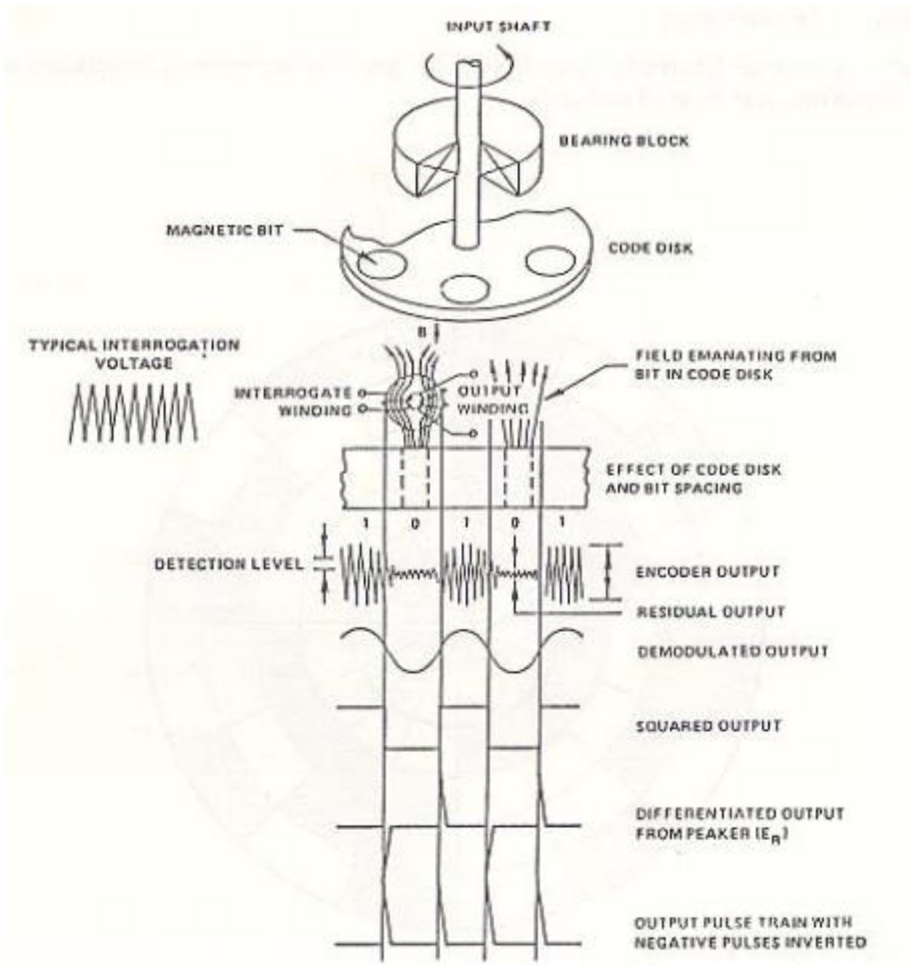


Figure 2-2: Typical Magnetic Coding

Source: http://irtfweb.ifa.hawaii.edu/~tcs3/tcs3/0306_conceptual_design/Docs/05_Encoders/encoder_primer.pdf

2.3.2. **Capacitive Encoders**

Capacitive encoders are the least used of the non-contacting sorts and have been developed in response to special needs. The readout is affected electrostatically the use of a section shift measuring gadget or a frequency manage method to improve the digital output.

Although capacitive units are no longer generally reachable as standard hardware, up to 19-bit, single flip gadgets have been produced. Theoretically, the capacitive method can be used to accomplish any of the encoding tasks carried out via the contact, optical, or magnetic type. However, practical problems of design, manufacture, and operation have limited the use of capacitive detection.

2.3.3. Optical Encoders

The optical encoder was once the earliest of the non-contact devices developed to take away the wear troubles inherent with contact encoders. Present day optical encoders grant the best decision and encoding accuracy and can be operated efficaciously at excessive speeds.

Optical encoder discs have opaque and obvious segments (see Figure 2-3). The discs can be produced by way of exposing a photographic emulsion to light, by using plating metallic on the substrate or by etching segments into

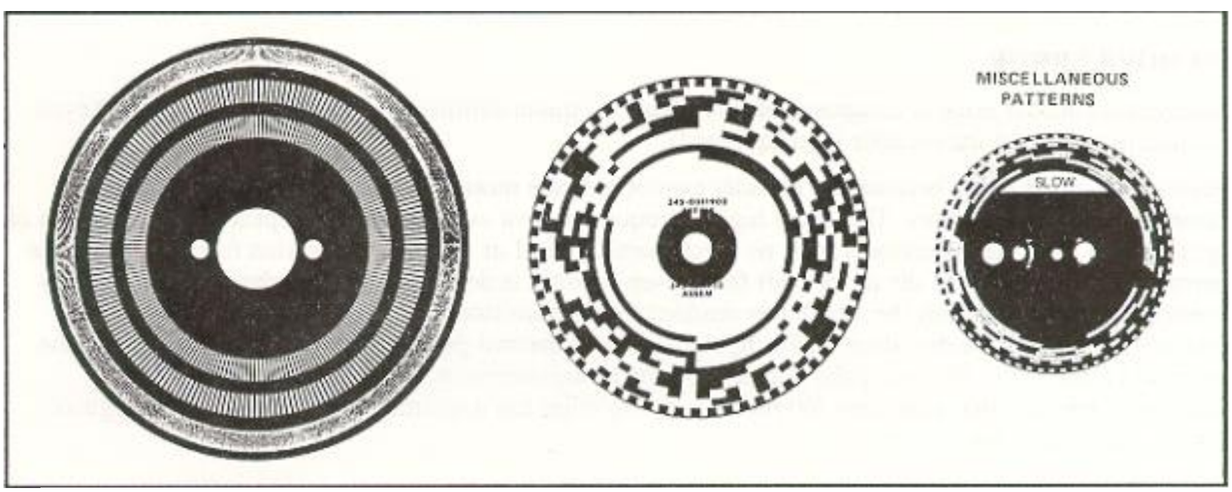


Figure 2-3: Encoder Disks

Source: http://irtfweb.ifa.hawaii.edu/~tcs3/tcs3/0306_conceptual_design/Docs/05_Encoders/encoder_primer.pdf a metallic substrate. Each kind has characteristics that may additionally make it preferable in positive applications.

Readout is affected by way of an array of carefully aligned photoelectric sensors positioned on one side of the disc. A mild supply on the other side offers excitation. As the disc rotates in response to an input variable, the opaque vicinity on the disc passes between the light beams modulating the sensor output in accordance with the selected code. Optical systems focal point the mild on the sensors. Light calumniating LED's, mirrors, prisms, lenses, fiber optics, laser diodes, and optical slits or diffraction gratings perform this function. Light detection can be carried out via one of countless devices. Materials for all types of light-detecting de-vices are selected from agencies III, IV, V of the periodic table and lie halfway in the spectrum between metals and non-metals. As such they are semiconductors. Each gadget responds to mild in a specific manner. Silicon or selenium primarily based photovoltaic cells generates an electric powered contemporary when exposed to light. The resistance of photoconductive cells varies with light intensity. The composition of photoconductive devices is generally cadmium sulfide or cadmium selenite, relying on the favored response of the device or the component of the light spectrum for which sensitivity is desired. Current competencies vary with the intensity of light. Photodiodes are similar to photoconductive cells. Photodiodes are used because their very small surface areas allow very high-frequency response. They are usually run with returned bias and the reverse leakage contemporary is modulated with the light.

Phototransistors are photodiodes with built-in transistor amplification. Photodiodes have better frequency response and are much less sensitive to temperature than phototransistors. In phototransistors, silicon-controlled rectifiers (SCR's) act as touchy high modern switches when uncovered to light.

Light sources for optical encoders can also be solid kingdom or incandescent, depending on the manufacturers sketch and utility of the encoder. Recently, enhancements to optical encoder working performances has reinforced its function in the motion manage markets. Ongoing improvements in decision capabilities, frequency response, accuracy, mechanical bearing assemblies, and environmental packaging serve to keep the optical encoder as the dominant desire for remarks devices.

2.4. Incremental Encoders

As discussed, an incremental encoder generates an output which is a digitally coded sign in the shape of a pulse train. However, the diagram of an incremental encoder relies upon on the kind of science used to generate the output signal. Four types of mechanisms for signal generation and pick-off can be identified. These techniques of signal generation are also applicable in absolute encoders. Based on these technologies, incremental encoders can be in addition categorized into 4 types. These are similarly defined in greater element with their benefits and disadvantages.

Incremental Encoders	Sliding Contact
	Magnetic Encoders
	Proximity Sensor Encoders
	Optical Encoders

2.4.1. **Sliding Contact Incremental Encoders**

An encoder with a sliding contact mechanism consists of a disc made up of an electrically insulating material. The disc carries round tracks with conducting and non-conducting areas. A slip ring is mounted on the shaft of the encoder which is linked with all conducting areas on the circular tracks of the disc. A voltage of steady magnitude is applied to the conducting vicinity of round tracks with the help of brushes sliding on the slip rings. To choose off the signal, a sliding contact is constant in such a way, that it touches the circular direction of the song (touching all conducting and non-conducting areas), as the disc rotates. The pattern of the generated pulse corresponds to the conducting and non-conducting areas of each track. It additionally relies upon the nature of rotation. The essential benefits of incremental encoders with sliding contact mechanism consist of the simplicity of the layout (economical) and the high sensitivity (proportional to the voltage). However, predominant disadvantages are because of the brush-slip ring commutation devices which includes, e.g., system defects in the signal, arcing, brush bounce.

2.4.2. Magnetic Incremental Encoders

In magnetic encoders, the encoder disc consists of magnetic and non-magnetic regions imprinted on circular tracks on the disc. These magnetic regions are just like obvious areas in the glass disc of optical encoders. A micro-transformer is used to pick the signal. The sensors used to pick the indicators are comparable to the core storage factors in historic technology computers. These sensors act as a transformer with foremost and secondary windings. A schematic arrangement of a magnetic incremental encoder is shown in Fig. 2-4. The enter voltage to the primary winding of the micro-transformer (sensing element) is an excessive frequency (100 kHz) voltage signal. The prompted voltage in the secondary has the same frequency. However, when magnetic spot on the disc approaches the sensing element, it saturates the core of the element. This outcomes in high reluctance and consequently decreases the prompted voltage in the secondary. The output sign can be received by demodulating the prompted voltage. It is vital to note that excessive top in the pulse corresponds to the non-magnetic place between magnetic spots on the disk. However, to pick out the path of the magnetic field, sensors like corridor effect and flux gate compasses can be used. The contact-less signal pick-off approach is the most important advantage of this kind of encoder. However, these encoders are high-priced in evaluation with sliding contact encoders, because of micro-transformer and circuitry to demodulate the brought-on voltage.

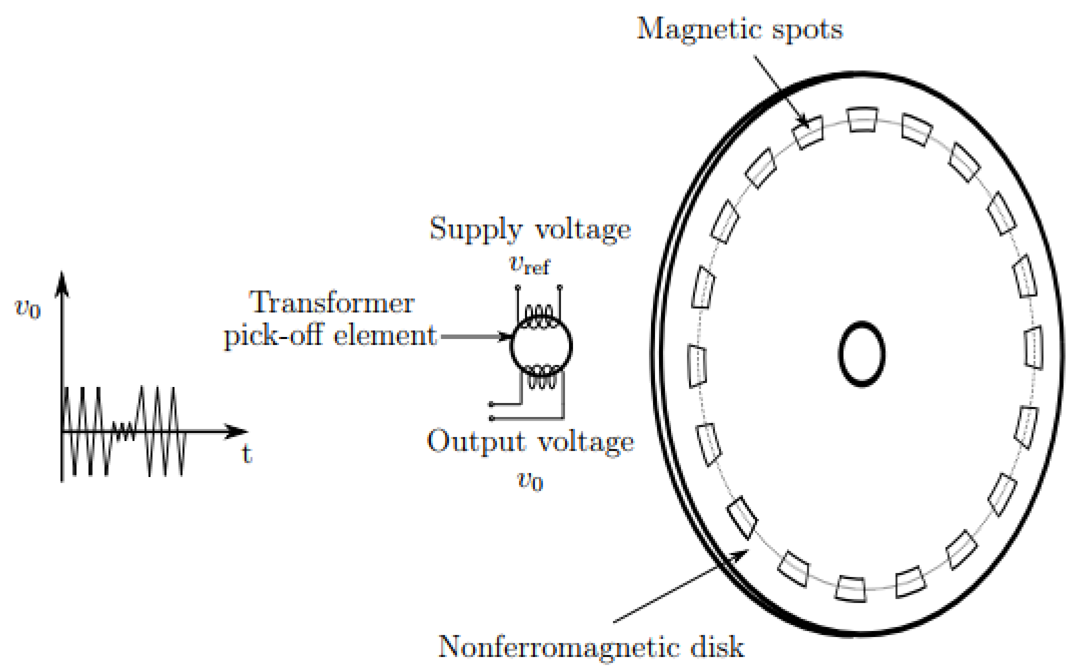


Figure 2-4: Magnetic incremental encoder schematic representation

2.4.3. Proximity Sensor Incremental Encoders

In proximity sensor incremental encoders, proximity sensors are used to sense the signal. Different proximity sensor elements such as eddy modern probe or magnetic induction probe are used to pick-off the signal from the rotating disk. However, magnetic induction probes are the most frequent choice. The encoder disk is now made of ferromagnetic fabric with raised spots on tracks. The fabric for these raised spots is the identical as that of

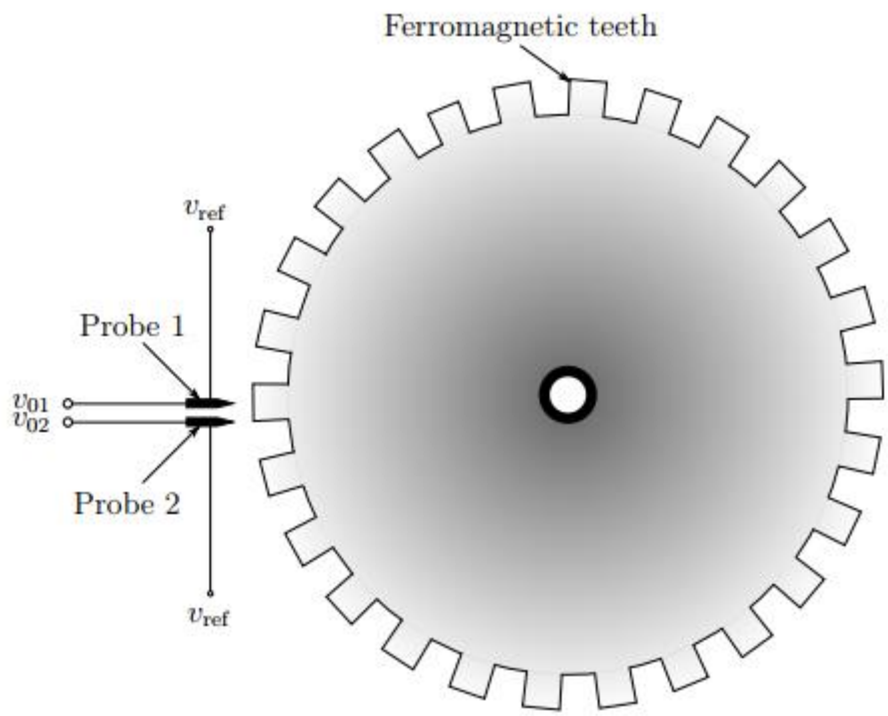


Figure 2-5: Proximity sensor incremental encoder disk configuration

disk. The ferromagnetic toothed disk can also be used with radially placed proximity sensors as proven in Fig. 2-5. With the toothed disk, an encoder behaves like a digital tachometer. Now, as the raised place or the teeth of the disk methods the probe, it will increase the flux linkage and reduces the reluctance. A reduce in reluctance outcomes in increased triggered voltage. The output is once more a modulated sign like in magnetic encoders and requires demodulating units for in addition interpretation. The probes are positioned in such a manner, that the output signals are shifted by means of 90°, required to discover the course of rotation.

2.4.4. **Optical Incremental Encoder**

As noted in the previous sections the optical incremental encoder is extensively used to display rotary and linear motion. In this section, the encoder manufactured by means of DRC will be described and the predominant advantages of its graph will be discussed.

Optical incremental encoders are the most frequent choice for angular function and speed calculation within electric powered drives or at the shaft of a wheel. This is due to the fact of the low cost, low maintenance, and high noise immunity. However, sign interpretation can also be the same for specific kinds of incremental encoders used in the industry. We may also now limit our in-addition discussion to optical incremental encoders.

Two feasible configurations of an optical incremental encoder disk can be found in:

1. Offset sensor configuration
2. Offset track configuration

In the offset sensor configuration, the encoder disk has a single round tune of equally spaced opaque and transparent windows. The vicinity of obvious

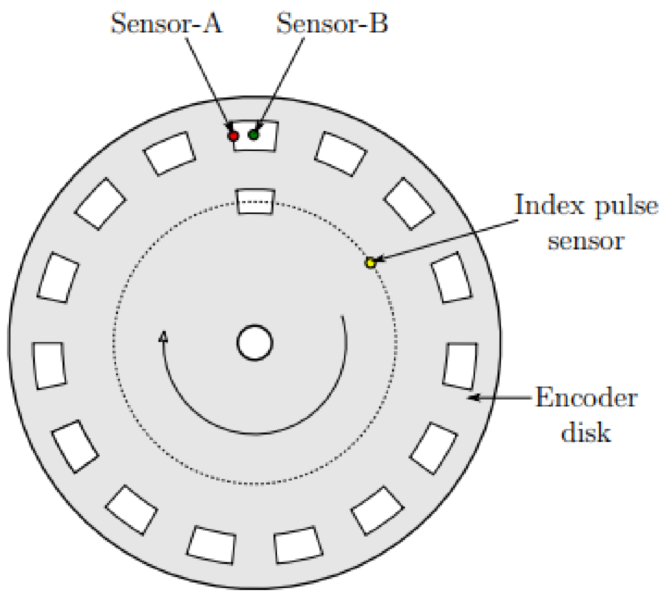


Figure 2-6: Offset sensor configuration

window is equal to the opaque vicinity (space between two obvious windows). For the reference pulse signal, a track with a single transparent window is additionally introduced. This pulse is generated once in a whole revolution. A schematic format is shown in Fig. 2-6. Two pairs of light sources and sensors are constant along the fundamental song at the quarter pitch. The pitch is middle to middle distance between two consecutive windows. Another pair of light sources and sensors is constant to generate and sense the pulse from the index window. It is important to note that each pulse sign from the primary music is on for half of of the time duration and off for the subsequent half. Thus, a continuous pulse instruct is generated as the disc rotates.

A trouble arises to fix sensors at quarter pitch distance alongside the graduation track of the encoder disc for the reason that there is no longer sufficient space. One solution is to introduce an offset of an integer wide variety of intervals between two sensing elements. The extension between two alerts is now an integer a couple of 360°, which can be without problems interpreted.

In the offset track configuration as shown in Fig. 2-7, there are two separate identical tracks, one is displaced from other by a quarter pitch. A separate track with a single transparent window is introduced for the index pulse

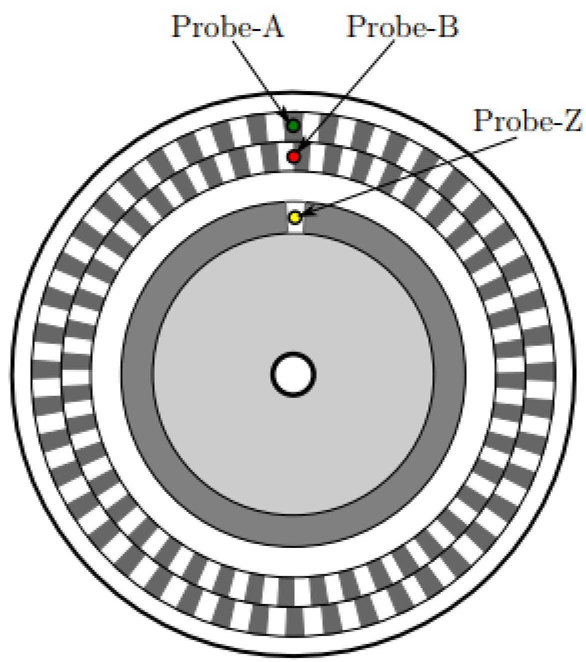


Figure 2-7: Offset track configuration

similar like in previous type.

When the shaft of the encoder is rotated, the disk additionally rotates, and the sensor corresponding to supply A and B generates two separate pulse trains. Each pulse covers an angle equal to the angular step of graduation θp. A commencement perspective is the one included by way of a distance of one successive obvious and non-transparent window in the graduation track. The ultimate angle θ, via which the disk is turned around is constantly an integer multiple of θg. Because the light sources alongside the principal song are constant by an offset equal to a quarter of θg, the indicators A and B are additionally shifted by using the equal angle (θg=4). There are four switching occasions in the output pulses due to this shift. The offset between the two pulses affords records about the route of rotation. The building precept for an optical incremental encoder with the offset sensor configuration is proven in Fig. 2-8. For the reference position, a separate index pulse (by LED-Z and corresponding sensor) is generated, as soon as in a complete revolution (360°). The angle θ, corresponding to counter-clockwise (CCW) course is generally considered positive, whilst terrible for clockwise (CW) rotation.

The output pulses (conditioned signals from all the three photo-sensors) are shown in Fig. 2-9. It can be noticed that for the duration of counterclockwise

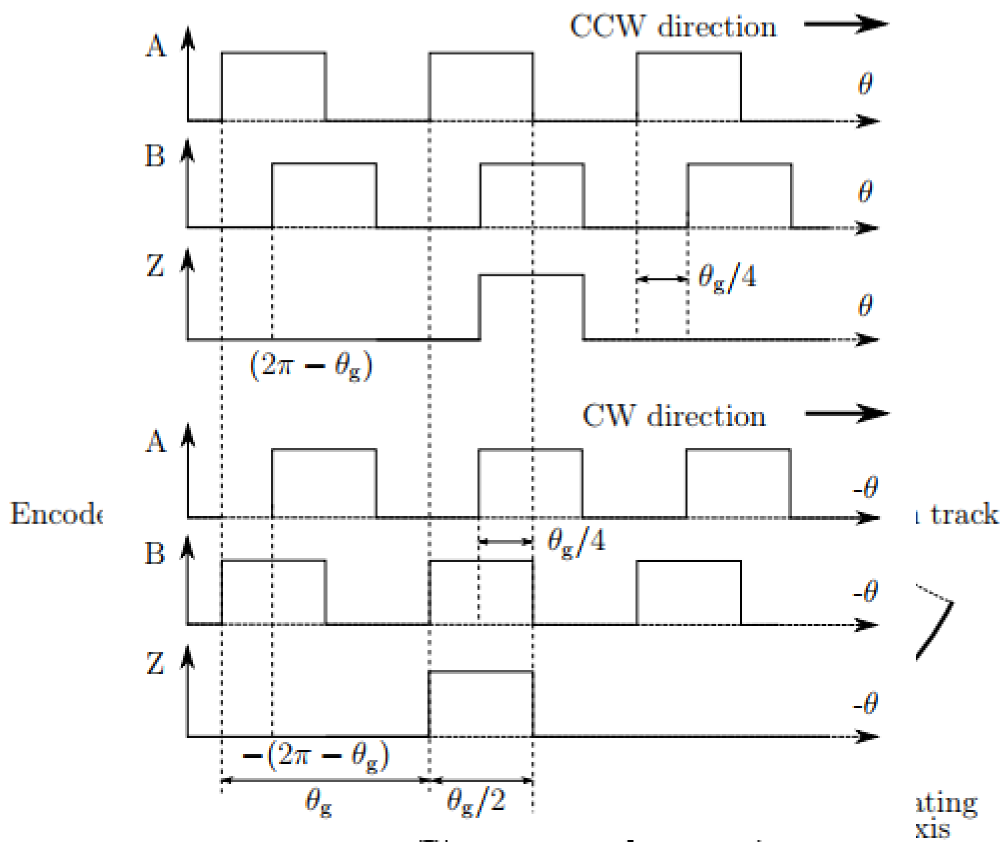


Figure 2-8: Output pulses for counter clockwise (CCW) and clockwise direction of

rotation (as shown in Fig. 2-8), the pulse A leads the pulse B by using an angle of θg=4. During the clockwise direction, it is vice versa. However, the index pulse (reference signal) comes once in one whole revolution. In reality, these pulses are no longer best in form.

Optical incremental encoders generally have very excellent decision compared to absolute encoders in a given technology. The magnetic scales are bit unsmooth compared to the optical scales. It is due to the fact the glass is the key component in fabricating high-resolution optical scales. The applications of optical incremental encoders may encompass the manipulate robotics, procedure equipment remarks and measuring equipment. Often, the implementation of a zeroing function is required in these purposes when the desktop is growing to become on. Additional zeroing cycles can additionally be used in order to avoid error in function dimension which can be corrupted due to noise.

Different environmental parameters affect the performance of an optical incremental encoder. These include vibrations, shaft speed, frequency, temperature and furnish voltage. The position, as properly as the speed, is

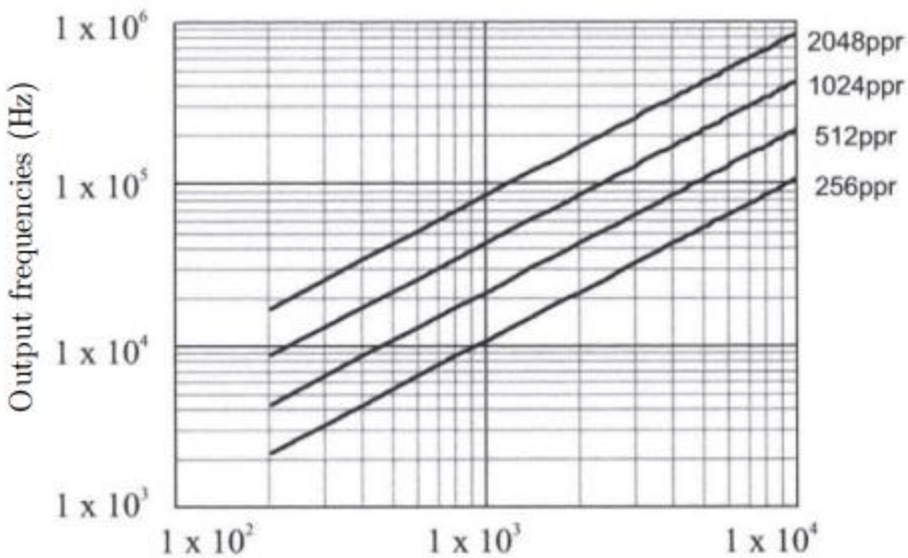


Figure 2-9: Encoder output frequency as function of speed for a range of incremental

without delay proportional to the frequency of output pulse signals. Fig. 2-10 suggests the output frequencies of the incremental encoders of distinct resolutions, as a feature of speed.

2.4.5. **Physical Resolution**

The resolution of an optical incremental encoder is determined through the range of pulses per revolution. The greater the pulses per revolution the greater would be the resolution. However, the factors, for example, the area for photo-sensors, and sign choose off at very excessive speeds, restriction the size of the transparent window, and for this reason the resolution.

Considering the detection of every rising side in one complete revolution of the coded disk, the resolution (physical) is introduced as the pitch perspective $360°/N_{pr}$, the place N_{pr} is the whole counted rising edges. Since there are two pulses with an offset from one every other by means of 1/4 of the pitch angle, one can also realize each rising and falling part in both output pulses. Hence, the decision can now be further multiplied through a element of four, given as

$$\Delta\theta_p = \theta_{max}/4N_{pr}$$

Where θ_{max} represents the maximum angle blanketed through rotation of the disk. It is assumed to be equal to 2π (one whole revolution) in order to calculate the bodily decision of an incremental encoder. $\Delta\theta_p$ is the bodily resolution which is inversely proportional to the variety of pulses per revolution.

Each output signal of an incremental encoder has a decision of half of the pitch, considering that all the transitions (rising and falling edges) are counted instead of counting pulses. According to this logic, for an encoder with 10,000 pulses per revolution, the resolution will be 0.018° when only one pulse is used (and two transitions in a single pulse, both rising and falling edges are detected). If both the pulses are used simultaneously, four transitions are then detected for the duration of a pitch cycle and therefore the decision will increase to 0.009°.

Table 2.1: Summary Chart of Resolution of Different Types of Encoders	
Device	Resolution
Optical Incremental	10000 ppr
Magnetic Incremental	2048 ppr
Optical Absolute	2^{22} cpr
Magnetic Absolute	4096 cpr

2.4.6. Encoders used in this Thesis

1. Rotary Encoder:

Rotary Encoders are sensors that discover role and speed via converting rotational mechanical displacements into electrical alerts and processing those signals. Sensors that observe mechanical displacement for straight strains are referred to as Linear Encoders.

2. **Hall Effect Encoder:**

   A two-channel Hall impact encoder is used to feel the rotation of a magnetic disk on a rear protrusion of the motor shaft. The quadrature encoder presents a resolution of 48 counts per revolution of the motor shaft when counting both edges of each channels.

3. **Optical Incremental Encoder**

4. **Optical Absolute Encoder**

3. Speed Decoding Algorithm

This section encloses the dialogue about more than a few speed decoding algorithms. The required standards for calculating the speed from the incremental encoder pulses are additionally explained, which are similarly required for comparison. A technique to detect the course of rotation is on account that it is being used by using all the algorithms.

3.1. Requirement Criteria

A velocity controller often requires direct velocity records from the motor for manage purposes. Considering an optical incremental encoder as comments sensor, a speed decoding system have to fulfill sure requirements in order to facilitate the controller for specific control, for example:

1. A gadget to extract velocity facts from the encoded sign supplied by means of a rotary pace sensor must be relatively accurate. Accuracy is the deviation of measured fee from the actual. For manipulate purposes, it is necessary to have accurate velocity information.
2. It is difficult to detect the immediate alternate in pace using an incremental encoder, however, a common of velocity statistics can be calculated throughout a short time period. If the time window is extended, the consciousness of rapid speed response turns into difficult.

It is because the lag time is also expanded in the manipulate system. Two Therefore, a speed measurement system has to now not solely be correct but additionally be capable to grant information except great computational delay.

3. A good speed decoding algorithm provides a highly accurate speed information during a very short observation time window. However, it must additionally be applicable to a wide speed range. Though, quite a number of algorithms are presented in the literature, but only a few can furnish suitable consequences in vast speed vary applications.
4. A top pace decoding technique be as simple as feasible for its implementation. Although one can compromise over this thinking about the preceding characteristics important. The complexity can amplify the lag time to process the information.

3.2. Frequency Measurement (M-Method)

To measure the motor speed from encoder pulses, M Method is an easy and widely used technique. By counting number of pulses in a fixed time

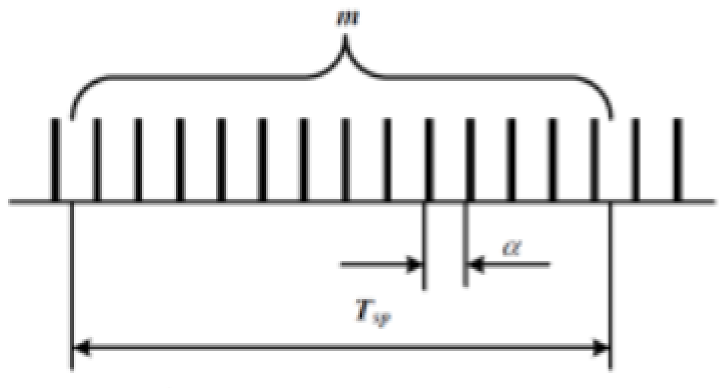


Figure 3-1: M Method

interval, this method is observed.

Speed Measurement by this method can be expressed as –

$$\omega = \frac{d\theta}{dt} \cong \frac{\Delta\theta}{T_{sp}} \cong \frac{2\pi \cdot \Delta N}{N_p \cdot T_{sp}} \left[rad \cdot s^{-1}\right]$$

$$\rightarrow \frac{60 \cdot \Delta N}{N_p \cdot T_{sp}} [RPM]$$

Here θ and ω are rotor angle and speed, T_{sp} is the sample period of speed, N_p is pulse per revolution (PPR) of encoder and ΔN number of counted pulse in the sample period. In this method the speed measurement error is constant at any speed and depends on the pulse per revolution and sample period as expressed in the following equation –

$$\frac{60}{Np * Tsp} [rpm]$$

This speed error can be tolerated at high speed whilst the speed measurement accuracy is getting worse at low speed region.

There are countless ways to decrease the constant speed measurement error in the low-speed region such as the use of a high-resolution encoder, growing sample length and the usage of low pass filter. However, high resolution encoder will increase the price of drive and increasing sample period or the usage of low pass filter minimize the bandwidth of speed control loop.

3.3. Time Measurement (T-Method)

By measuring the interval between two adjacent pulses, T-Method is observed. Time interval is measured by using a high frequency clock.

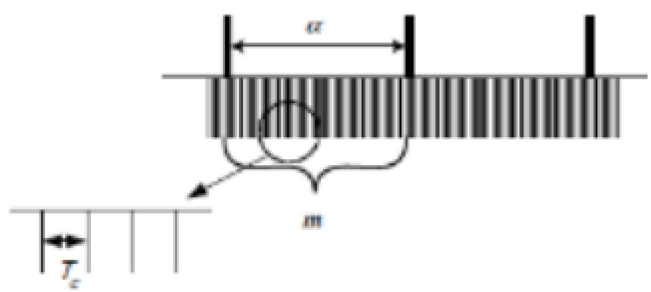


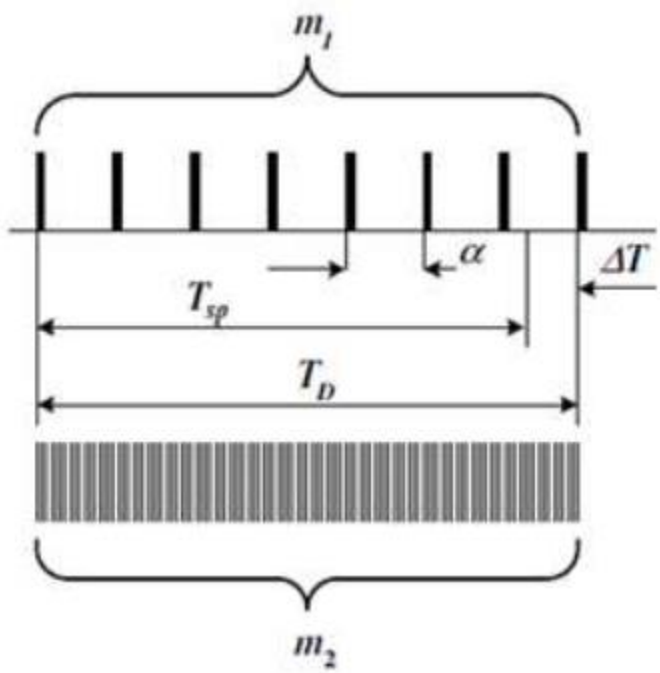
Figure 3-2: T Method

The speed measurement by T Method can be expressed as –

$$\omega = \frac{d\theta}{dt} = \frac{60}{N_p \cdot m \cdot T_c} [RPM]$$

Where, T_c is the period of the clock and m is the number of clock pulses. The speed accuracy with this method is accepted in the low speed region. But the speed measurement time is not constant as in M method and varies according to the speed. For this measurement speed has much time delay while speed control loop is executed at a controlled frequency. As a result, this situation decreases the speed control performance.

3.4. Frequency and Time Measurement Method (M/T-Method)



M/T Method is widely used in the industries. It is combined of M and T speed measurement methods. Speed at high and low speed range can be measured with this method. The speed is measured by counting the number of encoder pulses observed in the T_{sp} sampling period, within the measurement the time interval T_D which is synchronized to pulse right after $T_{sp.}$

The speed measurement equation by M/T Method is described as –

$$N_{M/T} = \frac{m_1 \alpha}{P_{PR}(T_{sp} + \Delta T)} = \frac{60 f_c m_1}{m_2 P_{PR}} (r/\min)$$

Where, f_c is clock frequency, m_1 number of encoder pulses in T_d time interval and m_2 is number of clock pulses.

4. **Observation & Experimental Methods**

4.1. Hardware Part

The Hardware part mainly consists of the experimental setup we build for this thesis. Total experimental setup consists of basically several parts. Each of the parts in the experimental setup is discussed separately in the later part of the discussion.

Total schematic diagram of the experimental setup is shown the figure

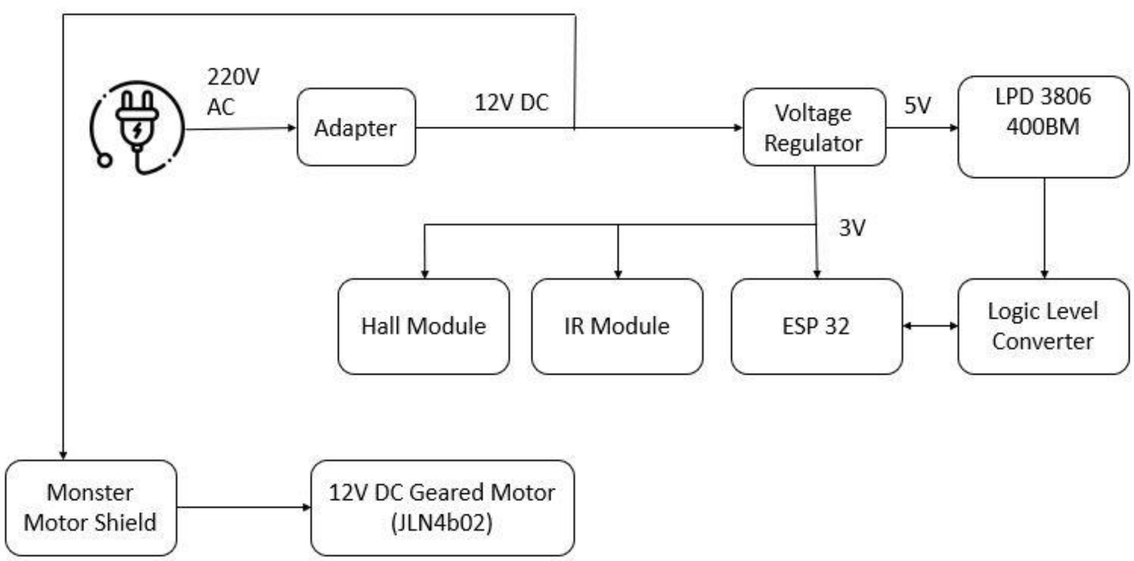


Figure 4-1: Total Schematic Diagram

4.1.1. 12V DC Motor (JLN4b02):

Here we take 12V DC Motor (JLN4b02) which have an RPM value of 100 for speed measurement.

4.1.2. Monster Motor shield (VNH2SP30):

Monster Motor shield (VNH2SP30) dual shield is used to drive the motor. VNH2SP30 dual monster motor shield can drive 2 motors at up to 12A sustained with adequate heat sinking. Monster Motor shield (VNH2SP30) can drive 2 DC motor at 5.5-16V. It can also supply 30A of peak current and 6A with no heat sink per channel. It can diagnostic output and detect thermal shutdown and similar kind of faults. This board can be assembled as a shield with any Arduino board also it can be used as a stand-alone board.

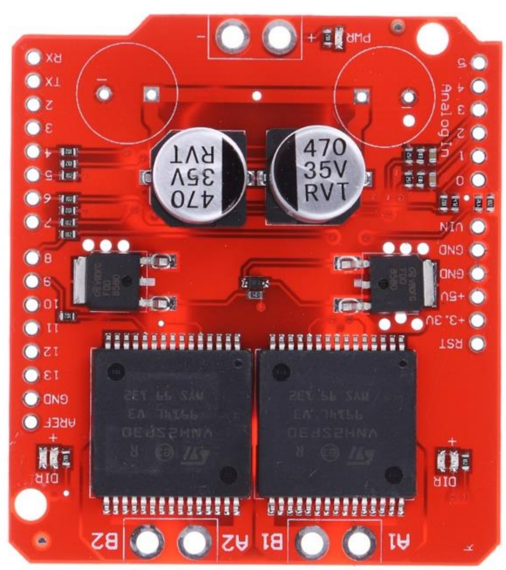


Figure 4-2: Monster Motor shield (VNH2SP30)

Technical specification of Monster Motor shield (VNH2SP30)

Operating Ratings	
Voltage Range	5.5-16V DC
Max current (peak)	30A
Max current (sustained)	12-14A (with heat sinking)

4.1.3. ESP 32

We use ESP32 to transfer the encoder data to the computer through Wi-Fi functionality

ESP32 can perform completely standalone device of a secondary device to a host MCU, which reduces the communication stack overhead on the main application processor. Wi-Fi functionality can be used through SPI/ I2C/ UART interfaces.

For transferring the encoder data, we first approaches for serial communication but in case of serial communication only one end communication can be possible at a time so later we shifted on ESP32 to transmit encoder data. The details process of that discussed in the software part.

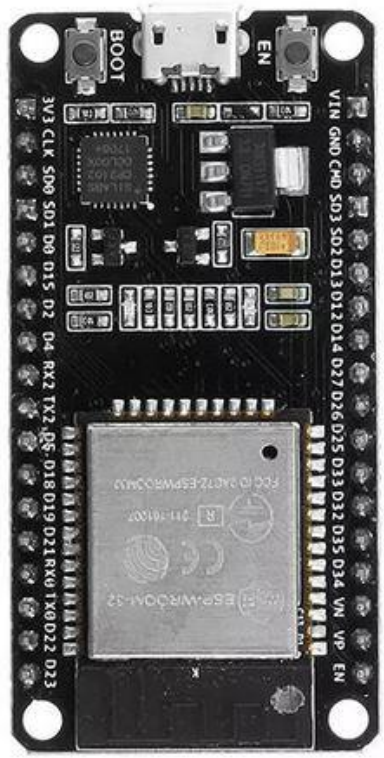


Figure 83: ESP32

Source https://www.banggood.com/ESP32-Development-Board-WiFibluetooth-Ultra-Low-Power-Consumption-Dual-Cores-ESP-32-ESP-32S-Board-p-1109512.html?cur_warehouse=CN

4.1.4. LPD3806-400BM

It is a two Phase 5-24V 400 Pulses Incremental Optical Rotary Encoder. This rotary encoder has 400 pulses per revolution. This encoder is coupled with the 12V DC motor using custom 3D printed gearing mechanism to measure the speed of the DC motor

Figure 4-4: LPD3806-400BM two Phase Incremental Optical Rotary Encoder

Source: https://www.robiz.net/lpd3806-400bm

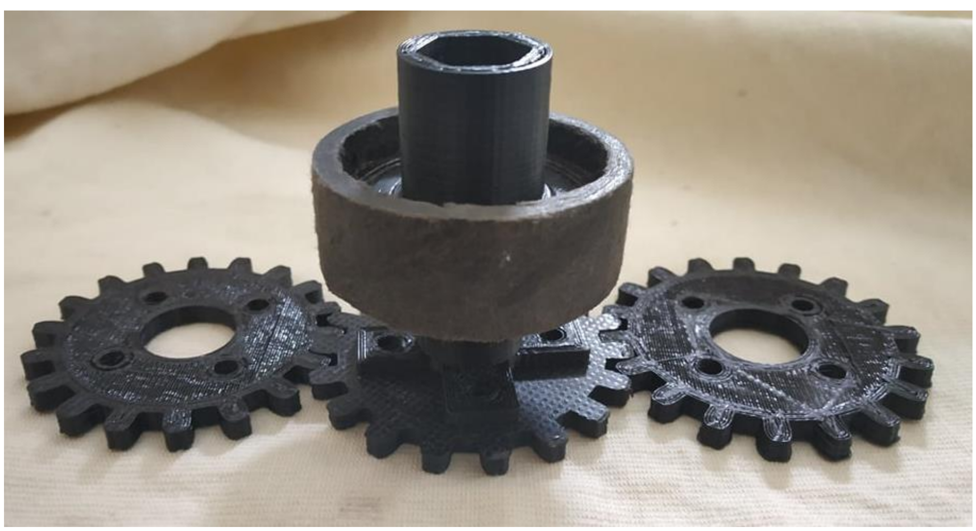


Figure 4-5: Custom made 3D printed gear

Technical specification of LPD3806-400BM incremental rotary encoder

Operating Ratings	
Operating Voltage	5-24V DC
Performance	400 pulses / rev
Maximum mechanical speed	5000 rev / min
The electrical response frequency	20K / sec
Integrated speed	2000 rev / min

4.1.5. Incremental optical rotary encoder

In the experimental setup there is a custom-made 3D printed incremental optical rotary encoder. There are total 75 slots and the operation are 3.3 V single phase. The reading is taken using an IR motor encoder module which follows the basic operation technique of the incremental optical rotary encoder. The figure below shows the IR motor encoder module used and the design of the optical rotary encoder. It is designed such a way that it can be coupled with the main 12V DC motor.

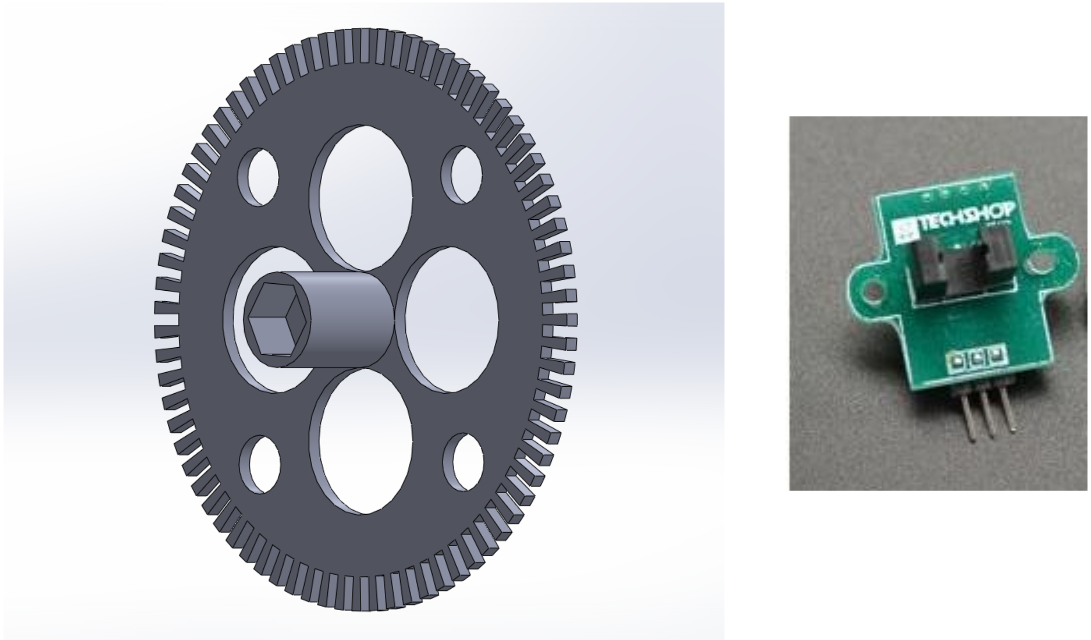


Figure 4-6: 3D printed incremental optical rotary encoder and IR motor encoder module

Source: https://www.techshopbd.com/product-categories/sensor/2299/motor-encoder-techshop-bangladesh

4.1.6. Hall effect encoder

For hall effect type encoder data, a motor embedded with hall effect encoder module is used this motor is also coupled with the 12V DC motor using custom made 3D Printed gearing mechanism shown in the case of LPD3806-400BM incremental rotary encoder type case.

4.1.7. Absolute optical encoder

In the experimental setup we use absolute optical encoder. In the case of absolute optical encoder, we use 7-bit gray code encoder shown in the figure. For taking reading we use QTR-8RC reflectance sensor array. This QTR-8RC sensor module has 8 IR phototransistor where each sensor separately provides digital I/O- measurable output.

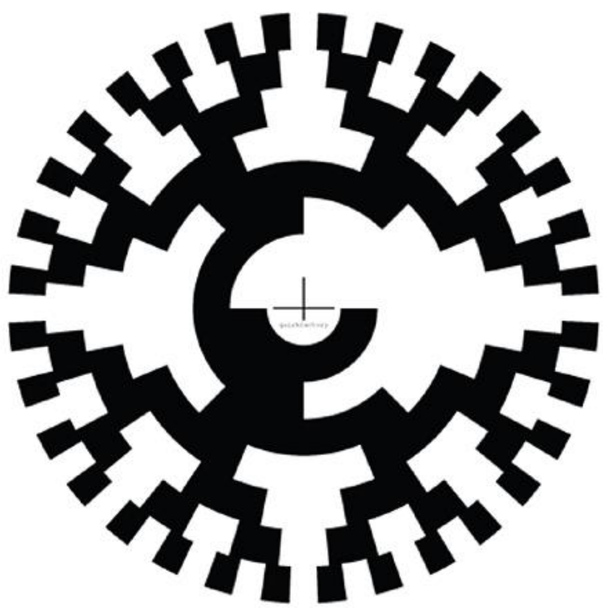


Figure 4-7: Figure 7 bits gray encoder

Source 2007 quirkfactory.com

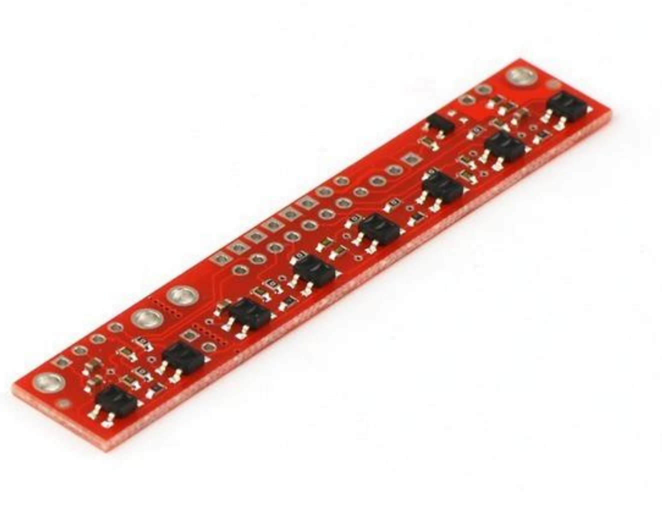


Figure 4-8: Figure QTR-8RC reflectance sensor array

Source https://www.pololu.com/product/961

Technical specification of QTR-8RC reflectance sensor array

Operating Ratings	
Operating Voltage	3.3-5V
Supply current	100mA
Output format	8 digital I/O compatible signals

4.1.8. Digital Tachometer

One digital tachometer is used to measure the actual speed and compare it with the values calculate by the encoders.

4.1.9. Protractor

In our experimental setup one protractor is attached to calculate the angle of the rotation of the motor. There is a 3D printed indicator attached with the main axis of the 12V DC motor thus the indicator moves with the rotation of the motor and thus the angle of rotation can be calculated.

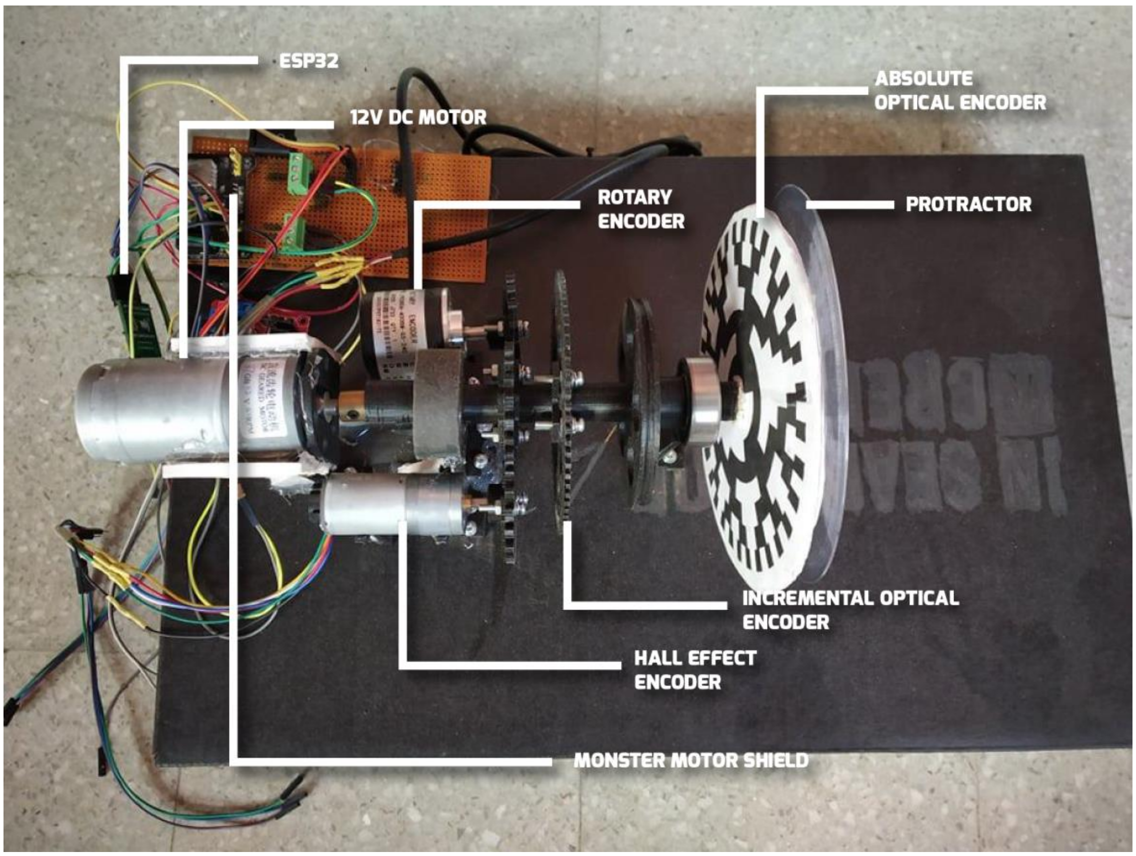


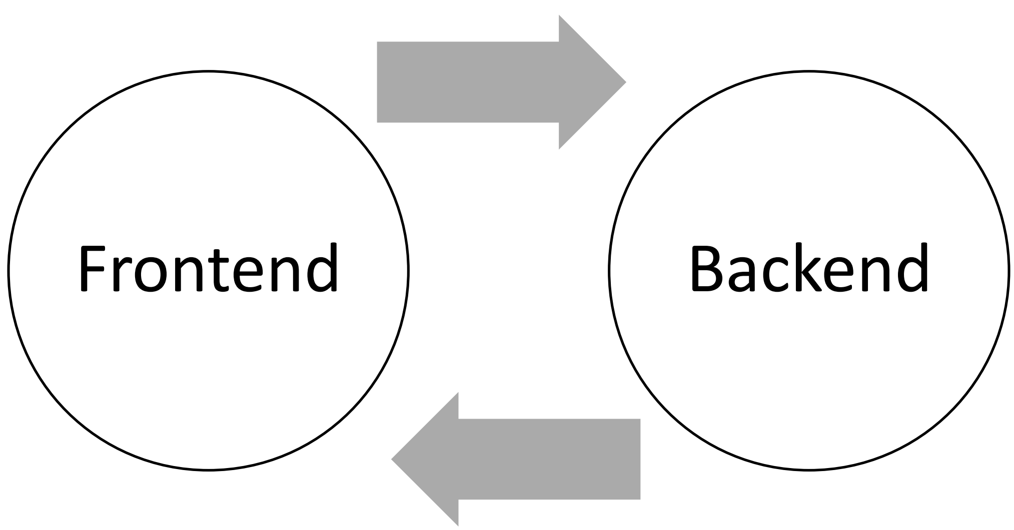
Figure 4-9: Total Experimental Setup

4.2. Software Part

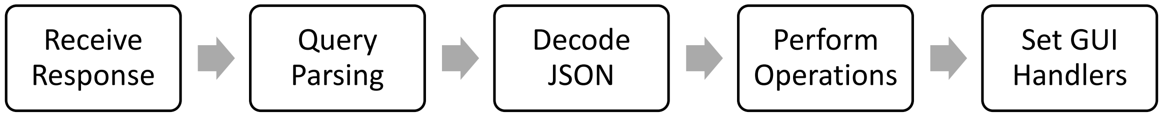
We built an interface to send and receive information from the machine using a server. We will first discuss the communication and then the graphical user interface (GUI).

4.2.1. Communication

The communication system is a combination of the server hosted using the ESP32 and the query system in MATLAB. We built the ESP server to make it possible to receive and serve requests to and from any online location. The communication system is divided into the frontend and backend. The frontend deals with the information fetching and sending in the GUI. The backend handles the requests from the frontend and sends the appropriate responses.



4.2.2. Frontend (Receiving a Request



4.2.2.1. Receive Request

The response is received from the server once a request is sent to an endpoint. The endpoint triggers the accompanying function which sends a response containing the query containing the JSON data.

4.2.2.2. Query Parsing

The request received from the server is in the form of a JSON contained in a query string. The request needs to be parsed in order to extract the JSON data from the query. This needs to be converted to make it accessible.

4.2.2.3. Decode JSON

The JSON data needs to convert to a built-in type before it can be used for calculations. It is converted to a struct using the *jsondecode* function in MATLAB. The keys of the JSON data can then be accessed with the dot notation.

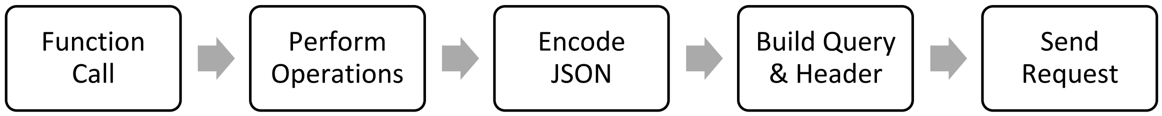
4.2.2.4. Perform Operations

Calculations with the desired data can then be performed as required. The results are stored in the local variables.

4.2.2.5. Set GUI Handler

The fields of the GUI are updated according to the previous operations. Updates are executed using the handlers.

4.2.3. Frontend (Sending a Request)



4.2.3.1. Function Call

A function call is invoked in the frontend when a request has to be sent to the server. The function starts the process of sending the request by passing any arguments to the next step.

4.2.3.2. Perform Operations

Calculations using the parameters are performed as defined in the function. The result needs to be converted in order to be sent via the HTTP header.

4.2.3.3. Encode JSON

The data can be sent either as plain text or as a JSON object. We have elected to use a JSON object in order to keep the query requests consistent and for easier memory allocation. Encoding can be achieved using the *jsonencoder* MATLAB function.

4.2.3.4. Build Query & Header

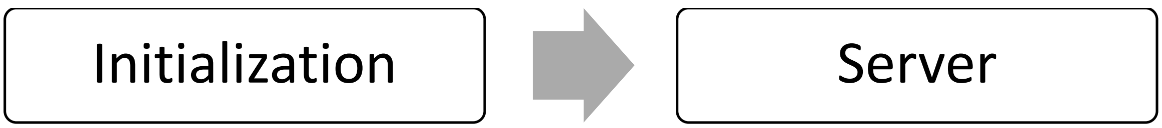
A query and a header have to be built in order to for the request to be transferred through the HTTP protocol. The JSON data is passed as a value of the query string which is then processed on the server.

4.2.3.5. Send Request

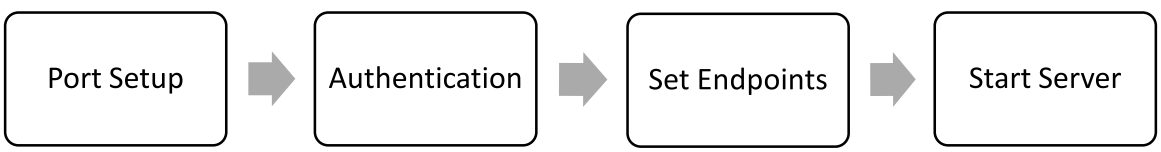
The request is sent to the server using the IP address provided by the server. An acknowledgement response is sent by the server once it completes the processing.

4.2.4. Backend

The backend mainly consists of the server which receives requests from the frontend and responds with the required code and query. The initialization stage is activated only once to start the server, at which point the server listens to requests.



4.2.5. Backend (Initialization)



4.2.5.1. Port Setup

The server needs to be allocated a port for the hosting to start. We set the server to port 80.

4.2.5.2. Authentication

The access point or SSID of the router is given as input and any password, if required. Credentials are authenticated by the router in this stage. A unique IP address is also generated which is used for communication from the frontend.

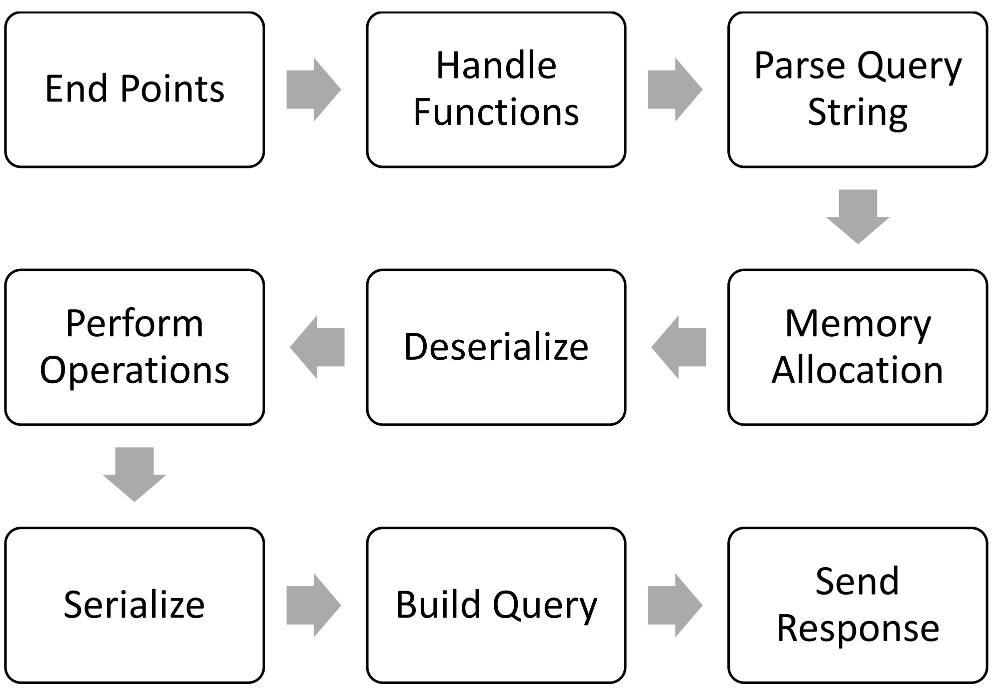
4.2.5.3. Set Endpoints

Endpoints are URLs that are associated with handle functions. When a request is received at these URLs the handle function is invoked which sends a response to the frontend.

4.2.5.4. Start Server

The server is started after the previous stages are completed successfully. It stays in a standby state to receive requests.

4.2.6. Backend (Server)



4.2.6.1. End Points

These are URLs that when receiving a request invokes the associated handle function. Requests from the frontend hits the end points and receives a response when the server the invoked function finishes running.

4.2.6.2. Handle Functions

Each action that may be required by the frontend is assigned a handle function with an associated end point. For example, a unique end point for reading data from the machine can be set up, along with a handle function.

4.2.6.3. Parse Query String

The request from the frontend is a key-value pair with the value being a JSON object formatted as a string as part of a string query. This JSON data is extracted using the *server.arg()* function and stored in a variable for further operations.

4.2.6.4. Memory Allocation

Memory needs to be allocated for storing the JSON object. This memory requirement is determined using the ArduinoJSON assistant (v6). Placeholder values are used to allocate the maximum allowed value for each key of the JSON object sent by the frontend.

4.2.6.5. Deserialize

In this process, a sequence of bytes is converted into a memory representation. We converted the JSON document to a hierarchy of C++ structures and arrays.

4.2.6.6. Perform Operations

Keys and values from the JSON object can be accessed easily now. Operations requiring the values received from the frontend are completed in this stage.

4.2.6.7. Serialize

This is the process of converting the C++ structures into a JSON document for transmission to the frontend. Memory is also allocated for this process in a similar way as before using the ArduinoJSON Assistant. The converted JSON object is stored in a variable as a string.

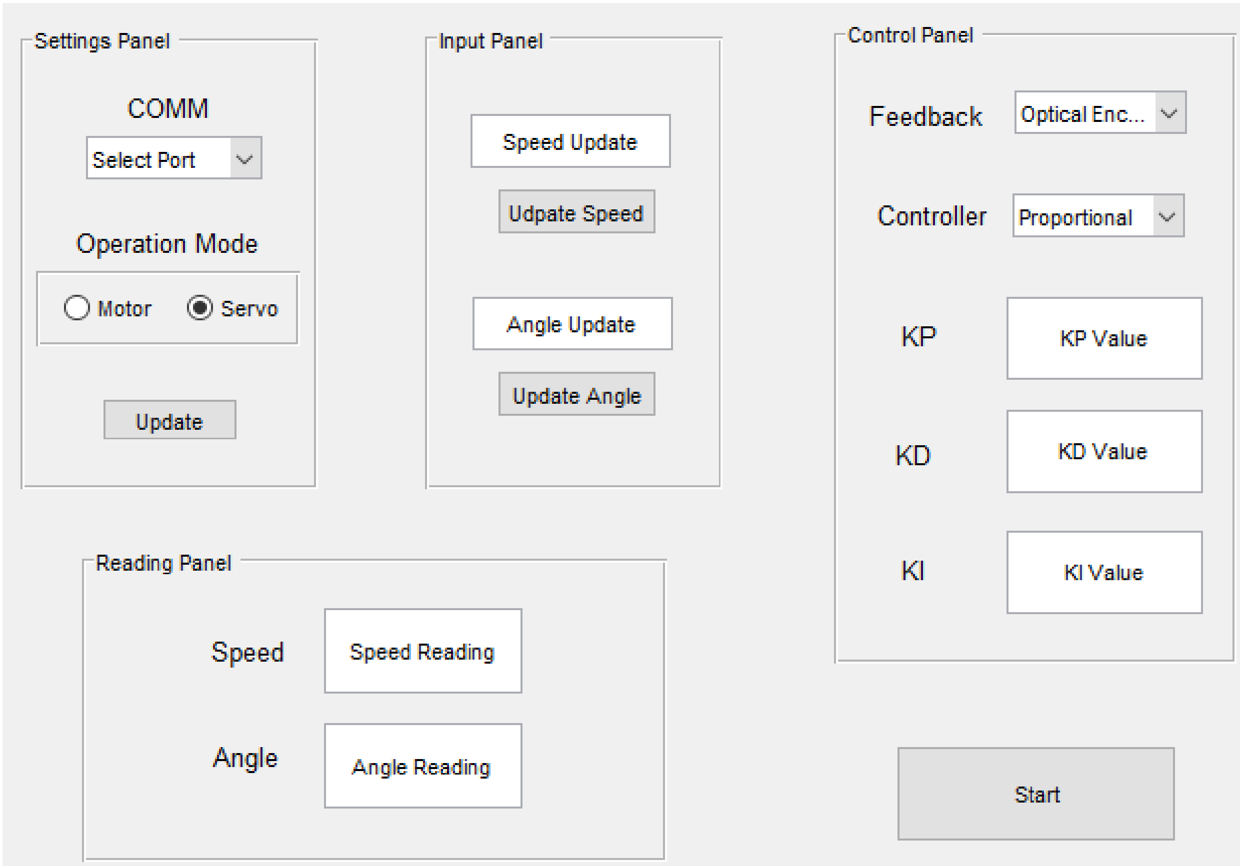
4.2.6.8. Build Query

Queries are built using the standard HTTP status and error codes. The JSON object is encoded as a plain text string in the query.

4.2.6.9. Send Response

Responses are sent, along with the status code to the frontend. The response is sent using the webserver.

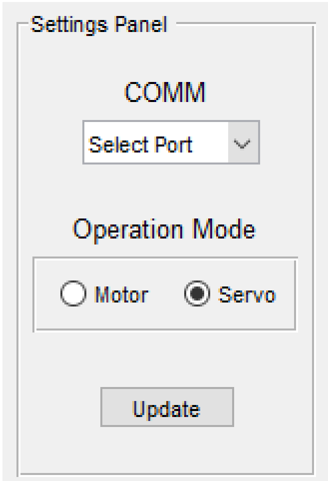
4.2.3. Interface



The interface is divided into four panels. Easier operation is achieved due to the compartmentalization of the different components. The four panels are:

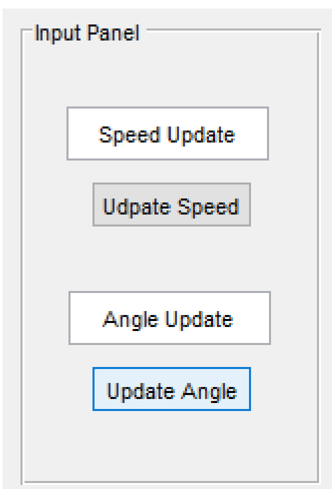
1. Settings Panel
2. Input Panel
3. Reading Panel
4. Control Panel

4.2.3.1. Settings Panel



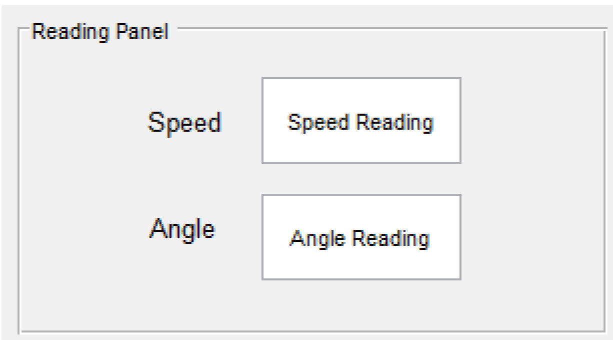
This panel allows the COMM port and the mode of operation to be set. The update button sends an HTTP request to the server which invokes the required handle function based on the arguments passed.

4.2.3.2. Input Panel



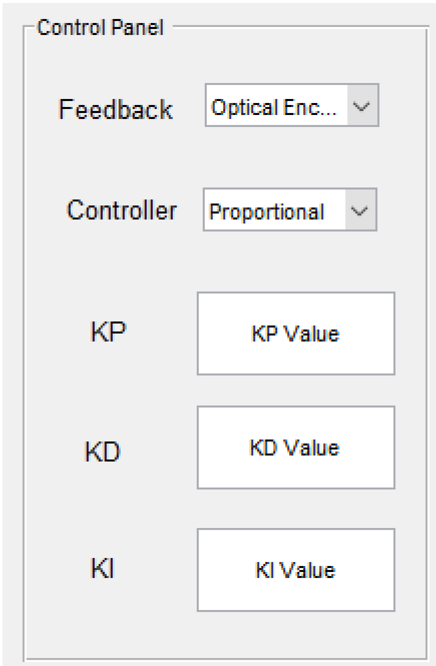
The “Update Speed” and “Update Angle” buttons takes the input along with the values from KP, KD, KI fields and sends a JSON object with all the required information to the server.

4.2.3.3. Reading Panel

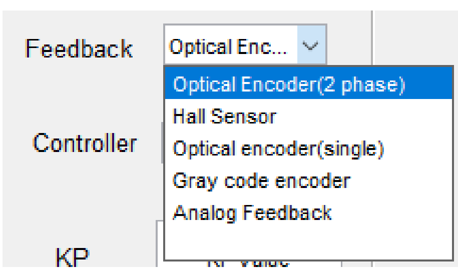


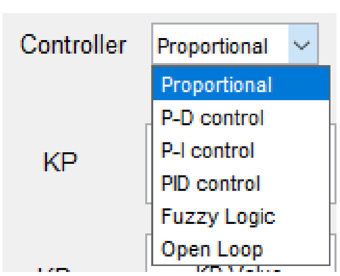
When the “Start” toggle button is enabled, continuous HTTP requests are sent to the server for the speed and angle information. The server returns the desired information in the form of a JSON object.

4.2.3.4. Control Panel



This panel allows users to set the feedback type, controller type, and the values for KP, KD, and KI. Multiple options are available for the feedback and controller.





5. Socio Economic Impact

Encoders are fundamentals of motion control process. Motion control process in modern automation technology and industry requires highly accurate speed information with high bandwidth.

Our thesis proves that how using this particular approach can cause an effect on socio economic status. So how does our approach help in socio economic build up?

5.1. Reduce Costs

Cost reduction and Cost effectiveness is one of the main and important approach of our thesis. The materials we have used are cheap and easy to access and easy to assemble, which reduces cost to a significant extent. Making it easy and available for everyone to access.

5.2. Easier Learning

Learning is important and we promote everyone should have easier access to learning. Learning should not be costlier and should easily be accessed to each and every one. So, we have built this in an efficient way that anyone and everyone can easily study, simulate and access the taste of learning the motion control process, let alone Control System.

5.3. Online Based Easy Access

As our thesis provides an online server-based solution and data recording. Anyone one can access from online database to get a reading or to know how his device is working and loading.

5.4. Save Time

The described process decreases time. As we have used 4 different encoders in this particular process, it saves time. Using data for 4 different process individually wastes time. So, rather using our process, helps us and saves the time.

5.5. Follows the Sustainable Development Goals

5.5.1. What are the Sustainable Development Goals?

The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by way of all United Nations Member States in 2015 as a prevalent name to motion to give up poverty, protect the planet and make sure that all people revel in peace and prosperity by means of 2030.

The 17 SDGs are integrated—that is, they understand that motion in one location will have an effect on outcomes in others, and that development should balance social, economic and environmental sustainability.

Through the pledge to Leave No One Behind, countries have committed to fast-track progress for these furthest behind first. That is why the SDGs are designed to carry the world to a number of life-changing 'zeros', consisting of zero poverty, hunger, AIDS and discrimination in opposition to female and girls.

Everyone is wished to attain these ambitious targets. The creativity, knowhow, science and economic assets from all of society is integral to reap the SDGs in each context.

The SDGs our thesis is following are –

1. Goal 4: Quality Education
2. Goal 7: Affordable and Clean Energy
3. Goal 10: Reduced Inequalities
4. Goal 12: Responsible Consumption and Production

5.5.2. Goal 4: Quality Education

Achieving inclusive and fantastic training for all reaffirms the belief that training is one of the most effective and validated automobiles for sustainable development. This aim ensures that all girls and boys complete free foremost and secondary education through 2030. It additionally aims to furnish equal get right of entry to low-cost vocational training, to dispose of gender and wealth disparities, and reap familiar access to a nice higher education.

5.5.3. Goal 7: Affordable and Clean Energy

As the populace continues to grow, so will the demand for less costly energy, and an economy reliant on fossil fuels is growing drastic adjustments to our climate.

Investing in solar, wind and thermal power, enhancing strength productivity, and ensuring power for all is crucial if we are to attain SDG 7 via 2030.

Expanding infrastructure and upgrading technology to furnish smooth and more efficient electricity in all international locations will encourage increase and assist the environment.

5.5.4. Goal 10: Reduced Inequalities

Income inequality requires international solutions. This involves improving the legislation and monitoring of financial markets and institutions, encouraging development assistance and foreign direct investment to regions where the need is greatest. Facilitating the protected migration and mobility of humans is also key to bridging the widening divide.

5.5.5. **Goal 12: Responsible Consumption and Production**

Achieving economic boom and sustainable development requires that we urgently limit our ecological footprint by changing the way we produce and eat items and resources. Agriculture is the biggest user of water worldwide, and irrigation now claims close to 70 percentage of all freshwater for human use.

The environment friendly administration of our shared natural resources, and the way we dispose of toxic waste and pollutants, are vital targets to gain this goal. Encouraging industries, organizations and shoppers to recycle and reduce waste is equally important, as is aiding creating nations to cross in the direction of greater sustainable patterns of consumption through 2030.

A giant share of the world populace is nonetheless consuming far too little to meet even their basic needs. Halving the per capita of international food waste at the retailer and customer degrees is additionally essential for growing greater efficient production and grant chains. This can help with food security, and shift us towards a greater aid environment friendly economy.

6. Conclusion

In this thesis, the state-of-the-art velocity decoding algorithms are presented for rotary incremental encoders. Each algorithm is investigated by way of a literature review. Various kinds of incremental encoders are also discussed based totally on their sketch structure and running principle. Each of the speed decoding algorithm alongside with an incremental encoder is carried out in MATLAB Simulink in order to further check out the behavior. The impact of incremental encoder decision is additionally analyzed. The speed response of every algorithm is examined in low, regular and high-speed regions. The last effects are analyzed and a comparative evaluation is performed based totally on accuracy, rapid response time and wide pace applications.

The outcomes show that the frequency size technique for pace calculation is the most appropriate preference for high-speed functions only. It offers a high relative error at low speeds which decreases when the quantity of encoder pulses internal time remark window increases. On the different hand, the relative error in the period measurement technique is high at high speeds. The duration size method has excessive accuracy in low-speed areas than the frequency dimension method. However, none of them is an appropriate desire for an extensive pace range. The mixed method performs properly in a vast velocity range and combines the blessings of both frequency and period dimension methods. It compares the relative error for both strategies and based on that switches to the fine method with low relative error. The quantization error hassle is still current due to a lack of synchronization of the time statement window and encoder pulses. In the pulse-window synchronization method for pace computation, the encoder pulses are synchronized with the observation window and corresponding quantization error reduces to zero. The pulse-window synchronization technique removes the quantization error without using a switching mechanism. The solely quantization error is brought at some point of the period dimension procedure via high-frequency counters. The fundamental downside of the pulse-window synchronization method is the correct sampling of statistics required for pace computation. Both the combined approach and pulse-window synchronization method for velocity calculation can be used for wide velocity applications.

Overall, the goals of this thesis are achieved. Based on consequences a comparative evaluation suggests that the mixed method and pulse-window synchronization can be the most appropriate preference for a large pace range. However, every of these methods has its personal limitations. In the pulse-window synchronization method, there is a need to resolve the problem of the correct sampling of data which is required to calculate speed. The pulse-window synchronization approach is challenging to enforce in two comparison with the combined method. On the other hand, the mixed approach only limits the quantization error due to lack of synchronization between encoder pulses and time window, but does no longer completely remove it. In the future, in addition trends are wished to clear up these problems in both methods to get more accurate results.

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