AUTONOMOUS GUIDED VEHICLE

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CERTIFICATE

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ABSTRACT

The Autonomous Guided Vehicle (AGV) Project aspires to construct a vehicle automatically guided without wires and with some intelligence to choose the correct path of travel.

The AGV has two front wheels driven by two PMDC motors and a free castor wheels at the back. For the simplest automation, the AGV would be following a line on a floor, either by image processing or by IR-Emitter-Detector sensors. The image is captures by a CCD Camera and sent to the frame grabber of the onboard computer. The computer processes the image and sends information to the motor drive circuits.

Speed control of the motors is done by driving an H-Bridge with Pulse Width Modulated signal.

The AGV robot can be remotely controlled, using AM transmitter receiver operating at 418 MHz. The working range is about 70 meters.

The AGV Vehicle also has two pairs of 40 KHz ultrasonic transmitter/receiver at the front. On sensing an obstacle on the vehicle's direction of movement, the AGV stops, steers and tries again.

Thus, the AGV is a good platform for robotics. On availability of good sensors, the AGV project can be extended to make a more sophisticated robot in the future.

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1. Introduction

1.1. The Project and its Aims

The project aims at building a programmable robot. By the term robot, a small dynamic vehicle is to be understood. Once the robot has been programmed, it should have an autonomous control over its job, guided by some means.

This Autonomous Guided Vehicle (AGV) is a mechanical challenge to design and construct a suitably sized vehicle, with a maximum specified weight (its own and the payload it could carry) able to tread on any given terrain.

AGV stands as an electronic challenge so as to design a control system in between the mechanical drive and the output control signals from the onboard computer, a reliable on board power supply system, and proper feedback system to dead reckon for good navigation.

Bringing life to the AGV is a software challenge. The sole purpose of the life of the AGV should be programmable, and could be changed as per requirement. This project specifies the aim of the AGV to be a line follower.

1.2. The Team and the Plan followed

This project is a part of the third year Engineering course offered at Kathmandu University, School of Engineering. The project team consists of third year engineering students from the Mechanical (ME), Electrical & Electronics (EE), and the Computer Engineering (CE) faculties.

The initiation of the project work started with the formation of the project team on Mid-August 2001. The Project was completed on June 2002. On the first half of the project, the team spent most of the time gathering resources, and building ideas with necessary laboratory work. On the other half of the project, the ideas were implemented to finally engineer a working vehicle. Details of the work done can be found on Section 6.2

1.3. Report Overview

This report is divided into three main parts - Mechanical Design, Electronic Design, and Software Design. The report is further divided into eight chapters, the first being this introduction. The second chapter will briefly deal about robotics and the research being done worldwide. The third, fourth and fifth chapters will include the three aspects of engineering involved in the design and construction of the AGV - Mechanical, Electrical, and Software respectively. The Sixth chapter is about the final product and the progress done by the team. The final seventh and eighth chapters are the references and the appendix. A Block diagram of the AGV Design, with an input of the image from the camera, and an output of the control of motor is shown in Figure 1.

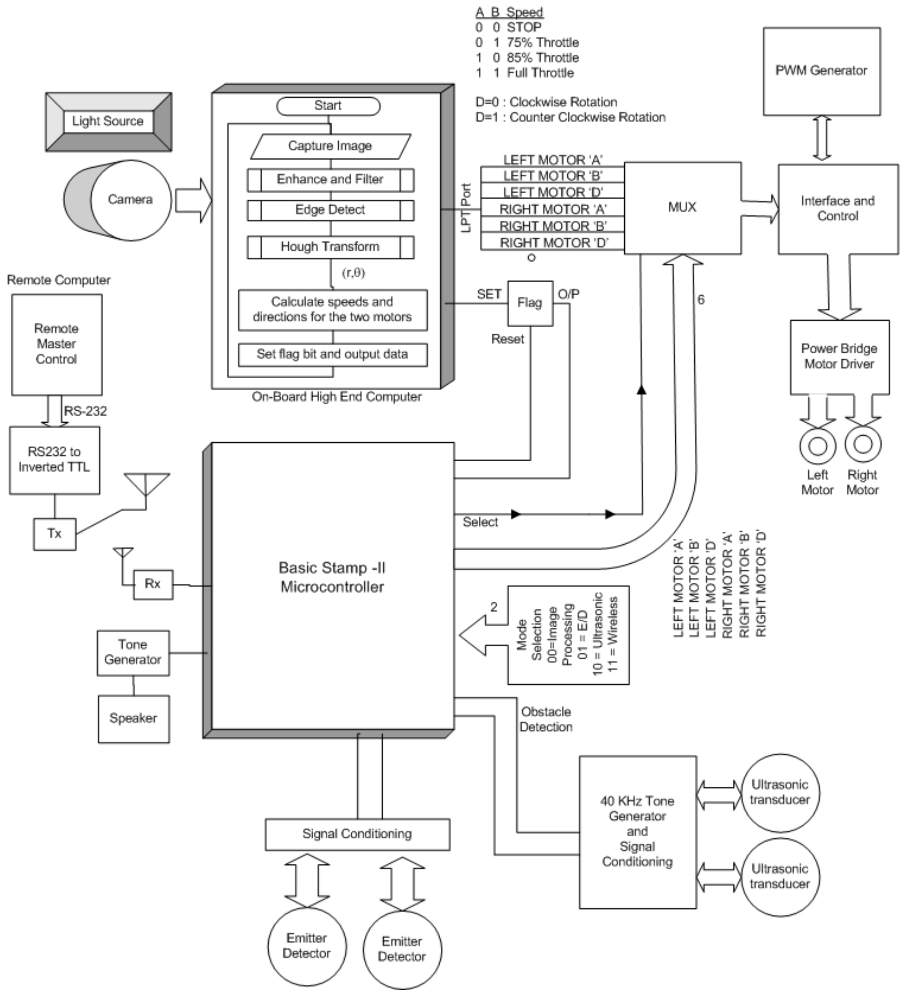

Fig 1. Block Diagram of AGV

2. Robotics

2.1. Introduction

Robotics is the leading field in Science & Technology which is going to shape the future of the human race. Since robots are used mainly in manufacturing, we see their impact in the products we use every day. Usually this results in a cheaper product. Robots are also used in cases where it can do a better job than a human such as surgery where high precision is a benefit. And, robots are used in exploration in dangerous places such as in volcanoes which allows us to learn without endangering ourselves.

The word "robot' was coined by Karel Capek who wrote a play entitled "R.U.R." or "Rossum's Universal Robots" back in 1921. The base for this word comes from the Czech word 'robotnik' which means 'worker'. In his play, machines modeled after humans had great power but without common human failings. In the end these machines were used for war and eventually turned against their human creators.

Popular science fiction writer Isaac Asimov created the Three Laws of Robotics:

#1 A robot must not injure a human being or, through inaction, allow a human being to come to harm.

#2 A robot must always obey orders given to it by a human being, except where it would conflict with the first law.

#3 A robot must protect it's own existence, except where it would conflict with the first or second law.

The population of robots is growing rapidly. This growth is lead by Japan that has almost twice as many robots as the USA. All estimates suggest that robots will play an ever-increasing role in modern society. They will continue to be used in tasks where danger, repetition, cost, and precision prevents humans from performing.

2.2. The R&D in Robotics

We live in a truly amazing, high technology world. The state of the art has a host of known problems with known solutions. The World Wide Web is making a tremendous amount of information available to everyone. The making of an intelligent robot is the ideal vision for all robotic enthusiasts. All one has to do to see the intelligent robot model is to look in a mirror. Ideally, all intelligent robots move dexterously, smoothly, precisely, using multiple degrees of coordinated motion and do something like a human but that a human now doesn't have to do. They have sensors that permit them to adapt to environmental changes.

They learn from the environment or from humans without making mistakes. They mimic expert human responses. They perform automatically, tirelessly, and accurately. They can diagnose their own problems and repair themselves. They can reproduce, not biologically but by robots making robots. They can be used in industry for a variety of applications. A good intelligent robot solution to an important problem can start an industry and spin off a totally new technology. For example, imagine a robot that can fill your car with gas, mow your lawn, a car that can drive you to work in heavy traffic, a machine that repairs itself when it breaks down, a physician assistant for microsurgery that reconnects 40,000 axons from a severed nerve.

Intelligent robots are also a reality. Many are used today. Many more prototypes have been built. Typical applications are: high speed spot welding robots, precise seam welding robots, spray painting robots moving around the contours of an automobile body, robots palletizing variable size parcels, robots loading and unloading machines.

2.3. AGV Products

AGV has found different levels of applications around the world. They are used in factories, hospitals carrying things around. They have also found a good use around the house as Autonomous Vacuum Cleaners.

2.4. AGV as a Robot

AGV has been a dream. An autonomous robot is a dream for now, a vehicle doing jobs for you, like bringing you a cup of coffee in the morning from the coffee maker in the kitchen. To make this dream a reality, we have to start from collecting the stones to build it. Collecting stones and making a skeletal robot is our aim for this project, which should have elementary vision capability, like line following.

3. Mechanical Design

3.1. Introduction

The AGV has stood as a mechanical challenge from the very first stages of the project. The mechanical design would determine directly or indirectly the rest of the design processes - electrical, electronics, and software.

The AGV design should minimize weight to reduce power required, as high power drives are not easily available and portable. The basic design requirements for the AGV are steering and forward and reverse drive. The drive could be either electrical or fuel. The fuel engine alternative is not feasible under the presumed vehicle dimension and weight. An electrical drive system is more viable for the AGV as visualized by the team.

3.2. Brief Description of the Mechanical Components

3.2.1. Wheels and Tyres

The importance of wheels and tyres in the automobile is obvious. Wheels are the important parts of the vehicle as they must support the weight of the vehicle and help protect it from the road shocks. In addition, the rear wheels must transmit the power, the front wheels must steer the vehicle, and all must resist braking stresses and withstand side thrusts. Wheels must be perfectly balanced.

The various requirements of an automobile wheel are:

i) It should be balanced both statically and dynamically.

ii) It should be lightest possible so that the up sprung weight is least.

iii) Its material should not deteriorate with weathering and age.

Types of wheels

There are three types of wheels, viz the pressed steel disc wheel, the wire wheel, and the light alloy cast wheel.

Because of simplicity, robust construction, lower cost of manufacture and ease in cleaning, the steel disc wheel is used universally. The disc wheel consists of two parts, a steel rim which is well based to receive the tyre and a pressed steel disc. The rim and the disc may be integral, permanently attached, depending upon the design.

The wire wheel has a separate hub, which is attached to the rim through a number of wire spokes. The spokes carry the weight, transmit the driving and braking torques and withstand the side forces. Spokes are long, thin wires and as such these cannot take any compressive of bending stresses.

Cast wheels are generally used in cars while forged wheels are preferred for heavy vehicles. The main advantage of light alloy wheels is their reduced weight which reduces unsprung weight.

TYRES

A tyre is a cushion provided with an automobile wheel. It consists of mainly the outer cover i.e., the tyre proper and the tube inside. The tyre tube assembly is mounted over the wheel rim. It is the air inside the tube that carries the entire load and provides the cushion.

The tyre performs the following functions;

- To support the vehicle load
- To provide cushion against shocks
- To transmit driving and braking forces to the road.
- To provide cornering power for smooth steering.

Types of Tyres

The different types of tyres are

a) Pneumatic tyre

b) Tube tyre

c) Tubeless tyre

The pneumatic tyres are designed to cushion the vehicle and its load from the shocks and vibrations resulting from road inequalities. The use of solid tyres on automobiles is now obsolete and only the pneumatic tyres are used universally. These pneumatic tyres are of two types, the conventional tyre with a tube and the tubeless tyre. The conventional tube tyre consists of two main parts, viz. The carcass and the tread. The carcass is the basic structure taking mainly the various loads and consists of a number of plies wound in a particular fashion. The tread is the part of the tyre which contacts the road surface when the wheel rolls. It is gene rally made of synthetic rubber.

Inside the tyre, there is a tube which contains the air under pressure. The tube being very thin and flexible, takes up the shape of the tyrecover when inflated. A valve stem is attached to the tube for inflating or deflating the same.

Desirable tyre properties:

Non-skidding

This is one of the most important tyre properties. The tread pattern on the trye must be suitably designed to permit least amount of skidding even on wet road.

Uniform Wear

To maintain the non skidding property, it is very essential that the wear on the tyre tread must be uniform. The ribbed tread patterns help to achieve this.

Load Carrying

The tyre is subjected to alternating stresses during each revolution of the wheeel. The tyre material and design must be able to ensure that the tyre is able to sustain these stresses.

Cushioning

The tyre should be able to absorb small, high frequency vibrations set up by the road surface and thus provide cushioning effect.

Power Consumption

The automotive tyre does absorb some power which is due to friction between the tread rubber and the road surface and also due to hysterisis loss on account of the tyre being continuously flexed and released. This power comes from the engine fuel and should be the least possible. It is seen that the synthetic tyres comsume more power while rolling than the ones made out of natural rubber.

Tyre Noise

The tyre nose may be in the form of definite pattern sing, a sequel or a lous roar. In all these cases, it is desirable that the noise hould be minimum

Balancing

This is very important consideration. The tyre being a rotating part of the automobile, it must be balanced statically as well as dynamically. The absence of balancing gives rise to peculiar oscillations

3.2.2. BEARINGS

Bearing is a machine element, which supports another machine element or member permitting the relative motion between the contact surfaces. There are two types of bearings - Sliding contact bearing or Journal bearing and Rolling or Anti friction bearing.

Types of Bearings:

Rolling or Anti friction bearing

The term rolling contact bearing, anti friction bearing and rolling bearings are all used to describe that class of bearing in which the main load is transferred through element in rolling contact rather than in sliding contact. In a rolling bearing, the starting friction is twice the running friction but still it is negligible in comparison to the starting friction of journal bearing.

Types of rolling contact bearings

-Ball bearings

-Roller bearings

Ball bearings:-

A ball bearing consists of following parts- outer race ,inner race, balls, and retainer. The outer and inner races are held concentric with each other by several spherical balls placed circumferentially equal. The ball retaining rings,(usually in two parts) ensure the equal spacing of the balls. the grooves, which form the path for the rolling elements, are known as raceways. Depending on the type of the load the bearing has to support, it may be either designed for radial load or axial load or both for combined. When a ball bearing supports only a radial load, the plate of the rotation of the ball is normal to the center line of the bearing. In the case of the axial loading, the axial shifts the plane of rotation of the balls.

3.2.3. SHAFTS

A shaft is a rotating member, usually of circular cross-section (either solid or hollow), transmitting power. It is supported by bearings, wheels etc. and is subjected to torsion and to transverse or axial load, acting singly or in combination. Generally shafts are not of uniform diameter but are stepped to provide shoulders for locating gears, pulleys, bearings etc. An axle is a stationary member primarily loaded in bending with rotating wheels, pulleys, etc. Short axles and shafts are often called spindles. Regardless of design requirement, care must be taken to reduce the stress concentration in notches, keyways, etc.

Power consideration of notch sensitivity may improve the strength more significantly than material consideration.

Material used for shaft

Generally shafts are made up of mild steel in ordinary case. When strength is required alloy steel such as nickel, nickel-chromium or chrome vanadium steel is used.

Types of shaft

-Transmission shaft

-Machine shaft

Transmission shaft

These shafts transmit power between the source and the machines absorbing power. The counter shaft, line shafts, overhead shafts and all factory shafts are all transmission shafts. Since these shafts carry machine parts such as pulleys, gears, etc, therefore they are subjected to bending in addition to twisting.

Machine shaft.

These shaft form an integral part of machine itself. The crankshaft is an example of machine shaft.

Stresses in Shaft

The following stresses are induced in the shafts

Shear stresses due to transmission of torque.

Bending stresses due to forces acting upon the machine elements like gears, pulleys, etc. as well as due to the weight of the shaft itself.

Stresses due to combined torsion and bearing loads.

3.2.4. FRAME

Frame is made up of Galvanized iron pipe and sheet. The functions of frame are as follows

A. To support the components, motor, camera, CPU etc.

B. To withstand static and dynamic load wit deflection or distortion.

Loads on the frame

a. Vertical loads when the wheel chair come across a bump or hump (which results in longitudinal torsion in longitudinal torsion due to one wheel lifted or lowered and other wheel at the usual road level .

b. Loads due it road chamber side wind, concerning force while taking a turn(which results I lateral bending of side members).

c. Load due to wheel impact with road obstacles i.e., one wheel tends to move (which cause distorting the frame to parallelogram shape).

d. Motor torque and braking torque (which cause to bend the side member in vertical plane).

e. Sudden impact load during collision 9which may result in a general collapse).

3.2.5. Sprocket

Two sprocket of same size and same no. of teeth will be used to transmit power of motor to shaft of wheel at the same rpm.

3.2.6. Chain

A chain is a mechanical component which will be fitted over the teeth of the sprocket for the transmission of the power from the motor to the shaft of the wheel.

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3.2.7. Castor wheel

The angle between the king pin centre line and the vertical, in the plane of the wheel is called the castor angle. If the king pin centre line meets the ground at a point in front of the wheel centre line, it is called positive castor while it is behind the wheel centre line, it is called negative castor.

Positive castor on the car wheels provides directional stability. The positive castor causes the wheel to be pulled in any direction.

Castor has another effect also. When the vehicle having positive castor takes a turn, the outer side of the vehicle is lowered while the inner one is raised, i.e. the positive castor help the centrifugal force in rolling out the vehicle.

3.3. Design Criteria

The final goal of the mechanical design is to fabricate a vehicle that is safe, economical and that is practical to manufacture. Different design approaches must have to be adjusted to be compatible with the market. In approaching the final design some criteria should be established to guide decision making processes. The following are the design criteria that should be established in designing the project.

The design of the vehicle and its various components for efficient operation.

- Selection of proper material
- Safety of operation
- Economic status

.

3.4. Design Options

3.4.1. MODEL 1

The vehicle can be made of four wheels. In this type of vehicle power is given to the shaft by means of motor and the differential gear is used in rear wheel for the turning of the wheels and another motor is connected with the steering which is used for turning front wheels.

3.4.2. MODEL 2

This model consist of three wheels. Two of them as rear wheel and one as front wheel. The two rear wheels would be driven by the DC motors. In this type of vehicle , motor is connected to the shaft of each wheels by means of chain and sprocket which is responsible for transmission of power. The ball castor is placed as the front wheel which can rotate in any direction to provide more degree of freedom to the vehicle.

3.4.3. Model Selection

Since the differential gear costs about eight thousand rupees, it will be difficult for us to install it from economical point of view. Also the steering system to be used for the turning movement of the vehicle will make difficult for the design of the vehicle. In the second model, the vehicle can be turned by varying the speed of the two motors, which are connected separately to two wheels. Also, the ball castor assembly as the front wheel will make easier for the turning movement of the wheel. Since it is also appropriate from cost point of view, we select model second for the design of the vehicle.

Working Principle of the selected Model:

The model we choose mainly consists of two 45 cm bicycle tyre, bearings, frames, shafts, chains, sprockets, ball castor as the mechanical part. Two 45 cm bicycle tyres are used as the rear wheels. Two electrical dc motors are connected to the two wheels separately. The speed of the two motors controls the movement of the vehicle. By varying the speed of the motors, the turning movement of the vehicle can be obtained. The shaft of wheel and motor is connected with chain and sprocket. sprocket of same size will be fitted on the shaft of wheel and motor so that same rpm is transmitted to wheel from motor.

For the placement of the other electrical and computer parts ,a frame made up of iron rod and plywood is placed as the base Firstly, the iron rod is fixed in position by the process of welding and upon which plywood are fixed by the process of drilling.

Two individual shafts are placed for the transmission of the power from the motor to the wheel. On each shaft and on the motor, sprocket is fixed and chains are placed over it for the transmission of the power. The fabrication of the vehicle is done in such a way that most of the parts can be disassembled easily i.e welding process is avoided as far as possible

To prevent damage to the electrical and computer parts, the vehicle incorporates the covering.

3.5. Brief of the manufacturing processes during fabrication

There are different manufacturing processes that were to be gone through in order to complete the fabrication of the vehicle. All the operations are performed in the workshop. The operations performed are

1) Welding

2) Drilling

3) Cutting

4) Grinding

5) Facing

6) Turning

7) Thread Cutting

Welding operation was performed to join the different components of the vehicle. The base of the vehicle is made of mild steel. The mild steel of size 73cm × 51 cm was joined for the base of the vehicle. Similarly, other components like the castor wheel was welded on the base of the vehicle. Welding operation was also carried to fix the motor-stand.

Drilling operation was performed to place the bearing cap on the frame of the vehicle. In the same way, drilling was also performed to assemble the castor wheel to the vehicle.

Cutting operations were performed to obtain the required sizes of the base of the vehicle. Hand grinding operation was performed to make the welded surfaces smooth.

Facing and the turning operations were carried out in lathe to make the shaft for the vehicle. Threads were also made in the shaft with the help of thread cutting die. The specifications of the die is

Tap size: ¾”	Tap Size : ½”
Drill Size : 16.25 mm	Drill size : 10.5 mm

3.6. DESIGN CALCULATIONS

3.6.1. Calculation of Power of Motor

Diameter of wheel, D = 43cm = 0.43m

Radius of wheel, R = 21.5cm = 0.215m

Circumference = $2\pi R$

$= 2 * \pi * 0.215 = 1.35$m

Required Speed of the wheel = 1m/s = v

Angular velocity (ω) = $2\pi n / 60$

therefore,

$v = r\,\omega$

or, $v = r\,2\pi n/60$

or, $n = 60 * v / 2\pi r$

$= 60 * 1 / (2\pi * 0.215)$

$= 44.41$rev/min

thus, required rpm of motor = 44.41 rpm

Now, Angular Velocity(ω) = $2\pi n / 60$

$= 2\pi * 44.41 / 60$

= 4.64 rad/sec

Self weight of the vehicle = 10 kg

Weight on the body = 15 kg

.

Net weight (ω) = 25kg = 245 N

Let us consider,

Maximum Frictional force =F_s

Coefficient of static friction = μ_s =0.4

Now, $\mu_s = F_s /W$

therefore, $F_s = \mu_s * W$

= 0.4 * 245 N

= 98 N

therefore, Initial torque = $F_s * R$

= 98 * 0.25

= 21.07 N-m

This torque is the maximum torque that is required. But during the motion the frictional forces reduces because of the lower value of coefficient of friction.

Frictional force in motion = F_d

Coefficient of dynamic friction = μ_d = 0.25

Now, $\mu_d = F_d /W$

therefore, $F_d = \mu_d * W$

= 0.25 * 245

=61.25

Torque (τ) = $F_d * R$

= 61.25 * 0.215 = 13.16 N-m, which is required running Torque.

Power required by the motor = $\tau * 2\pi n/ 60$

= 13.16 * 2 * 3.14 * 44.41 / 60

= 61.2 watt

= 0.082 hp.

Therefore, the required motor Power = 0.082 hp.

3.7. Shaft Design

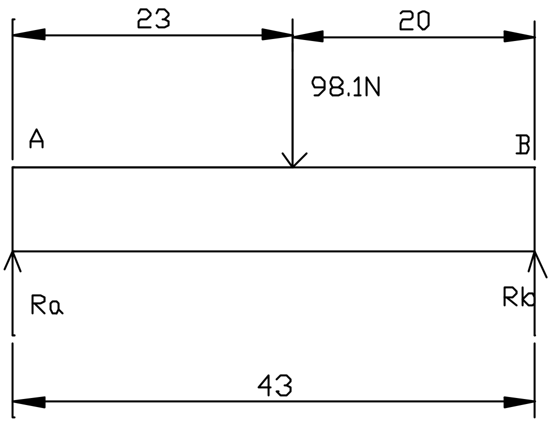

Fig 2. Shaft Design

Weight on the shaft (W) =10* 9.81=98.1N

Moment at A (M_A)= Wab^2 /l^2

=98.1*0.23*$(0.2)^2$/ $(0.43)^2$

= 5.6 N-m

Moment at B (M_B)= Wa^2b /l^2

=98.1*0.2*$(0.23)^2$/ $(0.43)^2$

= 4.88 N-m

M_{av}=(M_{max}+$M_{min)}$ /2

=5.6+4.8/2

=5.24 N-m

M_{rev}= M_{max}-M_{min} /2

= 5.6-4.8/2

=0.36N-m

.

A shaft subjected to transmit torque with gear, pulley, sprocket or similar devices result in bending moment as well as torque acting on the shaft and the relationship of combined stresses to fatigue failures must be considered. For this maximum shear stress theory is used for the ductile material.

$$ë_{max}=[(ó/2)^2+ ë^2]^{1/2}$$

For bending only

$$Fos=ó_y/ ó_{av}+Kf\ ó_r(ó_y/ó_e)$$

$$= ó_y/ ó_{max}$$

For shear stress part,

$$Fos=ë_y/ [ë_{av}+(Kf)s\ ë_r(ë_y/ ë_e)]$$

$$= ë_y /ë_{max}$$

For combined bending and torsion,

$$Fos= ë_y /[1/4\{ 2\ M_{av}/J *d/2+ Kf\ 2\ M_{rev}/J*d/2 * ó_y/ó_e\}^2 +\{ T_{av} /J *d/2 +Kfs *Tr/J *d/2* ë_y/ ë_e\}^2]^{1/2}$$

Where, $J=ð\ d^4/32$ =polar moment of inertia

$$.d^3 =Fos*16 [1/4\{ 2\ M_{av}/J *d/2+ Kf\ 2\ M_{rev}/J*d/2 * ó_y/ó_e\}^2 +\{ T_{av} /J *d/2 +Kfs *Tr/J *d/2* ë_y/ ë_e\}^2]^{1/2} /ð\ ë_y$$

T_{max}=21.07 N-m

T_{min}=13.16 N-m

Hence,

$T_{av} = T_{max} + T_{min} /2$

$= (21.07+13.16)/2$

$= 17.11$ N-m

$T_{rev} = T_{max} - T_{min} /2$

$=(21.07-13.16)/2$

$= 3.95$ N-m

For mild steel,

$ó_y = 304.11 * 10^6$ N/mm^2

[DESIGN DATA,PSG COLLEGE OF TECHNOLOGY

$ó_e = 568.98 * 10^6$ N/mm^2 PAGE 1.9]

[

$ë_y = ó_y /2 = 152.05 * 10^6$ N/mm^2

$ë_e = ó_e/2 = 284.49 * 10^6$ N/mm^2

Therefore,

$d^3 = 2 * 16 * [(30.56 + 411.14)]^{1/2} / ð * 152.05 * 10^6$

d=.0112m

d=11.2mm =12mm

Hence, the diameter of the shaft = 12mm

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3.8. Bearing Selection

Diameter of the shaft = 16mm

From, DESIGN DATA, PSG COLLEGE OF TECHNOLOGY,

Page 4.14

Bearing of basic design no.(SKF) =6201

ISI No. =15BC02

Outer diameter = 42mm

Inner diameter =16mm

Dynamic load rating capacity (c) =610 Kgf

Maximum permissible speed (rpm)=16000

For shaft diameter = 20mm

From, DESIGN DATA, PSG COLLEGE OF TECHNOLOGY,

Page 4.14

Bearing of basic design no.(SKF) =6304

ISI No. =20BC03

Outer diameter = 52mm

Inner diameter =20mm

Dynamic load rating capacity (c) =1250 Kgf

Maximum permissible speed (rpm)=13000

3.9. Problems raised during fabrication and remedies

1) Wheel Drive:

During the design of the vehicle, the vehicle was made four wheeler with two bicycle tyres as the front wheel and two wheels as the rear wheel. But, while taking a turn, there is probability of skidding off the vehicle. So instead of the tyres, ,two ball castors is used as the rear wheel. Again during the fabrication of the vehicle, the vehicle is made three wheeler with the ball castor as the front wheel and the two tyres as the rear wheel as it provides more degree of freedom to the vehicle.

2) Shaft:

Generally in the vehicle, power is supplied to single shaft for the driving mechanism and the differential gear is provided for the turning movement of the vehicle. As the differential gear is expensive one, different option was to be considered. So, individual power is given to two wheels by the use of chain and sprocket through two motors. It also enables to change the direction of the vehicle by varying the power of the two motors.

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3.10. Final Design Values of the Vehicle:

Following parameters and specifications are designed for the mechanical components of the Automated Guided Vehicle.

Vehicle Size:

Length * Breadth * height = 73cm * 90 * 50cm

Load on Vehicle: 10 kg

Vehicle Weight: About 10 kg

Vehicle Speed: 1 m/s

Motor: D.C Motor

Power Supply: 12 V, Rechargeable Battery (3 nos.)

Rear Wheels:

Number :2

3.11. Outside Diameter : 43 cm

Inside Diameter : 35 cm

SHAFT:

Material : Mild steel

Diameter : 12mm

Bearing Selection:

Bearing Type: Deep Groove Ball Bearing

i) Inside Diameter: 16mm

Outside diameter : 42 mm

SKF No. : 15BC02

ii) Inside Diameter : 20 mm

Outside Diameter : 52 mm

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SKF No. : 20BC03

Power Calculation:

Power of the motor: .082 hp

Speed of Motor : 44.41rpm

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3.12. COST ESTIMATION

The various costs incurred during the fabrication of the vehicle are

S. No	Particulars	Specifications	Rate (Rs.)	Quantity	Amount (Rs.)
1.	Bicycle Tyres	Outer dia=45cm Inner dia=35cm	600	2	1200.00
2.	sprocket		300	4	1200.00
3.	Ball Castor		100	2	200.00
4.	Bearing	ISI 6002 ISI 6004	95 195	2 2	190.00 390.00
5.	Bearing Cap		150	2	300.00
6	Shaft				120.00
7	chain				450.00
8	Nuts and bolts				150.00
9.	Miscellaneous				350.00
	Total				**4250.00**

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4. Software Design

4.1. Introduction

Software is the brain of the AGV. The software makes the vehicle automated, the A in AGV!

According to the modes on which the vehicle can be operated, different approaches have been taken into consideration to control the movement of vehicle through the computer. The models we have taken into consideration are listed below:

Image Processing Approach (Autonomous)

Wireless Control Approach (Manual)

4.2. Image Processing Approach

As the name of the project "Autonomous Guided Vehicle", the main objective of this project is to make the vehicle itself think and decide on driving, i.e. whether to move the vehicle forward, backward or left or right or to stop if the vehicle has reached the destination.

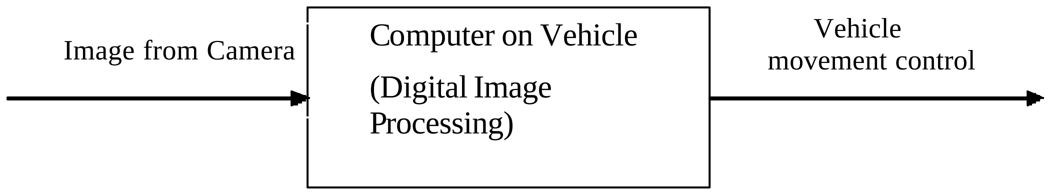

Fig 3. Image Processing Approach Outline

The main idea in this approach is the use of Digital Image Processing of the Input Image from Camera and control of the vehicle movement accordingly. The control data are transmitted through parallel port communication. The platform used to develop this model is Microsoft Visual C++ on Windows Operating System.

4.3. Digital Image Processing

A digital image is an array of real or complex numbers represented by a finite numbers of bits.

The term digital image processing generally refers to processing of two-dimensional picture by a digital computer. In other way, it can be said as digital processing of any two-dimensional data. A typical digital image processing sequence is shown in Figure 4.

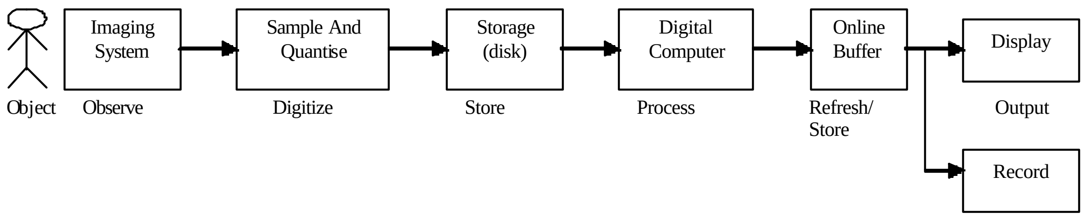

Fig 4. Digital Image Processing Sequence Block Diagram

Digital image processing has a broad spectrum of applications, such as remote sensing via satellites and other spacecrafts, image transmission and storage for business applications, medical processing, radar, sonar and acoustic image processing, robotics and automated inspection of industrial parts. There many image processing applications and problems as:

- Image representation and modeling
- Image enhancement
- Image analysis
- Image reconstruction
- Image data compression

In image representation one is concerned with characterization at the quantity that each picture element (PIXEL or PEL) represents. An image could represent luminance of objects in a scene (pictures taken by ordinary camera), the absorption characteristics of the body tissue (X-ray imaging), the radar cross-section of a target (radar imaging), etc.

In Image Enhancement, the goal is to accentuate certain image Features for subsequent analysis or for image display. It includes, Contract and Edge Enhance mar, pseudo coloring, noise filtering, sharpening and magnifying. It is useful in Image analysis, Feature Extraction and visual information display.

Image analysis is concerned with making quantitative measurements from an Image to produce a description of it. In the simplest form, this task could be reading on a grocery item, sorting different parts on an assembly line, or measur ing the size and orientation of blood cells in a medical Image. More advanced image analysis system measure quantitative information and use it to make a sophisticated decision, such as controlling the arm of a robot to move an after identifying it or navigating an aircraft with aid of images acquired along its trajectory.

Image reconstruction from projections is a special class of image restoration problems where a two-(or higher) dimensional object is reconstructed from several one-dimensional projections.

4.4. Image Acquisition

4.4.1. Preliminaries

The image is acquired through a sensor in the video camera known as the CCD. CCD is a collection of tiny light-sensitive diodes, which convert photons (light) into electrons (electrical charge). These diodes are called pho tosites. In a nutshell, each photosite is sensitive to light - the brighter the light that hits a single photosite, the greater the electrical charge that will accumulate at that site.

The CCD is the central element in an imaging system. Designers need to be aware of the special requirements for the signal conditioning of the CCD in order to achieve the maximum performance. The output signal of the CCD is a constant stream of the individual pixel “charges” and this result in the typical form of stepped DC voltage levels. This output signal also contains a DC-bias voltage, which is in the order of several volts. The next stage is used as a noise reduction circuit specific to CCD based systems: the correlated double sampler (CDS).

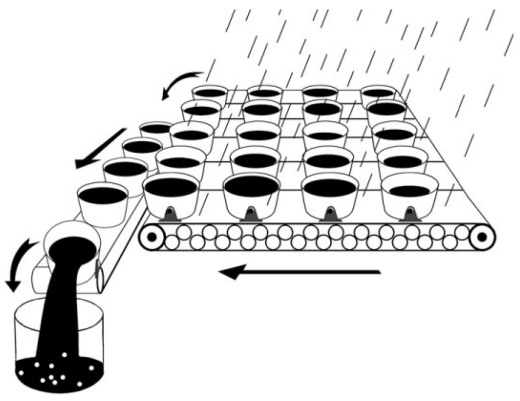

Fig 5. Basic CCD Theory

In its principle, the operation of a CCD array is quiet simple. A common analogy is shown above, using an array of buckets on conveyor belts. During a rain shower the raindrops will fill the lined up buckets more or less. Then the conveyor belts transport the buckets to the front belt and dump their content into another row of buckets. As they move forward the rainwater is spilled into the metering glass. The scale on the metering glass indicates how much water was collected in the individual bucket. When relating this model to a real CCD element, the “raindrops” are the light (photons) falling onto the CCD surface, the buckets are the many pixels of a CCD array and the “conveyor belts” are the shift registers that transport the pixel charge to the output stage. This output stage is mainly the sense capacitor, here the “metering glass”, and an output source follower is used to buffer this sense capacitor.

The Main Limiting Factor of the CCD is NOISE, Its sources are:

- CCD - output stage noise
- Semiconductor Noise — Shot, Flicker, White Noise
- Resistor / Thermal Noise
- ADC Quantization Noise

4.4.2. Camera components

The word camera comes from the term *camera obscura*. Camera means room (or chamber) and obscura means dark. In other words, a camera is a dark room. This dark room keeps out all unwanted light. At the click of a button, it allows a controlled amount of light to enter through an opening and focuses the light onto a sensor (either film or digital).

Aperture

The aperture is the size of the opening in the camera. It's located behind the lens. On a bright sunny day, the light reflected from the image may be very intense, and it doesn't take very much of it to create a good picture. In this situation, a small aperture is required. But on a cloudy day, or in twilight, the light is not so intense and the camera will need more light to create an image. In order to allow more light, the aperture must be enlarged.

Shutter Speed

Traditionally, the shutter speed is the amount of time that light is allowed to pass through the aperture. Think of a mechanical shutter as a window shade. It is placed across the back of the aperture to block out the light. Then, for a fixed amount of time, it opens and closes. The amount of time it is open is the shutter speed. One way of getting more light into the camera is to decrease the shutter speed. In other words, leave the shutter open for a longer period of time.

Film-based cameras must have a mechanical shutter. Once film is exposed to light, it can't be wiped clean to start again. Therefore, it must be protected from unwanted light. But the sensor in a digital camera can be reset electronically and used over and over again. This is called a digital shutter. Some digital cameras employ a combination of electrical and mechanical shutters.

Exposing the Sensor

These two aspects of a camera, aperture and shutter speed, work together to capture the proper amount of light needed to make a good image. In photographic terms, they set the exposure of the sensor. Most digital cameras automatically set aperture and shutter speed for optimal exposure, which gives them the appeal of a point-and-shoot camera.

Lens and Focal Length

A camera lens collects the available light and focuses it on the sensor. The focal length is the distance between the lens and the surface of the sensor. Technical details show that the surface of a film sensor is much larger than the surface of a CCD sensor. In fact, a typical 1.3 mega-pixel digital sensor is approximately one-sixth of the linear dimensions of film. In order to project the image onto a smaller sensor, it is necessary to shorten the focal length by the same proportion. Focal length is also the critical information in determining how much magnification we get when we look through the camera. In 35 mm cameras, a 50 mm lens gives a natural view of the subject. As the focal length is increased, we get greater magnification and objects appear to get closer. As we decrease the focal length, things appear to get further away, but we can capture a wider field of view in the camera.

4.4.3. Camera solution to obtain intensity images

Camera (can be assumed as digital) has a sensor that converts light into electrical charges. All the fun and interesting features of digital cameras come as a direct result of this shift from recording an image on film to recording the image in digital form.

The image sensor employed by most digital cameras is a charge-coupled device (CCD). Some low-end cameras use complementary metal oxide semiconductor (CMOS) technology. While CMOS sensors will almost certainly improve and become more popular in the future, they probably won't replace CCD sensors in higher-end digital cameras.

How the Camera Captures Color?

Unfortunately, each photosite is colorblind. It only keeps track of the total intensity of the light that strikes its surface. In order to get a full color image, most sensors use filtering to look at the light in its three primary colors. Once all three colors have been recorded, they can be added together to create the full spectrum of colors that you've grown accustomed to seeing on computer.

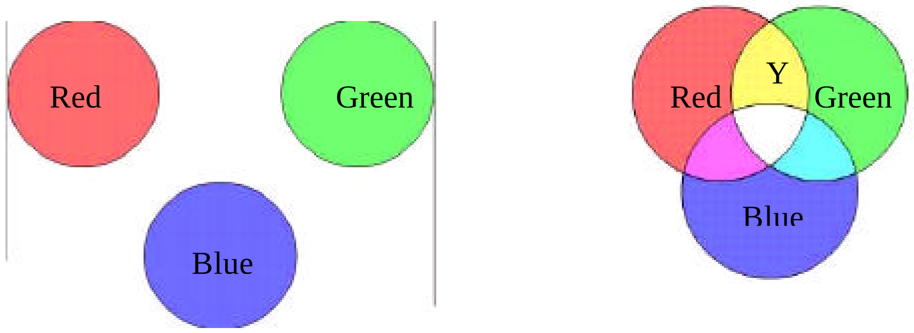

Fig 6. How the three colors mix to form many colors

There are several ways of recording the three colors in a digital camera. The highest quality cameras use three separate sensors, each with a different filter over it. Light is directed to the different sensors by placing a beam splitter in the camera. Think of the light entering the camera as water flowing through a pipe. A beam splitter would be like dividing an identical amount of water into three different pipes. Each sensor gets an identical look at the image, but because of the filters, they only respond to one of the primary colors.

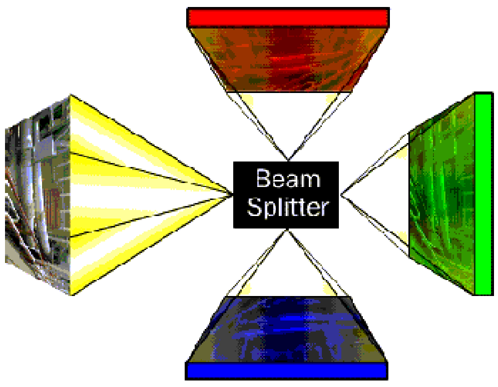

Fig 7. How the original image at the left is split in a beam splitter.

The advantage of this method is that the camera records each of the three colors at each pixel location. Unfortunately, cameras that use this method are both bulky and expensive.

A second method is to rotate a series of red, blue and green filters in front of a single sensor. The sensor records three separate images in rapid succession. This method also provides information on all three colors at each pixel location. But since the three images aren't taken at precisely the same moment, both the camera and the target of the photo must remain stationary for all three readings. This isn't practical for candid photography or handheld cameras.

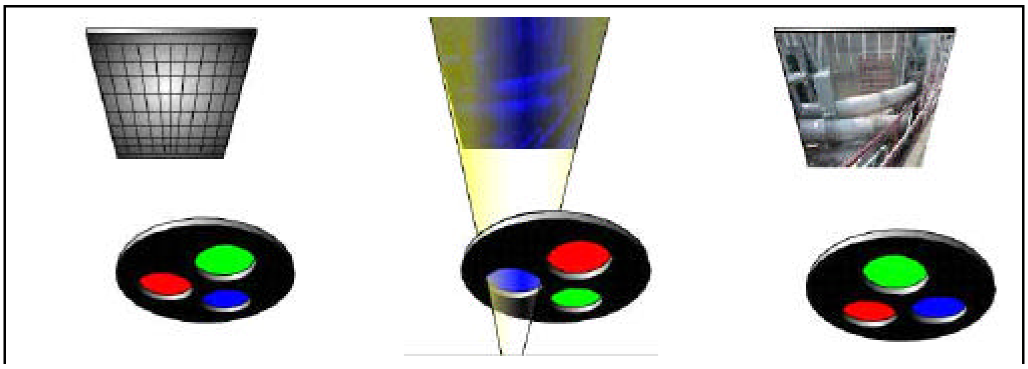

Fig 8. ***A spinning disk filter.***

A more economical and practical way to record the three primary colors from a single image is to permanently place a filter over each individual photosite. By breaking up the sensor into a variety of red, blue and green pixels, it is possible to get enough information in the general vicinity of each sensor to make very accurate guesses about the true color at that location. This process of looking at the other pixels in the neighborhood of a sensor and making an educated guess is called interpolation. (You'll learn more about pixels in the next section, but for now, think of one photosite as a single pixel.)

Frame buffer

A frame buffer device is an abstraction for the graphic hardware. It represents the frame buffer of some video hardware, and allows application software to access the graphic hardware through a well-defined interface, so that the software doesn't need to know anything about the low-level interface stuff.

The major advantage of the frame buffer drives is that it presents a generic interface across all platforms.

Intensity Images

Intensity images measure the amount of light impinging on a photosensitive device. The input to the photosensitive device, typically a camera, is the incoming light, which enters the camera's lens and hits the image plane. In a digital camera, the physical image plane is an array which contains a rectangular grid of photo sensors, each sensitive to light intensity. The output of the array is a continuous electric signal, the video signal. The video signal is sent to an electronic device called frame grabber, where it is digitized into a 2D rectangular array of integer values and stored in a memory buffer.

The interpretation of an intensity image depends strongly on the characteristics of the camera called the camera parameters. The parameters can be separated into extrinsic and intrinsic parameters.

The extrinsic parameters transform the camera reference frame to the world reference frame. These are the parameters that define the location and orientation of the camera reference frame with respect to a known world reference frame

The intrinsic parameters describe the optical, geometric and digital characteristics of the camera. One parameter, for example, can describe the geometric distortion introduced by the optics. So, these are the parameters necessary to link the pixel coordinates of an image point with the corresponding coordinates in the camera reference frame.

4.5. Camera parameters and calibration

4.5.1. Basic Optics

We first need to establish a few fundamental notions of optics. As for many natural visual systems, the process of image formation in computer vision begins with the light rays which enter the camera through an angular aperture (or pupil), and hit a screen or image plane, the camera's photosensitive device which registers light intensities. Notice that most of these rays are the result of the reflections of the rays emitted by the light sources and hitting object surfaces.

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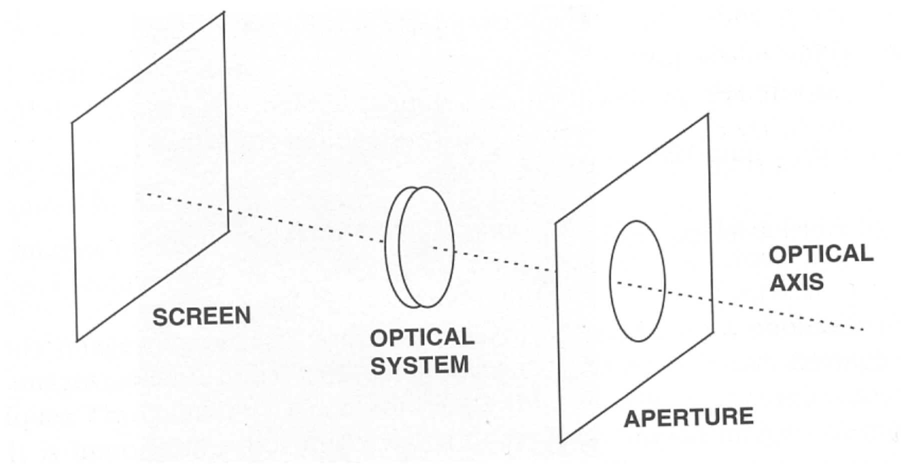


Fig 9. The basic element of an Imaging System

4.5.2. Image Focusing

Any single point of a scene reflects light coming from possibly many directions, so that many rays reflected by the same point may enter the camera. In order to obtain sharp images, all rays coming from a single scene point, P, must converge onto a single point on the image plane, p, the image of P. If this happen, we say that the image of P is in focus; if not, the image is spread over a circle. Focusing all rays from a scene point onto a single image point can be achieved in two ways:

Reducing the camera's aperture to a point is called a pinhole. This means that only one ray from any given point can enter the camera, and creates a one-to-one correspondence between visible points, rays and image points. This results in very sharp, undistorted images of objects at different distances from the camera.

Introducing an optical system composed of lenses, apertures, and other elements, explicitly designed to make all rays coming from the same 3-D point converge onto a single image point.

An obvious disadvantage of a pinhole aperture is its exposure time; that is, how long the image plane is allowed to receive light. Any photosensitive device (camera film, electronic sensors) needs a minimum amount of light to register a legible image. As a pinhole allows very little light into the camera per time unit, the exposure time necessary to form the image is too long (typically several seconds) to be of practical use. (Note: The exposure time is, roughly, inversely proportional to the square of the aperture diameter, which in turn is proportional to the amount of light that enters the imaging system). Optical systems, instead, can be adjusted to work under a wide range of illumination conditions and exposure times (the exposure time being controlled by a shutter).

Intuitively, an optical system can be regarded as a device that aims at producing the same image obtained by a pinhole aperture, but by means of a much larger aperture and a shorter exposure time. Moreover, an optical system enhances the light gathering power.

4.6. Geometric Image Formation

We now turn to the geometric aspect of image formation. The aim is to link the position of scene points with that of their corresponding image points. To do this, we need to model the geometric projection performed by the sensor.

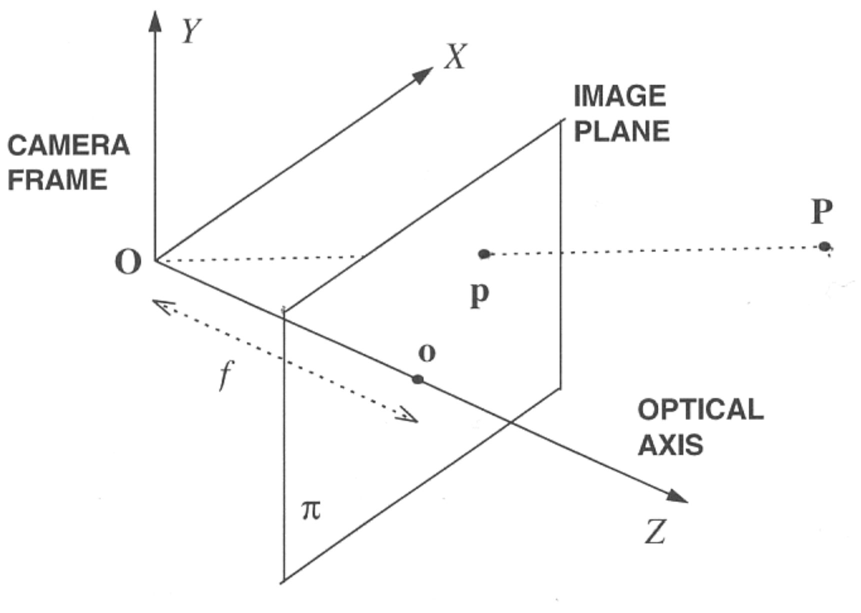


Fig 10. The Perspective Camera Model.

The Perspective Camera

The most common geometric model of an intensity camera is the perspective or pinhole model. The model consists of a plane π and O, the center or focus of projection. The distance between π and O is the focal length. The line through O and perpendicular to π is the optical axis, and o, the intersection between π and the optical axis, is named principal point or image center. As shown in Figure 10, p, the image of P, is the point at which the straight line through P and O intersects the image plane π. Consider the 3-D reference frame in which O is the origin and the plane π is orthogonal to the Z axis, and let $P = [X, Y, Z]^T$ and $p = [x, y, z]^T$. This reference frame, called the camera frame, has fundamental importance in computer vision. We now will write the basic equations of perspective projections in the camera frame.

Perspective Camera: Fundamental Equations

In the camera frame, we have

$$x = f\,(X/Z)$$

$$y = f\,(Y/Z) \qquad (4.1)$$

In the camera frame, the third component of an image point is always equal to the focal length (as the equation of the plane π is $z = f$). For this reason, we will often write $p = [x, y]^T$ instead of $p=[x, y, f\,]^T$.

Note that (4.1) are nonlinear because of the factor 1/Z, and do not preserve either distances between points (not even up to a common scaling factor), or angles between lines. However, they do map lines into lines.

The Weak-Perspective Camera

A classical approximation that turns (4.1) into linear equations is the weak-perspective camera model. This model requires that the relative distance along the optical axis, δz, of any two scene points (that is, the scene's depth) is much smaller than the average distance, Z, of the points from the viewing camera. In this case, for each scene point, P, we can write

$$x = f\frac{X}{Z} \approx \frac{f}{\bar{Z}}X$$

$$y = f\frac{Y}{Z} \approx \frac{f}{\bar{Z}}Y \qquad (4.2)$$

Indicatively, the weak-perspective approximation becomes viable for $\delta z < Z/20$ approximately.

These equations (4.2), describe a sequence of two transformations: an orthographic projection, in which world points are projected along rays parallel to the optical axis, that is,

x = X

y = Y,

followed by isotropic scaling by the factor $\frac{\bar{f}}{z}$.

The Perspective Camera Model

In the perspective camera model (nonlinear), the coordinates (x, y) of a point p, image of the 3-D point P = $[X, Y, X]^T$, are given by

x = f (X/Z)

y = f (Y/Z)

The Weak-Perspective Camera Model

If the average depth of the scene, $\bar{z}$, is much larger than the relative distance between any two scene points along the optical axis, the weak-perspective camera model (linear) holds:

x = f (X/Z#)

y = f (Y/Z#)

All equations are written in the camera reference frame.

4.7. Camera Parameters

We now come back to discuss the geometry of a vision system in greater detail. In particular, we want to characterize the parameters underlying camera models.

Definitions

Computer vision algorithms reconstructing the 3-D structure of a scene or computing the position of objects in space need equations linking the coordinates of points in 3-D space with the coordinates of their corresponding image points. These equations are written in the camera reference frame (4.1), but it is often assumed that

The camera reference frame can be located with respect to some other, known, reference frame (the world reference frame), and

The coordinates of the image points in the camera reference frame can be obtained from pixel coordinates, the only ones directly available from the images.

This is equivalent to assume knowledge of some camera's characteristics, known in vision as the camera's extrinsic and intrinsic parameters. Our next task is to understand the exact nature of the intrinsic and extrinsic parameters and why the equivalence holds.

Camera Parameters

The extrinsic parameters are the parameters that define the location and orientation of the camera reference frame with respect to a known world reference frame.

The intrinsic parameters are the parameters necessary to link the pixel coordinates of an image point with the corresponding coordinates in the camera reference frame.

We now try to write the basic equations that allow us to define the extrinsic and intrinsic parameters in practical terms. The problem of estimating the value of these parameters is called camera calibration.

Extrinsic Parameters

The camera reference frame has been introduced for the purpose of writing the fundamental equations of the perspective projection (4.1) in a simple form. However, the camera reference frame is often unknown, and a common problem is determining the location and orientation of the camera frame with respect to some known reference frame, using only image information. The extrinsic parameters are defined as any set of geometric parameters that identify uniquely the transformation between the unknown camera reference frame and a known reference frame.

A typical choice for describing the transformation between camera and world frame is to use

A 3-D translation vector, T, describing the relative positions of the origins of the two reference frames, and

A 3 X 3 rotation matrix, R, an orthogonal matrix ($R^TR = RR^T = I$) that brings the corresponding axes of the two frames onto each other.

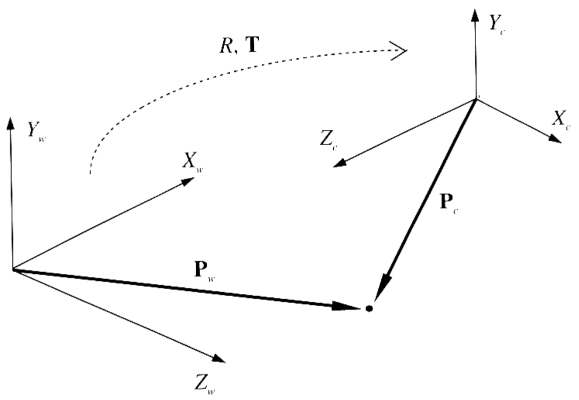


Fig 11. The Relation between camera and world coordinate frames

The orthogonality relations reduce the number of degrees of freedom of R to three.

In an obvious notation (see Figure 11), the relation between the coordinates of a point P in world and camera frame, P_w and Pc respectively, is

$P_w = R(P_c – T)$, (4.3)

With

$$R = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix}.$$

Extrinsic Parameters

The camera extrinsic parameters are the translation vector, T, and the rotation matrix, R (or, better, its free parameters), which specify the transformation between the camera and the world reference frame.

4.8. Intrinsic Parameters

The intrinsic parameters can be defined as the set of parameters needed to characterize the optical, geometric, and digital characteristics of the viewing camera. For a pinhole camera, we need three sets of intrinsic parameters, specifying respectively

The perspective projection, for which the only parameter is the focal length, f;

The transformation between camera frame coordinates and pixel coordinates;

The geometric distortion introduced by the optics.

From Camera to Pixel Coordinates

To find the second set of intrinsic parameters, we must link the coordinates (x_{im} , y_{im}) of an image point in pixel units with the coordinates (x, y) of the same point in the camera reference frame. The coordinates (x_{im}, y_{im}) can be thought of as coordinates of a new reference frame, sometimes called image reference frame.

Transformation between Camera and Image Frame Coordinates

Neglecting any geometric distortions possibly introduced by the optics and in the assumption that the CCD array is made of a rectangular grid of photosensitive elements, we have

$x = -(x_{im} - o_x)\, s_x$

$y = -(y_{im} - o_y)\, s_y$ (4.4)

with (o_x, o_y) the coordinates in pixel of the image center (the principal point), and (s_x, s_y) the effective size of the pixel (in millimeters) in the horizontal and vertical direction respectively.

Therefore, the current set of intrinsic parameters is f, ox , o_y, s_x , s_y,.

The sign change in (4.4) is due to the fact that the horizontal and vertical axes of the image and camera reference frames have opposite orientation.

In several cases, the optics introduces image distortions that become evident at the periphery of the image, or even elsewhere using optics with large fields of view. Fortunately, these distortions can be modeled rather accurately as simple radial distortions, according to the relations

$x = x_d(1 + k_1 r^2 + k_2 r^4)$

$y = y_d(1 + k_1 r^2 + k_2 r^4)$

with (x_d, y_d) the coordinates of the distorted points, and $r^2 = x_d^2 + y_d^2$. As shown by the equations above, this distortion is a radial displacement of the image points. The displacement is null at the image center, and increases with the distance of the point from the image center. k_1 and k_2 are further intrinsic parameters. Since they are usually very small, radial distortion is ignored whenever high accuracy is not required in all regions of the image, or when the peripheral pixels can be discarded. If not, as $k_2 << k_1$, k_2 is often set equal to 0, and k_1 is the only intrinsic parameter to be estimated in the radial distortion model.

The magnitude of geometric distortion depends on the quality of the lens used. As a rule of thumb, with optics of average quality and CCD size around 500 x 500, expect distortions of several pixels (say around 5) in the outer cornice of the image. Under these circumstances, a model with $k_2 = 0$ is still accurate.

Intrinsic Parameters

The camera intrinsic parameters are defined as the focal length, f, the location of the image center in pixel coordinates, (o_x, o_y), the effective pixel size in the horizontal and vertical direction (s_x, s_y), and if required, the radial distortion coefficient, k_1.

4.9. Camera Models Revisited

We are now fully equipped to write relations linking directly the pixel coordinates of an image point with the world coordinates of the corresponding 3-D point, without explicit reference to the camera reference frame needed by (4.1).

Linear Version of the Perspective Projection Equations

Plugging (4.3) and (4.4) into (4.1) we obtain

$$-(x_{im} - o_x)s_x = f\frac{\mathbf{R}_1^\top(\mathbf{P}_w - \mathbf{T})}{\mathbf{R}_3^\top(\mathbf{P}_w - \mathbf{T})}$$

$$-(y_{im} - o_y)s_y = f\frac{\mathbf{R}_2^\top(\mathbf{P}_w - \mathbf{T})}{\mathbf{R}_3^\top(\mathbf{P}_w - \mathbf{T})} \quad (4.5)$$

where R_i, i=1,2,3 is a 3-D vector formed by the i-th row of matrix R. Indeed, (4.5) relates the 3-D coordinates of a point in the world frame to the image coordinates of the corresponding image point, via the camera extrinsic and intrinsic parameters.

Notice that, due to the particular form of (4.5), not all the intrinsic parameters are independent. In particular, the focal length could be absorbed into the effective sizes of the CCD elements.

Neglecting radial distortion, we can rewrite (4.5) as a simple matrix product. To this purpose, we define two matrices, M_{int} and M_{ext}, as

$$M_{int} = \begin{pmatrix} -f/s_x & 0 & o_x \\ 0 & -f/s_y & o_y \\ 0 & 0 & 1 \end{pmatrix}$$

$$M_{ext} = \begin{pmatrix} r_{11} & r_{12} & r_{13} & -\mathbf{R}_1^\top \mathbf{T} \\ r_{21} & r_{22} & r_{23} & -\mathbf{R}_2^\top \mathbf{T} \\ r_{31} & r_{32} & r_{33} & -\mathbf{R}_3^\top \mathbf{T} \end{pmatrix},$$

so that the 3 x 3 matrix Mint depends only on the intrinsic parameters, while the 3 x 4 matrix M_{ext} only on the extrinsic parameters. If we now add a "1" as a fourth coordinate of (that is, express in homogeneous coordinates), and form the product M_{ext}, we obtain a linear matrix equation describing perspective projections.

The Linear Matrix Equation of Perspective Projections

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = M_{int} M_{ext} \begin{pmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{pmatrix}.$$

What is interesting about vector $[x1, x2, x3]^T$ is that the ratios and are nothing but the image coordinates:

$x_1/x_3 = x_{im}$

$x_2/x_3 = y_{im}$

Moreover, we have separated nicely the two steps of the world-image projection:

M_{ext} performs the transformation between the world and the camera reference frame;

M_{int} performs the transformation between the camera reference frame and the image reference frame.

In more formal terms, the relation between a 3-D point and its perspective projection on the image plane can be seen as a linear transformation from the projective space, the space of vectors $[x_w, y_w, z_w, 1]^T$, to the projective plane, the space of vectors $[x_1, x_2, x_3]^T$. This transformation is defined up to an arbitrary scale factor and so that the matrix M has only 11 independent entries.

The Perspective Camera Model

Various camera models, including the perspective and weak-perspective ones, can be derived by setting appropriate constraints on the matrix $M = M_{int} M_{ext}$ Assuming, for simplicity, $o_x=o_y=0$ and $s_x= s_y=1$, M can then be rewritten as

$$M = \begin{pmatrix} -fr_{11} & -fr_{12} & -fr_{13} & f\mathbf{R}_1^\top\mathbf{T} \\ -fr_{21} & -fr_{22} & -fr_{23} & f\mathbf{R}_2^\top\mathbf{T} \\ r_{31} & r_{32} & r_{33} & -\mathbf{R}_3^\top\mathbf{T} \end{pmatrix}.$$

When unconstrained, M describes the full-perspective camera model and is called projection matrix.

The Weak-Perspective Camera Model

The projection matrix M for the weak perspective model becomes

$$M_{wp} = \begin{pmatrix} -fr_{11} & -fr_{12} & -fr_{13} & f\mathbf{R}_1^\top\mathbf{T} \\ -fr_{21} & -fr_{22} & -fr_{23} & f\mathbf{R}_2^\top\mathbf{T} \\ 0 & 0 & 0 & \mathbf{R}_3^\top(\bar{\mathbf{P}} - \mathbf{T}) \end{pmatrix}.$$

where,

p is the image of a point **P**,

$|| \mathbf{R}_3^T(\mathbf{P} - \mathbf{T}) ||$ is simply the distance of P from the projection center along the optical axis,

$\mathbf{P}_1$, $\mathbf{P}_2$ are two points in 3-D space, and **P** the centroid of $\mathbf{P}_1$ and $\mathbf{P}_2$.

Rotation Vectors

A rigid rotation of a 3-D vector **v** onto a 3-D vector **v¢** can be represented by a linear transformation, defined by a 3x3 matrix R:

v¢ = R**v**,

subjected to the constraints,

$RR^T = R^TR = I \qquad \det(R) = 1,$

with 'I' the identity matrix. The first constraint tells that the inverse of R equal its transpose. The second that the transformation preserves the relative orientation of the reference frame, and therefore its right- or left-handedness.

A matrix R for which $RR^T = I$ is called orthogonal. The orthogonality property can be better appreciated by assuming that **v** and **v′** are expressed in two orthogonal references frames, defined by the unit vectors $\mathbf{e}_1$, $\mathbf{e}_2$, $\mathbf{e}_3$, and $\mathbf{e}_1'$, $\mathbf{e}_2'$, $\mathbf{e}_3'$ respectively. It can easily be seen that the generic entry r_{ij} of R is the cosine of the angle formed by the base vector, $\mathbf{e}_{\mathbf{im}}$ with the rotated base vector $\mathbf{e}'_j$:

$r_{ij} = \mathbf{e}_i^T\mathbf{e}'_j$

Therefore, we have that

$$\sum_{j=1}^{3} r_{ij}r_{kj} = \sum_{j=1}^{3} r_{ji}r_{jk} = \begin{cases} 0 & i \neq k \\ 1 & i = k \end{cases}$$

that is, the rows (and columns) of r are mutually orthogonal unit vectors. But even a slight perturbation of the entries of R, due to noise or small errors, destroys the orthogonality property and affects the estimation of the rotation parameters.

Two Useful Parameterizations

A 3x3 orthogonal matrix has nine elements which have to satisfy the six orthogonality constraints. This reduces the number of degrees of freedom of a 3-D rotation to 9-6=3 and tells that describing a rotation matrix through its nine entries is redundant and not really natural; in most cases it is useful and simpler to represent a rotation by means of more natural parameterization. We limit ourselves to the two parameterizations used in the book: rotations around the coordinate axes and axis and angle.

Rotations around the Coordinate Axes

We can express a 3-D rotation as the result of three consecutive rotations around the coordinate axes e_1, e_2, and e_3, by angles α, β, and γ respectively. The angles are then the three free parameters of R, and each rotation is expressed as a rotation matrix, R_j, rotation vectors around ej that is,

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}$$

$$R_2(\beta) = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix}$$

$$R_3(\gamma) = \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The matrix R describing the overall rotation is the product of the R_j:

$$R = R_1 R_2 R_3 = \begin{bmatrix} \cos\beta\cos\gamma & -\cos\beta\sin\gamma & \sin\beta \\ \sin\alpha\sin\beta\cos\gamma + \cos\alpha\sin\gamma & -\sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & -\sin\alpha\cos\beta \\ -\cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma & \cos\alpha\sin\beta\sin\gamma + \sin\alpha\cos\gamma & \cos\alpha\cos\gamma \end{bmatrix}$$

The order of multiplication matters, Different sequences give different results with the same triplet of angles. Notice that there are six ways to represent a rotation matrix as a product of rotations around three different coordinate axes.

However, if the matrix R has been obtained as the output of some numerical computation, we should always make sure that the estimated R is really orthogonal.

Axis and Angle

According to Euler’s theorem, any 3-D rotation can be described as a rotation by an angle, θ, around an axis identified by a unit vector $\mathbf{n} = [\mathbf{n}_1, \mathbf{n}_2, \mathbf{n}_3]^T$. The corresponding rotation matrix, R can then be obtained in terms of θ and the components of n, which gives you a total of four parameters. The redundancy of this parameterization (four parameters for three degrees of freedom) is eliminated by adding the constraint that n has unit norm, that is, by dividing each n_i by √($\mathbf{n}_{12} + \mathbf{n}_{22} + \mathbf{n}_{32}$).

The matrix R in terms of θ and n is given by

$$R = I\cos\theta + (1-\cos\theta)\begin{bmatrix} n_1^2 & n_1 n_2 & n_1 n_3 \\ n_2 n_1 & n_2^2 & n_2 n_3 \\ n_3 n_1 & n_3 n_2 & n_3^2 \end{bmatrix} + \sin\theta \begin{bmatrix} 0 & -n_3 & n_2 \\ n_3 & 0 & -n_1 \\ -n_2 & n_1 & 0 \end{bmatrix}$$

4.10. Noise Theory

The effect of noise is, essentially, that image values are not those expected, as these are corrupted during the various stages of image acquisition. As a consequence, the pixel values of two images of the same scene taken by the same camera and in the same light conditions are never exactly the same. Such fluctuations will introduce errors in the results of calculations based on pixel values; it is therefore important to estimate the magnitude of the noise.

Another cause of noise, which is important when a vision system is used for fine measurements, is that pixel values are not comp letely independent of each other. Some cross talking occurs between adjacent photo sensors in each row of the CCD array, due to the way the content of each CCD row is read in order to be sent to the frame buffer. This can be verified by computing the auto covariance $C_{EE}(i, j)$ of the image of a spatially uniform pattern parallel to the image plane and illuminated by diffuse light.

In computer vision, noise may refer to any entity, in images, data or intermediate results, which is not interesting for the purpose of the main computation.

4.10.1. Image Noise

The main image noise is additive and random; that is a spurious, random signal, n(i, j), added to the true pixel values I(i, j):

$I'(i, j) = I(i, j) + n(i, j)$

4.10.2. Noise Amount

The amount of noise in an image can be estimated by means of σ_n, the standard deviation of the random signal n(i, j). It is important to know how strong the noise is with respect to the interesting signal. This is specified by the signal-to-noise ratio (SNR).

$$SNR = \frac{\sigma_s}{\sigma_n}$$

Where σs is the standard deviation of the signal (the pixel values I(i, j)). The SNR is often expressed in decibel:

$$SNR_{db} = 10\log_{10}\frac{\sigma_s}{\sigma_n}$$

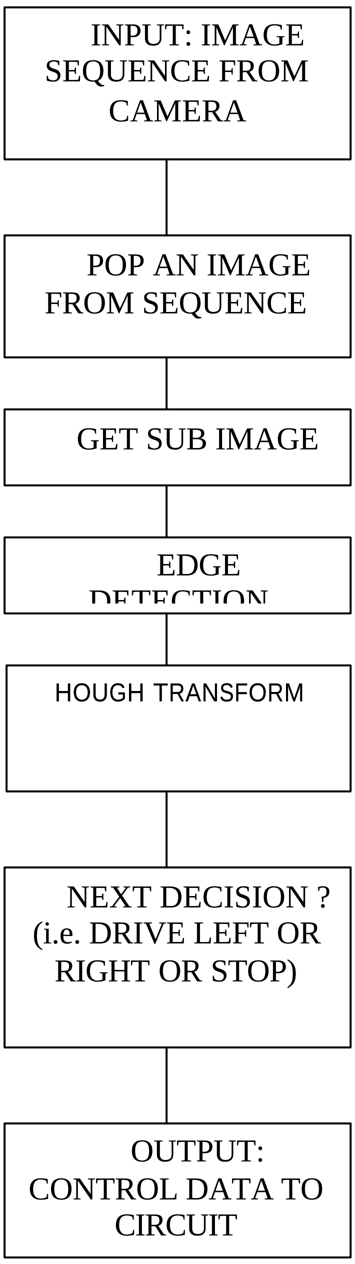
4.10.3. Gaussian Noise

In the absence of information, one often assumes n(i,j) to be modeled by a white, Gaussian, zero-mean stochastic process. For each location (i, j), this amounts to thinking of n(i, j) as random variables distributed according to a zero mean Gaussian distribution function of fixed standard deviation, which is added to I(i, j) and whose values are completely independent of each other and of the image in both space and time.

4.10.4. Impulsive Noise

Impulsive Noise, also known as spot or peak noise, occurs usually in addition to the one normally introduced by acquisition. Impulsive noise alters random pixels, making their values very different from the true values and very often from those of neighboring pixels too. Impulsive noise appears in the image as a sprinkle of dark and light spots. It can be caused by transmission errors, faulty elements in the CCD array, or external noise corrupting the analog-to-digital conversion.

4.11. Block diagram of image processing model



INPUT: IMAGE SEQUENCE FROM CAMERA
POP AN IMAGE FROM SEQUENCE
GET SUB IMAGE
EDGE DETECTION
HOUGH TRANSFORM
NEXT DECISION ? (i.e. DRIVE LEFT OR RIGHT OR STOP)
OUTPUT: CONTROL DATA TO CIRCUIT

Fig 12. Block Diagram of Software model (Image Processing Approach)

4.12. Image Analysis

The ultimate aim in a large number of image processing applications is to extract important features from image data, from which a description, interpretation, or understanding of the scene can be provided by the machine. Image analysis basically involves the study of feature extraction, segmentation and classification techniques.

Image Analysis Techniques

Feature Extraction	Segmentation	Classification
• Spatial Features	• Template Matching	• Clustering
• Transform Features	• Thresholding	• Statistical
• Edge & Boundaries	• Boundary Detection	• Decision Trees
• Shape Features	• Clustering	• Similarity Measures
• Moments	• Quad - Trees	• Minimum Spanning Trees
• Texture	• Texture Matching	

4.13. Edge Detection

How do edges come in an image? Probably, the answer to this question provides the early importance clue for locating edges in an image. The variations of image features, usually brightness, give rise to edges. More objectively, the edges are the representations of the discontinuities of image intensity function. There could be various reasons, such as lightening conditions, object(s) geometry, type of material, surface texture, etc., as well as their mutual interactions, for the discontinuities. Therefore, edge-detection algorithm is essentially a process of detection of these discontinuities in an image. Since the abrupt changes in brightness level indicates edge, its detection in binary or segmented image is quite straightforward (such edges are called border or boundary). However, the process of edge localization is quite complex in the case of gray level or intensity level images. The transition in intensity in gray-scale image is relatively smooth in nature rather than abrupt as in the case of segmented binary images. The nature of intensity variation points to the application of derivative operators for detecting edges. Application of derivative operators on intensity image produces another image, usually called gradient image as it reveals the rate of intensity variation. This image is made to undergo thresholding and/or edge linking in order to yield contours. Thus, the image is decomposed into various regions resulting in another kind of segmentation.

Edge points can be thought of as pixel locations of abrupt gray-level change. For example, it is responsible to define edge points in binary images as black pixels with at least one white nearest neighbor, that is, pixel locations (m, n) such that u(m, n)=0 and g(m, n)=1; where

g(m, n) ⊕ [u(m, n) ⊕ u(m±1, n)] , OR

[u(m, n) ⊕ u(m,n±1)]

Where ⊕ denotes the logical exc lusives or operation. For a continuous image f(x, y) its derivative assumes a local maximum in the direction of the Edge. Therefore, one edge direction technique is to measure the gradient of f along r in a direction è, that is,

$$\partial f/\partial r = \partial f/\partial x * \partial x/\partial r + \partial f/\partial y * \partial y/\partial r$$
$$= f_x \cos q + f_y \sin q$$

The maximum value of df/dr is obtained when (d/dφ) df/dr)= 0. This gives

$$-f_x \sin q_g + f_y \cos q_g = 0$$

$$q_g = \tan^{-1}(f_x / f_y)$$

$$(\partial f/\partial r)_{\max} = \sqrt{f_x^2 + f_y^2}$$

Where φg is the direction of the edge.

Based on these concepts, two types of edge detection operators have been introduced:

- Gradient Operators
- Compass Operators

For digital images these operators, are also called masks, represent finite difference approximations of either the orthogonal gradients f_x, f_y or the directional gradient df/dx. Let H denote a P x P mask and define, for an arbitrary image U, their inner product at location (m, n) as the correlation.

$$<U,H>_{m,n} \cong \sum_i \sum_j h(i,j)u(i+m,j+n) = u(m,n) \oplus h$$

4.13.1. Gradients Operators

These are represented by a pair of marks h_1, h_2 which measure the gradient of the image u(m,n) in two orthogonal directions. Defining the bi-directional gradients g1(m1)= <U,H1>$_{m,n}$, g1(m)= <U,H2>$_{m,n}$ the gradient vector magnitude and direction are given by:

$g(m,n)= \sqrt{g_1^2 (m,n)+ g_2^2 (m,n)}$

$\grave{e}g\ (m,n) = \tan^{-1}(g_2(m,n) / g_1(m,n))$

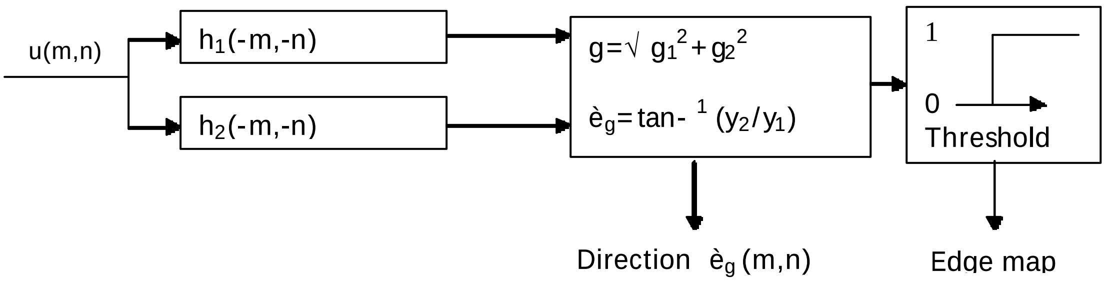


Fig 13. Edge detection via gradient operator

Rather than the above equation the magnitude gradient is calculated by:

$g(m,n) = | g_1(m,n) | + | g_2(m,n) |$

Some of the gradient operator are shown below:

$$
\begin{array}{lcc}
 & H_1 & H_2 \\
\text{Roberts} & \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} & \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \\
\text{Smoothed Prewitt} & \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} & \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} \\
\text{Sobel} & \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} & \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \\
\text{Isotrope} & \begin{bmatrix} -1 & 0 & 1 \\ & 0 & \\ -1 & \sqrt{2}\,0 & 1 \quad \sqrt{2} \end{bmatrix} & \begin{bmatrix} -1 & & -1 \\ & & -\sqrt{2} \\ 0 & 0 & 0 \\ 1 & & 1 \\ & & \sqrt{2} \end{bmatrix}
\end{array}
$$

4.13.2. Compass operators

Compass operators measure gradients in a selected number of directions

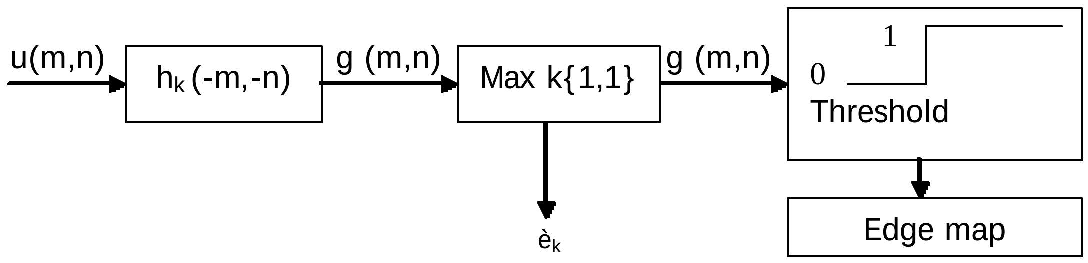


Fig 14. Edge detection via compass operator

4.14. The Hough Transform

The Hough transform is a technique, which can be used to isolate features of a particular shape within an image.

Because it requires that the desired features be specified in some parametric form, the classical Hough transform is most commonly used for the detection of regular curves such as lines, circles, ellipses, etc.

A generalized Hough transform can be employed in applications where a simple analytic description of a feature(s) is not possible.

The Hough transform has many applications, as most manufactured parts (and many anatomical parts investigated in medical imagery) contain feature boundaries, which can be described by regular curves or straight lines.

The main advantage of the Hough transform is that it is tolerant of gaps in feature boundary descriptions and is relatively unaffected by image noise.

4.14.1. Working Principle of Hough Transform

The Hough technique is useful for computing a global description of a feature(s) (where the number of solution classes need not be known a priori), given (possibly noisy) local measurements.

The motivating idea behind the Hough technique for line detection is that each input measurement (e.g. coordinate point) indicates its contribution to a globally consistent solution (e.g. the physical line which gave rise to that image point).

As a simple example, consider the common problem of fitting a set of line segments to a set of discrete image points (e.g. pixel locations output from an edge detector). The diagram below shows some possible solutions to this problem.

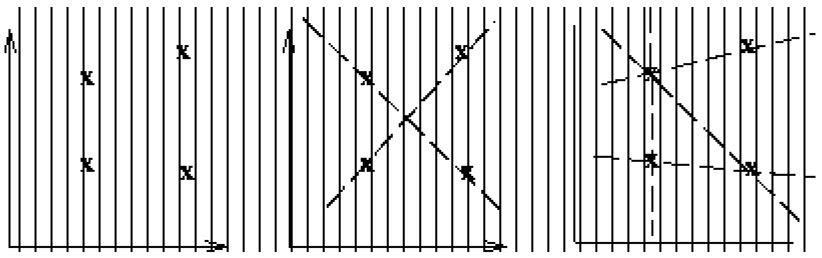


Fig 15. Coordinate points and possible straight line fittings

We can analytically describe a line segment in a number of forms. However, a convenient equation for describing a set of lines uses parametric or normal notion:

$$x \cos\theta + y \sin\theta = r$$

where r is the length of a normal from the origin to this line and è is the orientation of r with respect to the X-axis. For any point (x,y) on this line, r and è are constant.

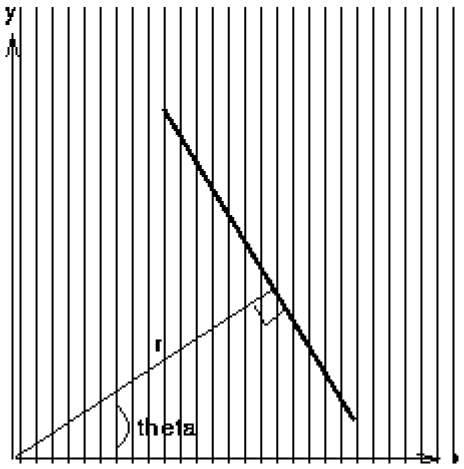


Fig 16. Parametric description of a straight line.

In an image analysis context, the coordinates of the point(s) of edge segments (i.e. (x_i, y_i) in the image are known and therefore serve as constants in the parametric line equation, while r and è are the unknown variables we seek. If we plot the possible (r, è) values defined by each (x_i, y_i), points in Cartesian image space map to curves (i.e. sinusoids) in the polar Hough parameter space. This point-to-curve transformation is the Hough transformation for straight lines. When viewed in Hough parameter space, points which are collinear in the

Cartesian image space become readily apparent as they yield curves which intersect at a common (r, è) point.

The transform is implemented by quantizing the Hough parameter space into finite intervals or accumulator cells. (i.e. a multidimensional array). As the algorithm runs, each (x_i, y_i) is transformed into a discretized (r, è) curve and the accumulator cells which lie along this curve are incremented.

Peaks in the accumulator array represent strong evidence that a corresponding straight line exists in the image.

We can use this same procedure to detect other features with analytical descriptions. For instance, in the case of circles, the parametric equation is

$$(x - a)^2 + (y - b)^2 = r^2$$

Where a and b are the coordinates of the center of the circle and r is the radius. In this case, the computational complexity of the algorithm begins to increase as we now have three coordinates in the parameter space and a 3-D accumulator. (In general, the computation and the size of the accumulator array increase polynomially with the number of parameters. Thus, the basic Hough technique described here is only practical for simple curves.)

The Hough transform can be used to identify the parameter(s) of a curve, which best fits a set of given edge points.

This edge description is commonly obtained by using an edge detector such as the zero crossings of the Laplacian. The edge image may be noisy, i.e. it may contain multiple edge fragments corresponding to a single whole feature.

Since the output of an edge detector defines only where features are in an image, the work of the Hough transform is to determine both what the features are (i.e. to detect the feature(s) for which it has a parametric description) and how many of them exist in the image.

In order to illustrate the Hough transform in detail, we begin with the simple image of two occluding rectangles, An edge detector can produce a set of boundary descriptions for this part, as shown below

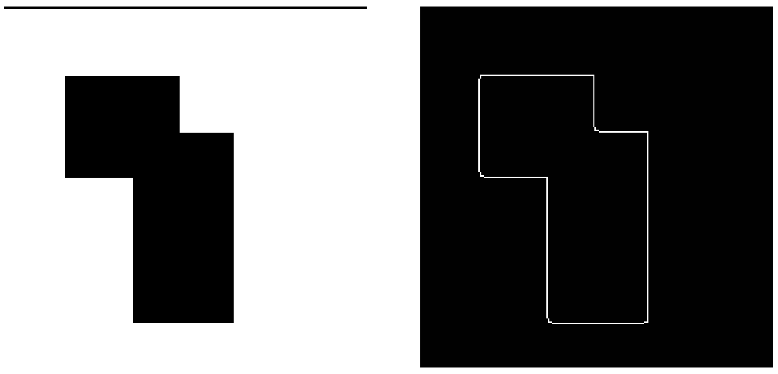


Fig 17. Original and Edge Detected Image

Here we see the overall boundaries in the image, but this result tells us nothing about the identity (and quantity) of feature(s) within this boundary description. In this case, we can use the Hough (line detecting) transform to detect the eight separate straight lines segments of this image and thereby identify the true geometric structure of the subject.

If we use these edge/boundary points as input to the Hough transform, a curve is generated in polar (r, è) space for each edge point in Cartesian space. The accumulator array, when viewed as an intensity image, looks like

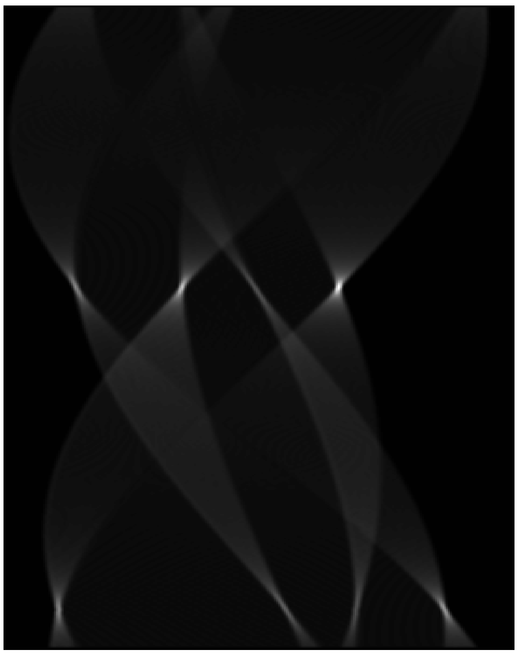


Fig 18. The Hough Transformed Image

Although r and è are notionally polar coordinates, the accumulator space is plotted rectangularly.

Note that the accumulator space wraps around at the vertical edge of the image such that, in fact, there are only 8 real peaks.

Curves generated by collinear points in the gradient image intersect in peaks (r, è) in the Hough transform space. These intersection points characterize the straight line segments of the original image.

There are a number of methods, which one might employ to extract these bright points, or local maxima, from the accumulator array.

For example, a simple method involves thresholding and then applying some thinning to the isolated clusters of bright spots in the accumulator array image.

Here we use a relative threshold to extract the unique (r, è) points corresponding to each of the straight-line edges in the original image.

(In other words, we take only those local maxima in the accumulator array whose values are equal to or greater than some fixed percentage of the global maximum value.)

4.15. Platform Used: Microsoft Visual C++

Visual C++ is a powerful and a complex tool for building 32-bit application for Windows 95 and Windows NT, including database application, Internet application, application that taps the power of the ActiveX technology. These applications are larger and more complex than their predecessor for 16-bit Windows or older programs that didn't use a graphical interface. Yet, as a program size and complexity has increased, programmer effort has decreased at least for the programmers who are using the right tools.

Visual C++ is one of the right tools with its code-generating wizard, it can produce the shell of the working Windows application in seconds. The class library included with Visual C++, the Microsoft foundation classes [MFC], has become industry standard for Windows software development in a variety of C++ compilers. The visual editing tools make layout of menus and dialog a snap.

Microsoft Visual C++ is one component of the Microsoft developer Studio. It is called an Integrated Development Environment [IDE] because within a single tool, it can perform the following:

- Generate starter applications without writing code.
- View a project in several different ways.
- Edit sources and include files.
- Build the visual interface of your application.
- Compile and link.
- Debug an application when it runs.

In general, Visual C++ does not just compile code but it generates code too. It can create Windows Applications with a very effective tool called AppWizard that copies into your application the code that almost all Windows Application requires, thus building a variety of Windows Applications.

4.16. Image Processing Libraries

There are many Image Processing libraries available that can be used for image processing, some of which are discussed below:

4.16.1. Intel OpenCV

This open-source computer vision software library is a beautiful offering and has a dedicated user group. Frustrating however is that it has compile bugs, code is not well-documented and some examples rely on compiled object code or DirectX. Those comfortable with DirectX, MFC and Win32 API can perhaps debug and develop applications. Those without such experience will find the learning curve very steep.

4.16.2. Microsoft Vision SDK

The Microsoft Vision SDK is a library for writing programs to perform image manipulation and analysis on computers running Microsoft Windows operating systems. The Microsoft Vision SDK was developed by the Vision Technology Research Group in Microsoft Research to support researchers and developers of advanced applications, including real-time image-processing applications. It is a low-level library, intended to provide a strong programming foundation for research and application development; it is not a high-level platform for end-users to experiment with imaging operations. The Microsoft Vision SDK includes classes and functions for working with images, but it does not include image-processing functions. The Microsoft Vision SDK is a C++ library of object definitions, related software, and documentation for use with Microsoft Visual C++.

4.17. The Parallel Port

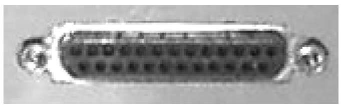


Fig 19. The Parallel Port Connector

A parallel port has eight lines for sending all the bits that comprise 1 byte of data simultaneously across eight wires. This interface is fast and has traditionally been used for printers. However, programs those transfer data between systems have always used the parallel port as an option for transmitting data because it can do so 4 bits at a time rather than 1 bit at a time with a serial interface.

Typical serial port can transfer data 115,200 bits per second. Parallel port can be 100 times faster than serial port. However, their capable cannot be extended for any great length without amplifying the signals or errors in the data.

The following is the pin out for a standard PC parallel port:

Pin	Description	I/O
1	-Strobe	Out
2	+Data Bit 0	Out
3	+Data Bit 1	Out
4	+Data Bit 2	Out
5	+Data Bit 3	Out
6	+Data Bit 4	Out
7	+Data Bit 5	Out
8	+Data Bit 6	Out
9	+Data Bit 7	Out
10	Acknowledgement	In
11	+Busy	In
12	+Paper End	In
13	+Select	In
14	-Auto Feed	Out
15	-Error	In
16	-Initialize Printer	Out
17	-Select Input	Out
18	Data Bit 0 Return (GND)	In
19	Data Bit 1 Return (GND)	In
20	Data Bit 2 Return (GND)	In
21	Data Bit 3 Return (GND)	In
22	Data Bit 4 Return (GND)	In
23	Data Bit 5 Return (GND)	In
24	Data Bit 6 Return (GND)	In
25	Data Bit 7 Return (GND)	In

Table 1. Standard Parallel Port pin-out

Primary types of parallel parts found in system today are:

- Unidirectional (4-bit)
- Bi-directional (8-bit)
- Enhanced parallel port (EPP)
- Enhanced capability port (ECP)

4.17.1. Unidirectional (4-bits)

Older PCs didn't have different types of parallel ports available. The only port available was the parallel port used to send information from the computer to device, such as printers. This does not mean to say that unidirectional parallel ports were not available; indeed, they were common in other computers in the market and in hobbyist computer at that time.

The unidirectional nature of the original PC parallel port is consistent with its primary use, that is, of sending data to printer. There were times, however, when it was desirable to have a unidirectional port- for example, when you need feed back from a printer, which is common with post-script printer. This could not be done easily with the original unidirectional ports.

4 bits ports are capable of effective transfer rates of about 40-60 K/sec with typical device and can be pushed to upward of 140 K/sec with certain design tricks.

4.17.2. Bi-directional (8-bits)

With the introduction of the ps/2 in 1987, IBM introduced bi-directional parallel port. These are commonly found in PC-compatible system today, and may be designated "PS/2 type", "Bi-directional" or "extended" parallel port. This port design opened the way for the communication between the computer and the peripheral across the parallel port. This was done by defining status bit to indicate which direction information was traveling across the channel.

These ports can do both 8-bit input and output using the standard eight data lines, and are considerably faster than the 4-bits ports when used with external devices. 8-bits ports are capable of speeds ranging from 80-300 Kb/sec, depending on the speed of the attached device, the quality of the driver software, and the ports electrical characteristics.

4.17.3. Enhanced parallel port (EPP)

EPP operates almost at ISA bus speed, and offer a 10-fold increase in the raw through put capability over a conventional parallel port. EPP is especially designed for parallel port peripheral such as LAN adapters, disc drivers, and tape backup. EPP has been included in the new IEEE 1284 parallel port standard. Transfer rate of 1 to 2 M/sec are possible with EPP.

EPP ports were more common with IBM machines than other hardware manufactures that seemed to stay away from the printer port (ECP) was introduced by Microsoft and Hewlett Packard (HP). However because the EPP port is defined in the IEEE 1284 standard, it has gained software and driver support including support in Windows NT.

4.17.4. Enhanced capability port (ECP)

ECP is included in IEEE 1284 just like EPP. Unlike EPP, ECP is not tailored to support PC’s Parallel port peripherals; it purposes is to support an inexpensive attachment to a very high performance printer. Further ECP mode requires the use of a DMA channel, which EPP did not define. Most PC’s with newer “super I/O” chips will be able to support either EPP or ECP mode.

4.18. Functions and Properties of Classes

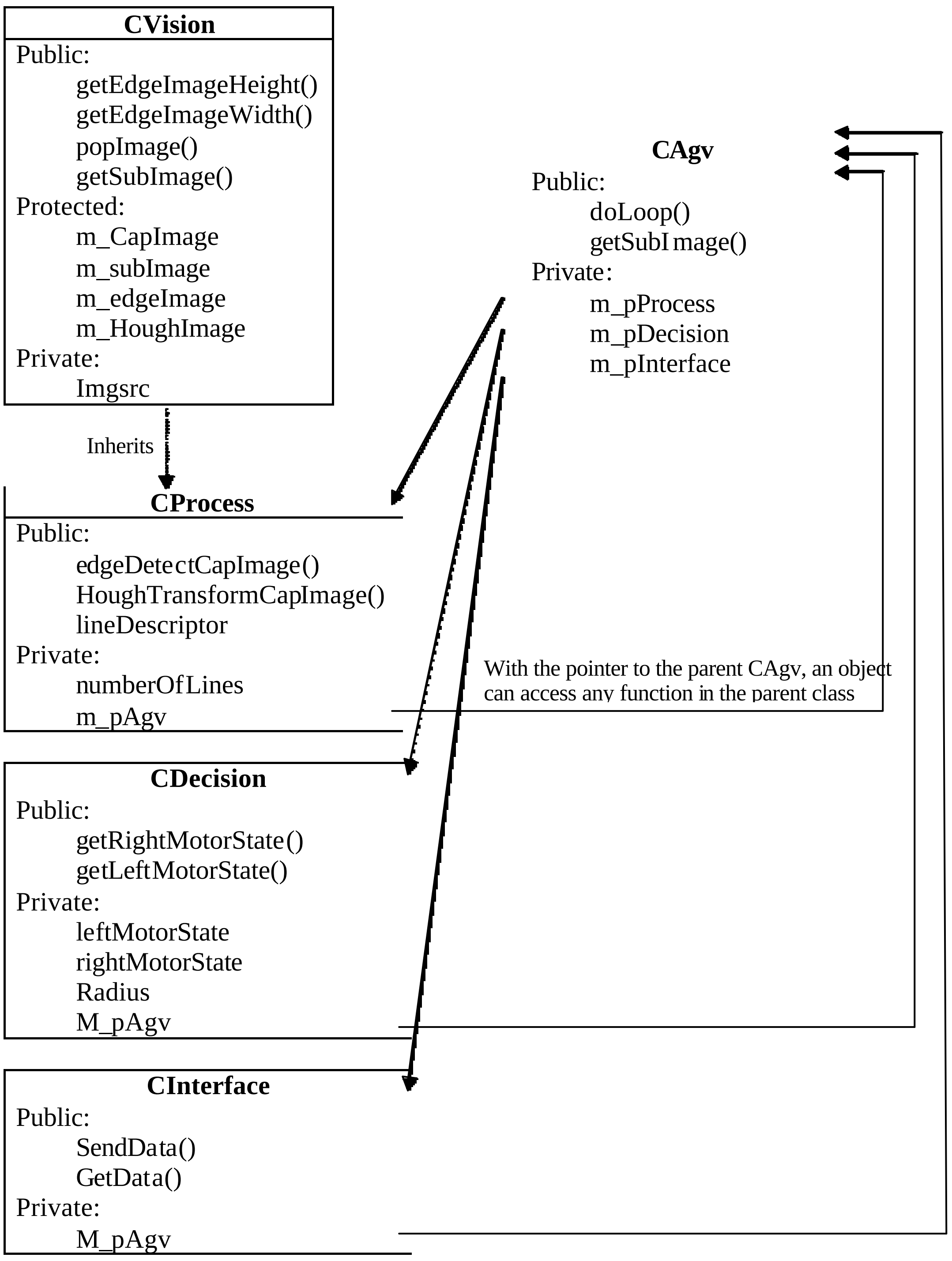


Fig 20. Relationship between classes

A little more thought needs to be kept to the structure of the CAgv class and how we might use objects created from it. As shown in our diagram, a real AGV includes different stages of processes to perform its task. The information of the image that the camera captures must be processed to detect the edges and find out the line descriptions. Similarly, the decisions should be made and the necessary instructions whether to move left, right, forward, backward or stop. The data are then send to the respective motors controlling circuitry. Hence, the image processing unit, decision unit and interface unit need to communicate with one another so that information can be passed between the friend objects that the AGV owns.

For this we use the CAgv object itself as the link between the object it owns. We store the pointers to the objects that are the main components of the AGV and then create the objects dynamically in the AGV class constructor.

This allows us to pass to the Process, Decision and Interface objects a pointer to the parent AGV, when these objects are created. Any of the objects could then obtain a pointer to any of the other objects through member functions of the CAgv class. To implement this we use three member variables in the CAgv class.

- m_pProcess – a pointer to an object of class CProcess
- m_pDecision – a pointer to an object of class CDecision
- m_pInterface – a pointer to an object of class CInterface, and
- m_pAgv – a pointer to the main class CAgv.

4.18.1. CAgv

CAgv is the main class which controls other classes in this project.

The Declaration of CAgv is as:

```
class CAgv {
public:
            CAgv();
   virtual ~CAgv();

   void doLoop(DWORD popDelay, char *szFileName, int times);
//doLoop is the main control loop element.
private:
          CProcess* m_pProcess;
   CDecision* m_pDecision;
   CInterface* m_pInterface;

friend CProcess;  /* CProcess may require access to m_pInterface */
friend CDecision; /* CDecision Requires access to m_pProcess */
friend CInterface; /* CInterface Requires access to m_pDecision */
};
```

Now let’s consider each element of CAgv in detail:

CAgv()

A constructor CAgv() will instantiate and initialize the objects of each classes CProcess, CDecision and CInterface. And the Destructor virtual ~CAgv() will delete all the objects instantiated by constructor.

void doLoop(DWORD popDelay, char *szFileName, int times);

doLoop is the main control loop method which runs forever. Classes CProcess, CDecision and CInterface are a friend of class CAgv, so all the members of these classes can be accessed from class CAgv. Within doLoop a method to acquire image from camera is called, an edge detection algorithm is applied on that image, now Hough transform is applied to the image with edges to extract the feature of an image. From the extracted feature of an image a decision is made accordingly and finally with that decision an interface byte is sent out from parallel port to the motor controlling circuitry.

4.18.2. CVision

This class includes the file “ViImSrc.h” (A header file of Vision SDK that deals with the acquiring of an image from camera, manipulation of image sequence, and other related methods that help for image processing image analysis). This class primarily deals with the capture of image from sequence of images captured through camera. The Declaration of CVision is:

```
class CVision
{
public:
CVision();
          virtual ~CVision();

   void popImage(DWORD delay);
void getSubImage(double percentage);
int getEdgeImageWidth();
```

```
   //Writes the image to a bmp file, used while coding
   void WriteCapImageToFile(char* szFileName);
   void WriteSubImageToFile(char* szFileName);
   void WriteEdgeImageToFile(char *szFileName);
   void WriteHoughImageToFile(char *szFileName);

protected:
          CVisGrayByteImage m_capImage;
   CVisGrayByteImage m_subImage;
   CVisGrayByteImage m_edgeImage;
   CVisGrayByteImage m_HoughImage;

private:
          CVisImageSource imgsrc;
   CVisSequence<CVisGrayBytePixel> sequence;
};
```

Now let's consider each element of CVision in detail:

CVision()

The CVision() constructor tries to find and connect a sequence to the image source. And the Destructor virtual ~CVision() will try to disconnect the sequence from the image source, if the source has been previously connected.

void popImage(DWORD delay)

Once sequence has been connected to an image source, it is ready to grab images from the digitizer. Sequences have similar semantics to a que ue. In order to get the oldest image popImage() is called. Since by default sequences are of 0 length, we may be forced to wait for the next available frame from the digitizer. This waiting time is determined by the delay time passed as an argument to this method.

void getSubImage(double percentage)

Given a percentage value as an argument, getSubImage() will reduce the image size by percentage/2 on each side of the image.

void WritexxxxImageToFile(char* szFileName);

This method was used for debugging. Each time the captured image is manipulated, the changed image was written to a file of type .bmp so that the result expected was easily verified.

int getEdgeImageWidth()

.

For image analysis and Hough transform, the width of captured image has to be determined which is given by this method.

4.18.3. CProcess

CProcess as the name suggests contains all the methods for processing the image, for example the process like Edge Detection, Hough Transform are included. This class inherits the behavior of CVision. The Declaratio n of CProcess is:

```
class CProcess  : public CVision
{
public:
CProcess(CAgv *pAgv);
virtual ~CProcess();

   void edgeDetectCapImage(int gradientThValue);
   void HoughTransformCapImage();
          void setLineDescriptor(int HoughThresh);
   int getNumberOfLines();

   struct lineDescriptor{
                 int theta;
          int r;
   }line[40];

private:
          CAgv* m_pAgv; //To access the AGV Object
   int numberOfLines;
};
```

Now let’s consider each element of CProcess in detail:

CProcess(CAgv *pAgv)

A pointer to an instance of class CAgv is created with the construction of CProcess() and is deleted with the destruction ~CProcess(). Since CProcess() class is a friend of CAgv, all the methods are visible from CAgv.

void edgeDetectCapImage(int gradientThValue)

To detect an edges present on the captured image, this method is used which simply uses ROBERTS EDGE DETECTION ALGORITHM. The result image with edges only is stored in “m_edgeImage”, a protected graybyte image field of class CVision.

void HoughTransformCapImage()

The HOUGH TRANSFORM ALGORITHM is applied on the image with edge detected, and thus resulting with a Hough Image. This Hough image is used for feature extraction. The result Hough image is stored in "m_HoughImage", which is also a protected graybyte imagefield of class CVision.

void setLineDescriptor(int HoughThresh)

After Hough Image is found out, the next step will be to describe the characteristics of line captured by the camera. Characteristic of a set of lines can be found out by checking the pixel value of Hough image and HoughThresh value. All of these line descriptions are stored in an array of structure containing two elements rvalue and thetavalue, which denotes the slope of line and its perpendicular distance from origin.

4.18.4. CDecision

Now that after feature of image has been extracted, a decision on what to do next has to be considered which is accomplished by it. The Declaration of CDecision is:

```
class CDecision
{
public:
        CDecision(CAgv *pAgv);
  virtual ~CDecision();

  void classifyLine();
        void decideNext();
  motorState getRightMotorState();
  motorState getLeftMotorState();
private:
        CAgv* m_pAgv; //so that Decision Objects can access Agv Object
        typeOfLine lineType;

        motorState leftMotorState, rightMotorState; //motorState is an
enumerated data type
  double radius;
  double theta;
};
```

Now let's consider each element of CDecision in detail:

CDecision(CAgv *pAgv)

A pointer to an instance of class CAgv is created with the construction of CDecision () and is deleted with the destruction ~CDecision().

void decideNext()

After a structure lineDescriptor is filled with the characteristic of line, the decideNext method will decide whether to move the left motor Clockwise or Counter Clockwise, move right motor, to stop both e.t.c.

motorState getRightMotorState()

motorState getLeftMotorState()

Before decoding the output data to control circuitry, the decided motorstate should be read. These two methods will do the same

4.18.5. CInterface

After the correct decision is made, i.e. whether to move vehicle or not, if yes then to which direction and with what speed. All of these controls is decoded and sent out through parallel port to the control circuit. This is what CInterface is used for. The Declaration of CInterface is:

```
class CInterface
{
public:
          CInterface(CAgv *pAgv);
   virtual ~CInterface();

          void sendData();//To LPT Port
   int getDataOut();//To display in console
private:
          CAgv* m_pAgv; //so that Decision Objects can access Agv Object
   unsigned char dataOut;//8 bit - 0 to 255
};
```

Now let's consider each element of CInterface in detail:

CInterface(CAgv *pAgv)

The data value to be sent out, i.e. "dataOut" is initialized on construction of CInterface class.

void sendData()

After checking the result from decideNext, the appropriate data to be sent is first encoded and then sent out to parallel port. This is the primary function of this method.

int getDataOut()

This method is also used for debugging. To continuously monitor what data has been sent to the parallel port, furthermore the feedback data can be verified with the data just sent out.

4.19. Wireless Control Approach

An alternative to the Image Processing mode of operation is the wireless control mode. In this mode the control of the vehicle is done from a remote computer. The actual control signal can either be manual or automated at the remote end.

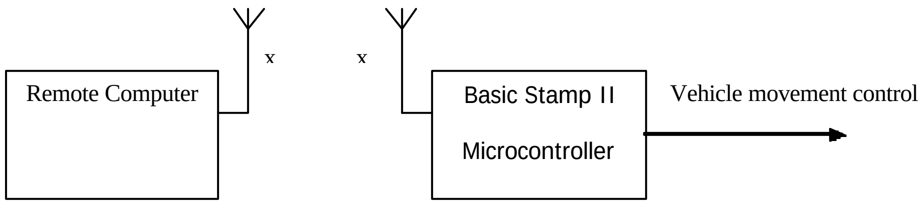


Fig 21. Wireless Control Approach Block Diagram

The control of vehicle movement is done accordingly to the transmission of data through serial communication. The Microsoft Communication Control (MSComm) is used to send the control data bit sequence from serial port. The receiving unit is a circuitry consisting of a Basic Stamp II micro controller which then decodes the signal and controls the drive motors. The platform used for the serial communication is Microsoft Visual Basic (Windows OS).

4.19.1. MSComm Control

The MSComm control provides serial communications for the application by allowing the transmission and reception of data through a serial port. It provides the following two ways for handling communications:

Event-driven communications is a very powerful method for handling serial port interactions. In many situations we want to be notified the moment an event takes place, such as when a character arrives or a change occurs in the Carrier Detect (CD) or Request To Send (RTS) lines. In such cases, we use the MSComm control's OnComm event to trap and handle these communications events. The OnComm event also detects and handles communications errors.

We can also poll for events and errors by checking the value of the CommEvent property after each critical function of your program. This may be preferable if the application is small and self-contained. For example, if we are writing a simple phone dialer, it may not make sense to generate an event after receiving every character, because the only characters we plan to receive are the OK response from the modem.

Each MSComm control we use corresponds to one serial port. If we need to access more than one serial port in the application, we must use more than one MSComm control. The port address and interrupt address can be changed from the Windows Control Panel. Although the MSComm control has many important properties, few of them are listed below:

Properties	Description
CommPort	Sets and returns the communications port number.
Settings	Sets and returns the baud rate, parity, data bits, and stop bits as a string.
PortOpen	Sets and returns the state of a communications port. Also opens and closes a port.
Input	Returns and removes characters from the receive buffer.
Output	Writes a string of characters to the transmit buffer.

Table 2. Important MSComm Control Properties

The Communications control allows us to add both simple serial port communication functionality to the application and advanced functionality to create a full-featured, event-driven communications tool. It also provides an interface to a standard set of communications commands. It allows you to establish a connection to a serial port, connect to another communication device (a modem, for instance), issue commands, exchange data, and monitor and respond to various events and errors that may be encountered during a serial connection.

Possible Uses

- To dial a phone number.
- To monitor a serial port for incoming data.
- To create a full-featured terminal program.

4.19.2. Serial Port

Serial refers to data sent over a single wire, with each bit lining up in a series as the bits are sent. This type of communication is used over the phone system because the system provides one wire for data in one direction.

Virtually all motherboard include built-in super I/O that add one or two serial ports to the motherboard, meaning no additional interface card is required.

Asynchronous serial interface was designed as a system-to–system communication port. Asynchronous means that no synchronization or clocking signal is present, so characters may be sent with any arbitrary time spacing.

Each character send over a serial connection is framed by a standard start-and-stop signal. A single 0 bit, called the start bit, precedes each character to tell the receiving system that the next eight bit constitute a byte of data. One or two stop bits follow the character to signal that the character has been sent. At the receiving end of the communication, characters are recognized by the start-and-stop signal instead of by the timing of their arrival. The asynchronous interface is character- oriented and has about a 20% overhead for the extra information needed to identify each character.

Serial ports may connect to a variety of devices as modems, plotters, printers, other computers, bar code readers, scales and device control circuits. Basically, anything that needs a two-way connection to the PC uses the Industry-Standard Reference Standard number 232revision C (RS-232c) serial port. This device enables data transfer between otherwise incompatible devices.

The heart of any serial port is the Universal Asynchronous Receiver/Transmitter (UART) chip. This chip completely controls the process of breaking the native parallel data within the PC into serial format and later converting serial data back into the parallel format.

9-PIN (AT) Serial Port Connector

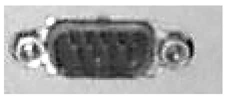


Fig 22. 9-pin AT Serial Port Connector

Pin	Signal	Description	I/O
1	CD	Carrier Detect	In
2	RD	Receive Data	In
3	TD	Transmit Data	Out
4	DTR	Data Terminal Ready	Out
5	SG	Signal Ground	-
6	DSR	Data Set Ready	In
7	RTS	Request To Send	Out
8	CTS	Clear To Send	In
9	RI	Ring Indicator	In

Table 3. 9-pin Serial Port Pin-Out

25-PIN (PC, XT and PS/2) Serial Port Connector

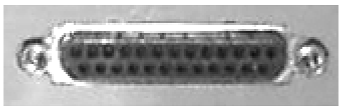


Fig 23. 25-pin Serial Port Connector

Pin	Signal	Description	I/O
1	-	Chasis Ground	-
2	TD	Transmit Data	Out
3	RD	Receive Data	In
4	RTS	Request To Send	Out
5	CTS	Clear To Send	
6	DSR	Data Set Ready	
7	SG	Signal Ground	
8	CD	Carrier Detect	
9	-	+ Transmit Current Loop Return	
11	-	- Transmit Current Loop Data	Out
18	-	+ Receive Current Loop Data	Out
20	DTR	Data Terminal Ready	In
22	RI	Ring Indicator	Out
25	-	- Receive Current Loop Return	In
			In

Table 4. 25-pin Serial Port Pin-Out

4.19.3. Serial Port Configuration:

Each time a character is received by a serial port, it has to get the attention of the computer by raising an Interrupt Request line (IRQ). Eight-bit ISA bus systems

.

have eight of these lines and systems with 16-bit ISA bus have 16 lines. The 8259 Interrupt Controller chip usually handles their request for attention. In standard configuration, COM1 uses IRQ4 and COM2 uses IRQ3.

When a serial port is installed in a system, it must be configured to use specific I/O addresses (ports) and interrupts (called IRQs for Interrupt Request).

System	COMX	Port	IRQ
All	COM1	3F8-3FFh	IRQ4
All	COM2	2F8-2FFh	IRQ3
ISA Bus	COM3	3F8-3EFh	IRQ4
ISA Bus	COM4	2E8-2EFh	IRQ3

Table 5. Standard Serial I/O Port Addresses and Interrupts

4.19.4. USER INTERFACE

Major Functions Used

Form_keydown()

According to the key pressed on form the botMove () function is called with the corresponding movecode.

botMove()

This function is used to send the string byte through the serial port. According to the key pressed by the user, the corresponding data byte will be transmitted.

5. Electronic Design

5.1. Introduction

The AGV had stood as an electronic challenge from its humble beginnings. This challenge involved the design of a motor controller capable of controlling the drive motors at variable speeds in forward and reverse directions so that the two forward drive wheels could be driven electrically. DC motors were chosen for its simplicity and precise control of speed. Moreover, as the power supply for the AGV (which is mobile) is a DC battery, a DC Motor makes better sense than using AC motors. The disadvantage of using DC motors as seen by the team is that DC motors are not easily available in the market of the homeland of the team members, which happens to be a third world country! Other disadvantages include high price to power ratings.

The two front drive motors of the AGV would require independent controllers for independent drives as required by the skid-steering principle. The principle of DC motors and its control will be explained in the first half of this section.

The next hurdle faced was to make the AGV know about its surroundings by means of sensors. Sensors are the major part of any intelligent robotic system. Utilizing the limited and scarce components available the AGV team was able to come up with CCD (Charged Coupled Device) Camera, ultrasonic and optical emitter-detector sensors. These three sensors constitute three of the four modes of operation of the AGV. The mode of operation can be selected by means of jumpers. The modes are controlled by the Basic Stamp II microcontroller.

5.1.1. CCD Camera – Image Processing Mode

A powerful method for a robot to sense its environment is through robotic vision. An USB (Universal Serial Bus) digital video camera was chosen as the source of vision. The camera is powered from the USB port itself.

Robotic Vision would involve image processing and extensive computing power. Thus a fast Pentium III 800MHz CPU was chosen to crunch the bits of the captured image. The image processing program would send out information for the motor controller boards through the parallel port. This interfacing between the software and the hardware proved to be another challenge.

5.1.2. Ultrasonic Mode – Obstacle Avoidance

In this mode, the vehicle moves ahead straight until obstructed by an obstacle. The presence of an obstacle is detected by the reflective property of the obstacle to ultrasonic sound waves. Two such detectors are placed at the left and right positions of the front side of the vehicle.

5.1.3. Emitter Detector – Line Following

The ‘G’ in the AGV means the AGV is guided by some means. One of the easiest and intuitive way by which the AGV can be guided is by means of an emitter detector set, made to follow a given line on the floor.

5.1.4. Manual Wireless Control Mode

This is the fourth mode in which the AGV can be operated in. Wireless control would involve manual control of the vehicle without wires. Manual control may not justify the true name of AGV – Autonomous Guided Vehicle, but this mode proves to be quite interesting for the robotic enthusiast. In this mode, the direction of travel is signaled from a remote computer using the serial port, which is transmitted via AM waves, and received and sent to be processed by the Basic Stamp II microcontroller.

5.2. DC Motor

DC motors are widely used in industrial and consumer applications. The speed of the DC motor can be controlled much more easily than the AC motors. Thus the adaptability of DC motor in speed control finds its application in modern industrial drives.

In this project, two DC motors are used in the front wheels. The DC motors are used to drive the vehicle. The forward and reverse drive of the two motors can drive the vehicle in forward or backward direction or skid-steer the vehicle when the speed of the two motors is different. The third wheel at the back is a free castor wheel.

5.2.1. Construction of the DC Motor

Like any rotating machine DC motor also consist of a rotor and a stator. Concentrated magnetic poles are created from field windings mounted in the stator and the armature windings are wound in the cylindrical rotor. The armature is distributed type and may be wound in various ways.

Depending upon the source of magnetic flux, DC motors are classified as PMDC motors and excited DC motors. In PMDC motors, permanent magnets are mounted in the stator with alternating poles. In excited type motors, magnetic flux is produced by exciting the field windings wound around the salient pole.

The two ends of the armature winding is connected to two conducting segments insulated from each other and to the shaft, to which they are mounted to. Armature excitation is applied to the commutator segments by means of brushes. The armature is mounted on a shaft, which is supported by the bearings. One end of the shaft is coupled mechanically to the external load.

Some important facts to be considered in construction of DC motors

The brushes are kept electrically in the inter-polar region and hence make 900 electrical with the axes of the adjacent poles.

The brushes are alternatively positive and negative.

The number of brushes depends upon the armature winding and number of poles.

5.2.2. PMDC Motors

PMDC motors are constructed using permanent magnets made up of materials having high residual flux and high coercivity for the field. PMDC motors have the advantage of no field windings and no field loss and hence are smaller in size. The PMDC motors offer the characteristics of a shunt motor and can be controlled by armature control method.

5.2.3. Characteristics of DC motor

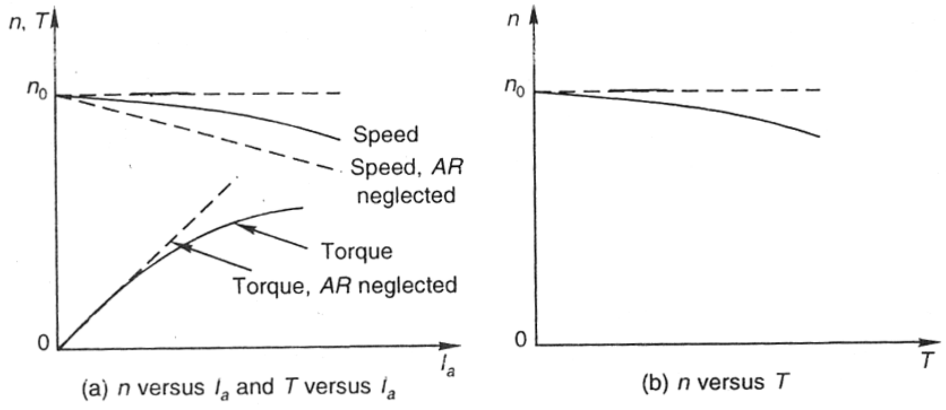


Fig 24. Characteristics of Shunt DC Motors (V, If constant)

The characteristics of DC motors are governed by two fundamental relation ships i.e. emf and torque relationships.

$E_a = K_a\phi\omega = \phi nZP/60A$ &

$T = \phi I_a ZP/2\pi A = K_a\phi I_a$

To study the characteristic (speed and torque characteristics), it is convenient to express the fundamental relations in terms of speed and torque.

$n = 60AE_a/PZ\phi = K_N E_a/\phi$ &

$T = K_T\phi I_a$

As we know, PMDC motors show similar characteristics to that of shunt type DC motors.

For a shunt DC motor, the induced emf in armature windings is given by

$E_a = V - I_a R_a$

which gives on substitution to above equations

$n = K_N(V - I_a R_a)/ \phi$

Also for PMDC motors f i.e. flux per pole is constant. From the above relation, it is obvious that the speed may fall due to armature resistance drop slightly. Also torque current characteristic is a fairly straight line slightly sloping downwards.

Speed torque characteristics also plays an important role in the performance of DC motors. From the relation for and speed and torque, eliminating I_a we get,

$n = K_N V/\phi - K_N R_a T/ \phi^2 KT$

which is an equation of a straight line. But due to the armature reaction, speed falls off slightly from no load to full load, however the speed remains fairly constant.

5.2.4. DC Motor Used

Under the limited budget and scarce availability, two identical DC wiper motors were used to drive the AGV wheels. Though the motors were rated at a mere 17watts, at 12 volts, the motors drew a stall current of 2.5A. The vehicle had to be engineered according to this limiting power.

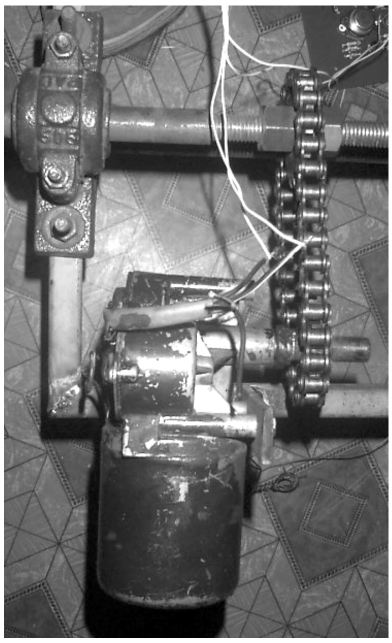


Fig 25. The DC Motor used for the AGV

5.3. Speed Control of DC Motor

The speed of the DC motors is given by

$n = Kn (V – IaRa)/\phi$

This equation shows that speed of DC motor can be controlled by two methods. The first method is to change the flux per pole, ϕ, and the second method is to change the armature voltage V. The first method is known as field control and the second method is armature control.

However, the wiper motor we are using is a Permanent Magnet DC motor (PMDC), so the flux per pole is always constant. So field control method cannot be used to control speed the only alternative available is to vary the armature voltage.

The main requirement of armature control scheme is the varying voltage supply to the armature. This can be obtained in various ways such as use of converters, choppers etc. As AGV has a DC Battery as a power supply, a chopper is the viable solution for the speed control of DC Motor.

5.3.1. Chopper and PWM

A chopper is a static device that converts fixed de input voltage to a variable dc output voltage directly. A chopper may be thought of as dc equivalent of an ac transformer since they behave in an identical manner. As choppers involve one stage conversion, these are more efficient. As with AGV, the future electric automobiles are likely to use choppers for their speed control and braking. Chopper systems offer smooth control, high efficiency, fast response and regeneration.

The power semiconductor devices used for a chopper circuit can be power BJT, power MOSFET, GTO or force-commutated thyristor. These devices, in general, can be represented by a switch SW with an arrow as shown in Figure 26. When the switch is off, no current can flow. When the switch is on, current flows in the direction of arrow only. The power semiconductor devices have on-state voltage drops of 0.5 V to 2.5 V across them.

Like a transformer, a chopper can be used to step down or step up the fixed dc input voltage. We would be using a step-down dc chopper to obtain various voltage levels below the 12V dc battery supply, which would in turn control the speed of the motor.

A chopper is basically a high speed on/off semiconductor switch. It connects source to load and disconnects the load from source at a fast speed. In this manner, a chopped load voltage as shown in Figure 26(b) is obtained from a constant dc supply of magnitude Vs.

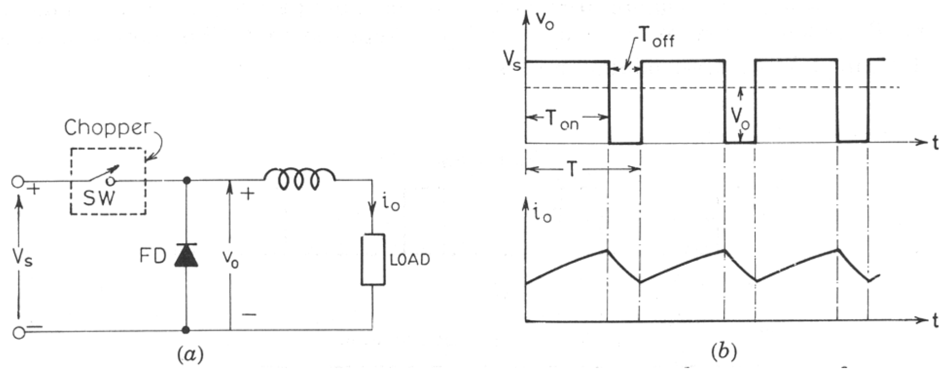


Fig 26. An Elementary Chopper Circuit and (b) output voltage and current waveforms

In Figure 26 (a), a chopper is represented by a switch SW inside a dotted rectangle, which may be turned-on or turned-off as desired. During the period Ton, the chopper is on and the load voltage is equal to source voltage Vs. During the interval T_{off}, the chopper is off, and the load current flows through the freewheeling diode FD. As a result, load terminals are short circuited by FD and load voltage is therefore zero during T_{off}. In this manner, a chopped dc voltage is produced at the load terminals.

The load current as shown in Figure 26 (b) is continuous. From Figure 26 (b), the average load voltage V_o is given by

$$V_0 = \frac{T_{on}}{T_{on} + T_{off}} V_s = \frac{T_{on}}{T} V = \alpha V_s$$

$$T_{on} = \text{on–time} ; T_{off} = \text{off–time}$$

$$T = T_{on} + T_{off} = \text{chopping period}$$

$$\alpha = \frac{T_{on}}{T} = \text{duty cycle}$$

Thus load voltage can be controlled by varying duty cycle α. The above equation shows that load voltage is independent of load current.

Thus the average value of output voltage V_o can be controlled through α by opening and closing the semiconductor switch periodically. The various control strategies for varying duty cycle are as follows:

Constant Frequency System (PWM)

Variable Frequency System (PFM)

In the Constant Frequency System, the on-time T_{on} is varied but chopping frequency f (or chopping period T) is kept constant. Variation of Ton means adjustment of pulse width, thus the name Pulse Width Modulation (PWM). This scheme has also been referred to as time-ratio control (TRC) by some authors.

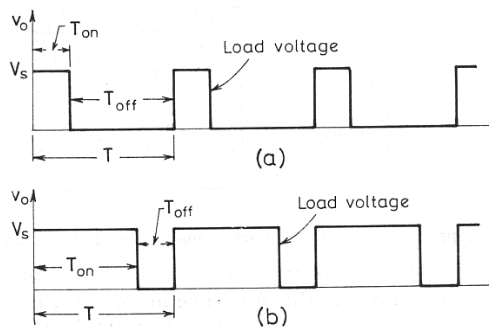


Fig 27. Principle of Pulse Width Modulation (Constant T)

Figure 28 illustrates the principle of PWM. Here chopping period T is constant. In Figure 28 (a), T_{on} = ¼ T so that α = 0.25 or α = 25%. In fig 28 (b), T_{on} = ¾ T so that α = 0.75 or 75%. Ideally a can be varied from zero to infinity. Therefore output voltage can be varied between zero and source voltage V_S.

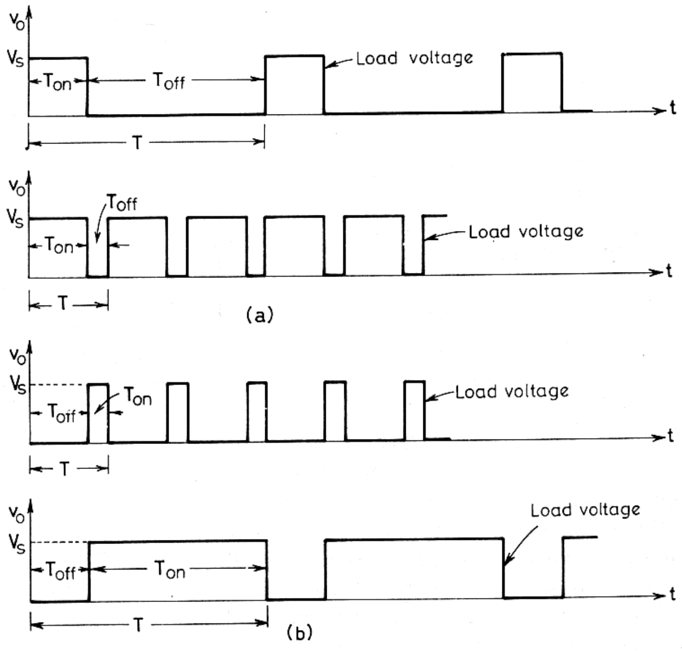


Fig 28. Principle of Frequency Modulation (a) on-time Ton constant and (b) off-time Toff constant

In the Variable Frequency Scheme, the chopping frequency f (or chopping period T) is varied and either (i) on-time T_{on} is kept constant or (ii) off-time T_{off} is kept constant. This method of controlling α is also called frequency-modulation scheme.

Figure 28 illustrates the principle of frequency modulation. In Figure 28 (a), Ton is kept constant but T is varied. In the upper diagram of Figure 25 (a), T_{on} = ¼ T so that α = 0.25. In the lower diagram of Figure 25 (a), T_{on} = ¾ T so that α = 0.75. In Figure 28 (b), T_{off} is kept constant and T is varied. In the upper diagram of this figure, T_{on} = ¼ T so that α = 0.25 and in the lower diagram T_{on} = ¾ T so that α = 0.75.

Frequency modulation scheme has some disadvantages as compared to pulse-width modulation scheme. These are as under:

i) The chopping frequency has to be varied over a wide range for the control of output voltage in frequency modulation. Filter design for such wide frequency variation is, therefore, quite difficult.

ii) For the control of α, frequency variation would be wide. As such, there is a possibility of interference with signaling and telephone lines in frequency modulation scheme.

iii) The large off-time in frequency modulation scheme may make the load current discontinuous which is undesirable.

It is seen from above discussions that constant frequency (PWM) scheme is better than variable frequency scheme. PWM technique has, however, a limitation such as, Ton cannot be reduced to near zero for most of the commutation circuits used in choppers. As such, low range of α control is not possible in PWM. This can, however, be achieved by increasing the chopping period (or decreasing the chopping frequency) of the chopper.

5.4. H-Bridge

5.4.1. Theory

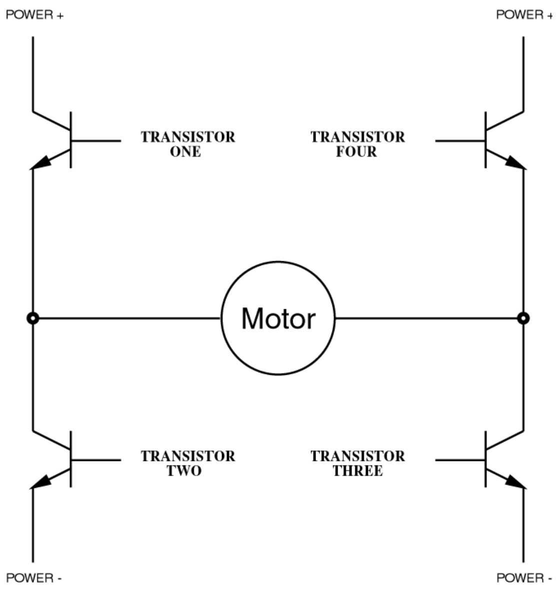


Fig 29. BJT H-Bridge

A circuit known as the H-bridge (named for its topological similarity to the letter H") is commonly used to drive motors. In this circuit (depicted in Figure 29), two of four transistors are selectively enabled to control current flow through a motor.

As shown in Figure 30, an opposite pair of transistors (Transistor One and Transistor Three) is enabled, allowing current to flow through the motor. The other pair is disabled, and can be thought of as out of the circuit.

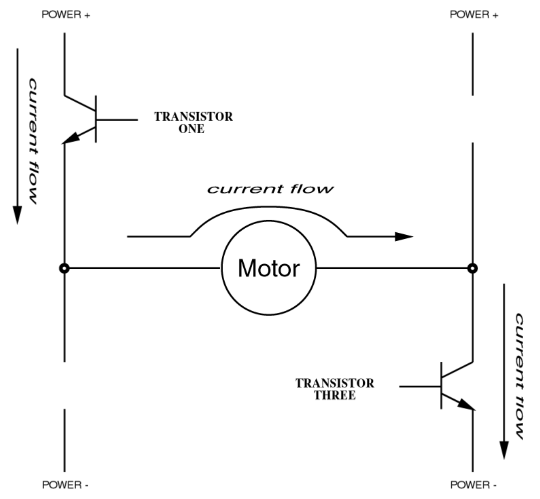


Fig 30. The H-Bridge with left to right current flow

By determining which pair of transistors is enabled, current can be made to flow in either of the two directions through the motor. Because permanent-magnet motors reverse their direction of turn when the current flow is reversed, this circuit allows bidirectional control of the motor.

It should be clear that one would never want to enable Transistors One and Two or Transistors Three and Four simultaneously. This would cause current to flow from Power+ to Power-.

To facilitate control of the H-bridge circuit, enable circuitry as depicted in Figure 31 is typically used. In this circuit, the inverters ensure that the vertical pairs of transistors are never enabled simultaneously. The Enable input determines whether or not the whole circuit is operational. If this input is false, then none of the transistors are enabled, and the motor is free to coast to a stop.

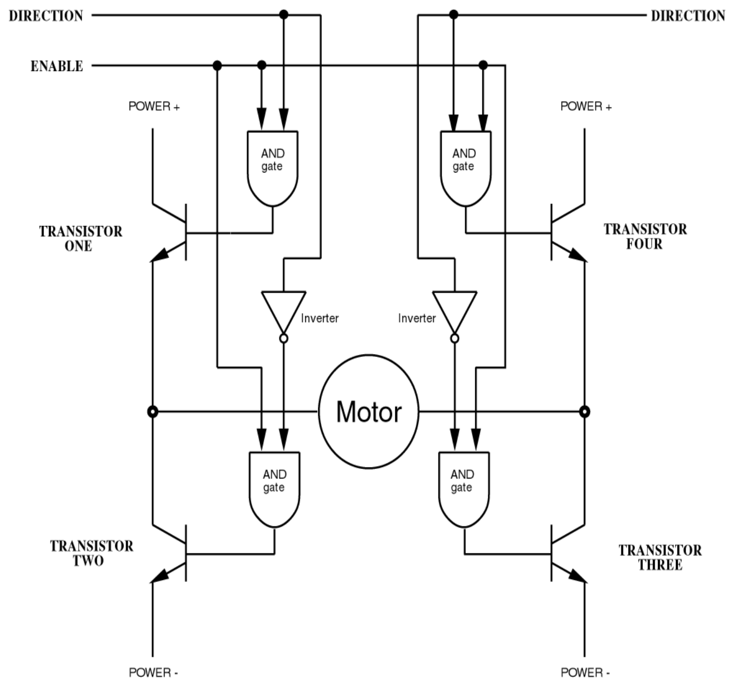


Fig 31. The H-Bridge with Enable Circuitry

By turning on the Enable input and controlling the two Direction inputs, the motor can be made to turn in either direction.

Note that if both direction inputs are the same state (either true or false) and the circuit is enabled, both terminals will be brought to the same voltage (Power + or Power – respectively). This operation will actively brake the motor, due to the back EMF property of motors, in which a motor that is turning generates a voltage counter to its rotation. When both terminals of the motor are brought to the same electrical potential, the back EMF causes resistance to the motor's rotation.

5.4.2. H-Bridge Design

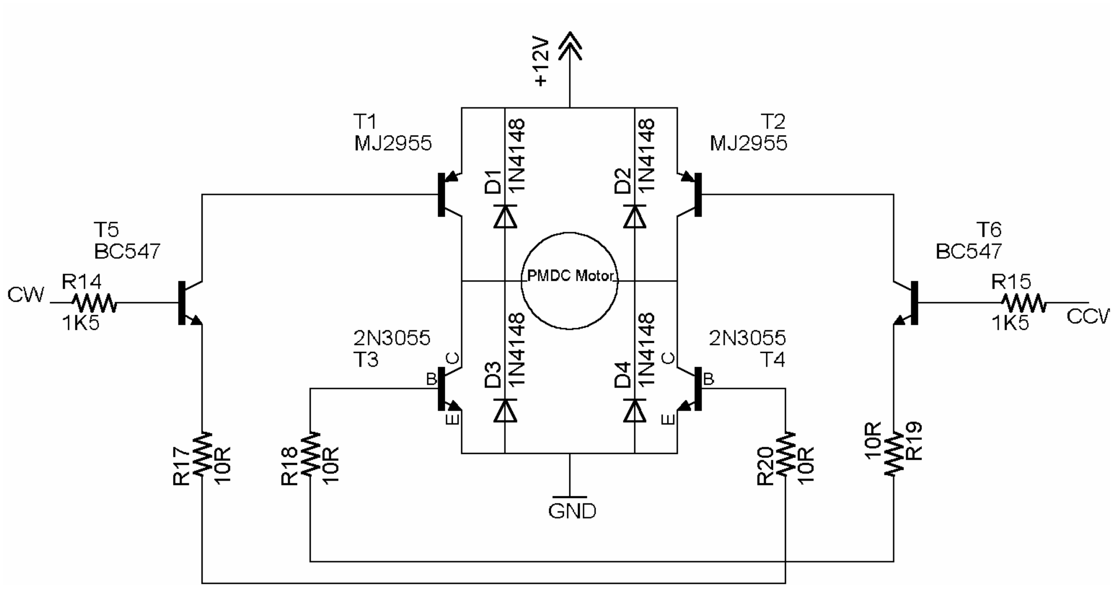


Fig 32. Power H-Bridge Design

The above H-Bridge is the final design for the AGV drive motors. Two such Bridges were constructed for the two drive motors. A brief overview of its design follows:

Transistor Selection

The first thing to consider is rating of the DC Motor. As seen on Section 5.2.4, the DC motor had a stall current of 2.5A at 12 volts. The bridge was thus designed for a motor current of 3A. Robust power BJTs were chosen as the switching element after repeated destruction of the limited power MOSFETs. Sure, MOSFETS have very less Drain to Source voltage drop, but they are very hard to handle, as they are more static sensitive.

2N3055 NPN power BJT was chosen as the lower side switching element, and its complementary MJ2955 PNP power BJT was chosen as the upper side switching element due to its cheap price, good performance, and availability. These power BJTs have a continuous collector current rating of 15A, overkill for the 2.5A stall current DC motors.

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector–Emitter Voltage	V_{CEO}	60	Vdc
Collector–Emitter Voltage	V_{CER}	70	Vdc
Collector–Base Voltage	V_{CB}	100	Vdc
Emitter–Base Voltage	V_{EB}	7	Vdc
Collector Current — Continuous	I_C	15	Adc
Base Current	I_B	7	Adc
Total Power Dissipation @ T_C = 25•C Derate above 25•C	P_D	115 0.657	Watts W/•C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–65 to +200	•C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.52	•C/W

Table 6. 2N3055/MJ2955 Transistor Ratings

At 30 watts (12V x 2.5A) and a junction to case thermal resistance of 1.52^0C/W, we get the junction temperature of 25^0C + 1.52^0C/W x 30W = 70.6^0C, which is under the rated operating and storage junction temperature with an upper limit of 200^oC.

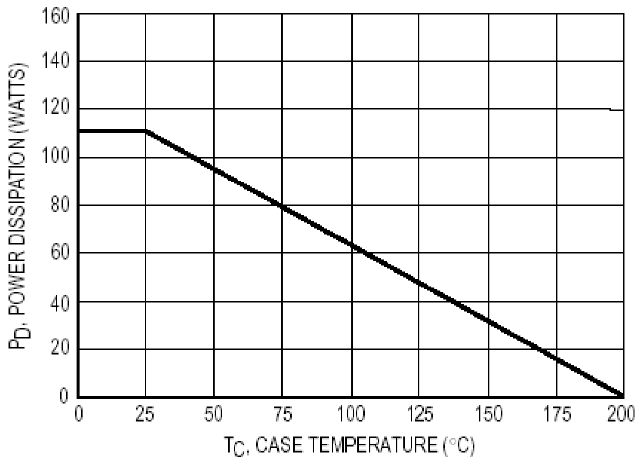


Fig 33. Power Derating of the 2N3055/MJ2955 transistors

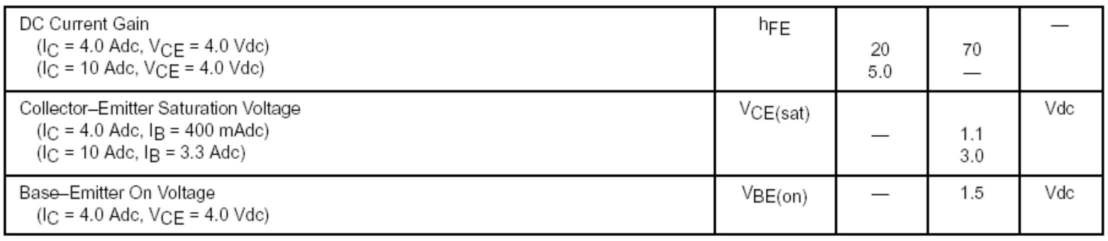
With a power derating of $0.657W/^0C$, we have the total power dissipation rating of

P_D = 115W - $0.657W/^0C$ x (70.6-25) ^0C = 80.04Watts,

which is well above the 30W power to be dissipated.

Thus no heat sink would be required. The BJTs would be directly mounted on the PCB.

BJT Driver Design



DC Current Gain (I_C = 4.0 Adc, V_{CE} = 4.0 Vdc) (I_C = 10 Adc, V_{CE} = 4.0 Vdc)	h_{FE}	20 5.0	70 —	—
Collector–Emitter Saturation Voltage (I_C = 4.0 Adc, I_B = 400 mAdc) (I_C = 10 Adc, I_B = 3.3 Adc)	$V_{CE(sat)}$	—	1.1 3.0	Vdc
Base–Emitter On Voltage (I_C = 4.0 Adc, V_{CE} = 4.0 Vdc)	$V_{BE(on)}$	—	1.5	Vdc

Table 7. On Characteristics of the 2N3055/MJ2955 transistors

With a minimum DC Current Gain of 20, for a collector current of 2.5A, 125mA base current is required to turn on the transistors. This cannot be supplied by any of the logic circuits. Thus we need a second stage of transistors, BC547, in our case.

Thus, when T5 is switched (CW = HIGH) on by a logic high 5V, base current is taken off the MJ2955 PNP transistor (T1), and fed to base of the NPN 2N3055 transistor (T5). Hence T1 and T5 are turned on, driving the motor in clockwise direction.

Similarly, when T6 is switched on (CCW = HIGH) by a logic high 5V, motor in driven in an anticlockwise direction.

It should be noted that T5 and t6 are never to be turned on simultaneously.

5.5. Software – Hardware Interface

5.5.1. Introduction

In the Image Processing mode, the onboard computer has to 'talk' with the Motor Controller boards. Each motor is assigned seven states – Stopped, 75% Full Speed, 85% Full Speed, and 100% Full Speed in both clockwise (CW) and counterclockwise (CCW) directions. The computer tells the Interface Circuitry which state the motor should be run at through six motor state bits of the parallel port.

The OS used for the image processing is Windows, a non-real-time system. The time sharing nature of its operation may prove critical, as the vehicle may go out of its path if the software slows down, or crashes. Thus, the interface circuits should have fault-tolerance capabilities.

The same hardware interface should work for other modes of operation besides the image processing mode.

5.5.2. Multiplexing

In the electronics of AGV, the commands may originate from the computer or the Basic Stamp II. The same PWM generation and other further circuits are to be used for both the situations – when BSII is in control and when the computer is in control.

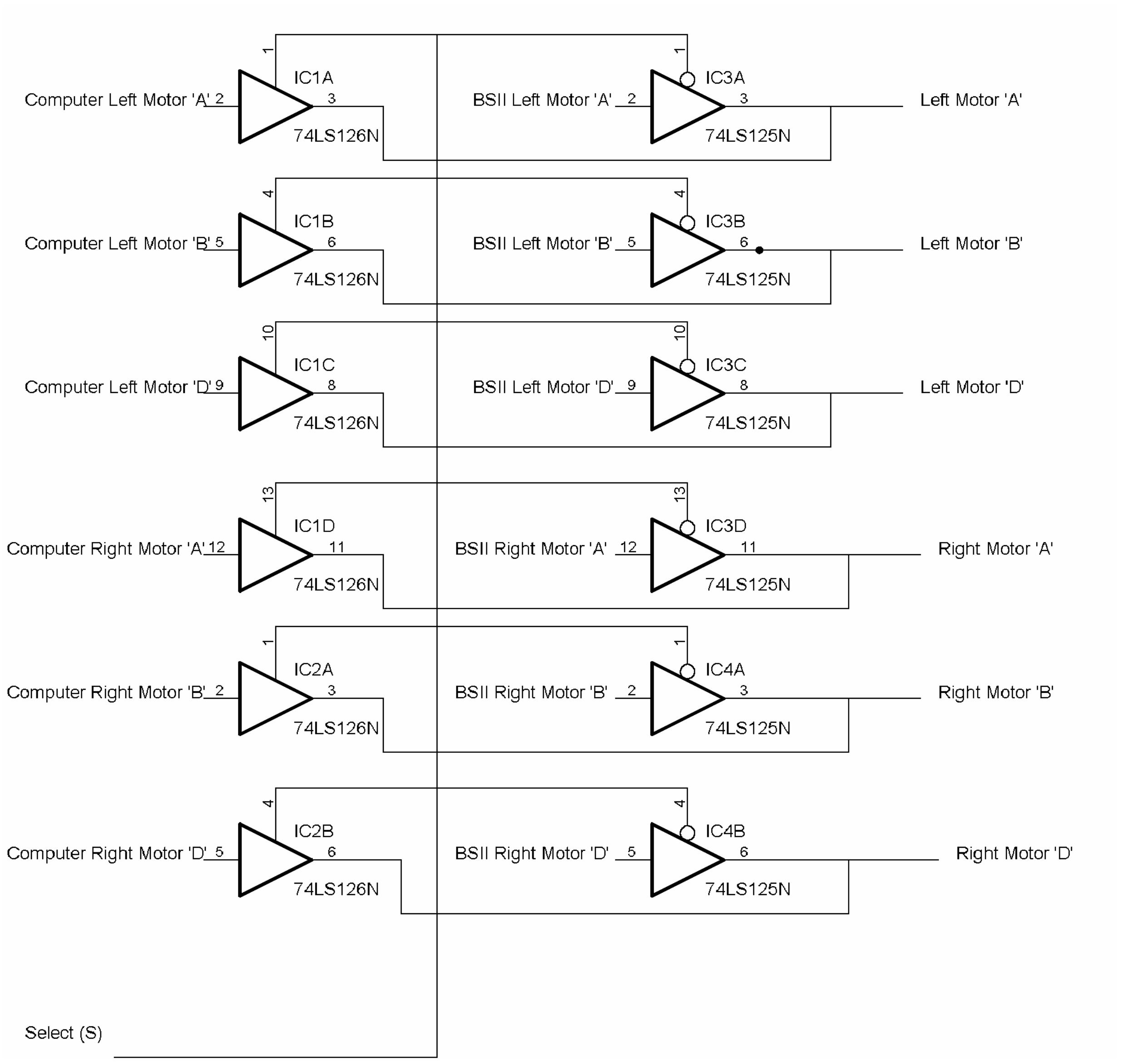


Fig 34. Multiplexing

Using 74LS125 and 74LS126 tri-state buffers, the Select line can select either the 6 bit output from the computer or the Basic Stamp II. Here, when S=0, Output=Computer, and when S=1, Output=BSII.

5.5.3. PWM Generation

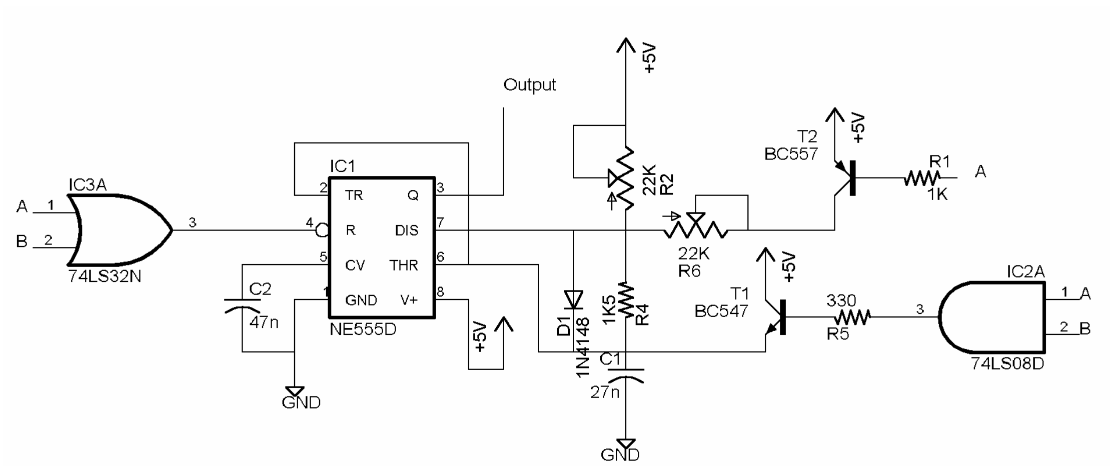


Fig 35. PWM Generator

Analyzing the astable multivibrator circuit above, we get the following results:

When A = 0 and B = 0, the reset pin of the 555 timer is held low, and the output is low.

When A = 0 and B = 1, T2 is turned on and R2 and R6 come in parallel, and the charging time of the 555 timer would be 0.69 (R2//R6) 27nF, and the discharging time would be 0.69 x 1.5K x 27nF. R2 and R5 are so set that the duty cycle of the output is around 75%.

When A=1 and B=0, T2 is turned off. Adjusting R2 we obtain a duty cycle of around 85%.

When A=1 and B=1, T1 is turned on, and the voltage across the capacitor is held high, so the output of the timer is a constant +5 V.

5.5.4. Direction Control

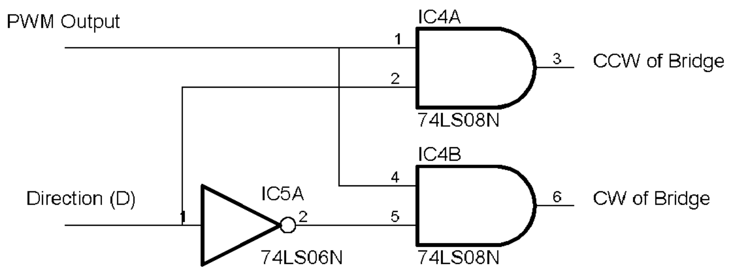


Fig 36. Direction Control

Between the PWM Generator and the Bridge is the above Direction Control circuit. We see that when D=0 the bridge would be turned on so that the motor would revolve in a Clockwise direction, and when D=1 the bridge would be turned on so that the motor would revolve in a Counter Clockwise direction.

5.5.5. Fault Tolerance System

A fault tolerance interface system must tolerate a fault caused by the computer and not complain about it. It should not be faulty, if the computer becomes faulty. Thus, a simple mechanism has been developed using a D-Latch as a flag.

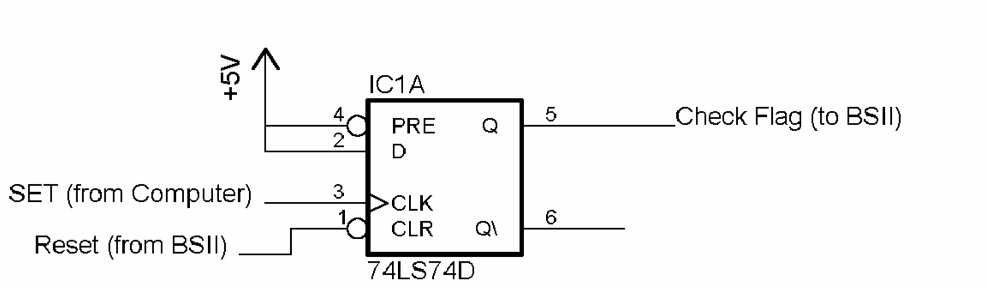


Fig 37. A Flag setting/resetting mechanism

Each time the computer outputs the 6-bit output, it strobes the data by setting a 74LS74 flip-flop by providing a positive going pulse at the CLK of the 74LS74. The Data input (D) is always held high.

At the beginning of the image processing loop mode of the BSII, the CLR pin of the 7474 is held high. The BSII checks if flag=1. If so, it clears the flag and makes the select line to the MUX low, selecting the computer output, and waits about 1.5 seconds to give the computer some time to complete its image processing loop and write a new data at the port, setting the flag again. Otherwise, if the flag is not set, it selects its own 6-bit output by making the select bit high, and outputs data to stop both the motors.

Thus the BSII would be checking the flag every 1.5 seconds (time can be changed), and if the flag is not set, it stops the motor. Hence, if by any chance, the image processing loop crashes, the vehicle tolerates the fault and stops.

5.6. The Basic Stamp II

5.6.1. Introduction

BASIC Stamps are microcontrollers (tiny computers) that are designed for use in a wide array of applications. Many projects that require an embedded system with some level of intelligence can use a BASIC Stamp module as the controller.

Each BASIC Stamp comes with a BASIC Interpreter chip, internal memory (RAM and EEPROM), a 5-volt regulator, a number of general-purpose I/O pins (TTL-level, 0-5 volts), and a set of built-in commands for math and I/O pin operations. BASIC Stamps are capable of running a few thousand instructions per second and are programmed with a simplified, but customized form of the BASIC programming language, called PBASIC.

There are five popular models of the BASIC Stamp; the BASIC Stamp 1, BASIC Stamp 2, BASIC Stamp 2e, BASIC Stamp 2sx and BASIC Stamp 2p. The Basic Stamp used in AGV is the Basic Stamp II.

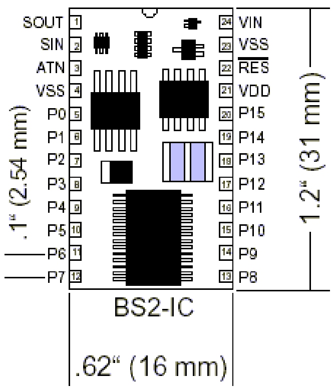
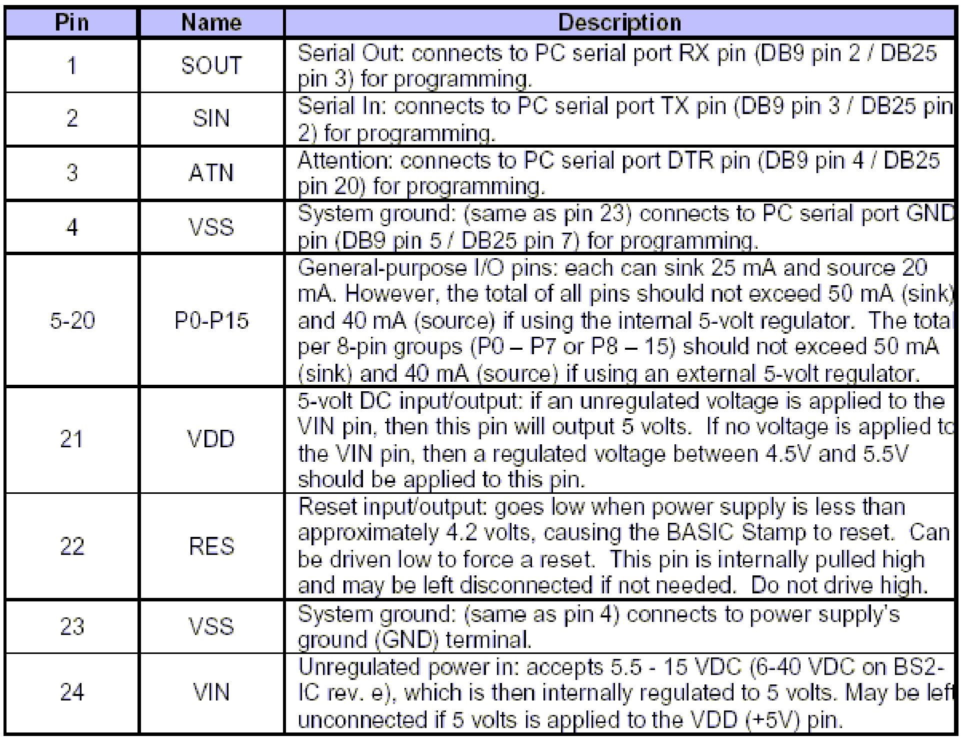
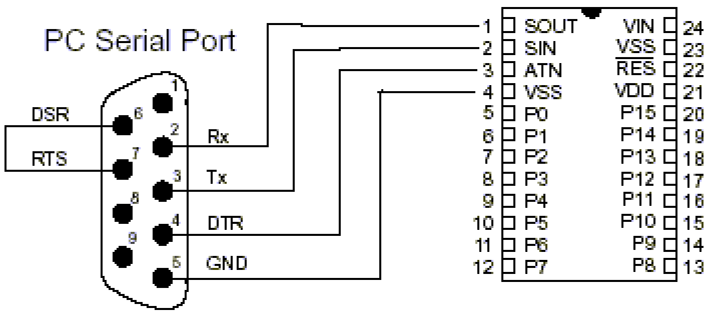


Fig 38. The Basic Stamp II IC.



Pin	Name	Description
1	SOUT	Serial Out: connects to PC serial port RX pin (DB9 pin 2 / DB25 pin 3) for programming.
2	SIN	Serial In: connects to PC serial port TX pin (DB9 pin 3 / DB25 pin 2) for programming.
3	ATN	Attention: connects to PC serial port DTR pin (DB9 pin 4 / DB25 pin 20) for programming.
4	VSS	System ground: (same as pin 23) connects to PC serial port GND pin (DB9 pin 5 / DB25 pin 7) for programming.
5-20	P0-P15	General-purpose I/O pins: each can sink 25 mA and source 20 mA. However, the total of all pins should not exceed 50 mA (sink) and 40 mA (source) if using the internal 5-volt regulator. The tota per 8-pin groups (P0 – P7 or P8 – 15) should not exceed 50 mA (sink) and 40 mA (source) if using an external 5-volt regulator.
21	VDD	5-volt DC input/output: if an unregulated voltage is applied to the VIN pin, then this pin will output 5 volts. If no voltage is applied t the VIN pin, then a regulated voltage between 4.5V and 5.5V should be applied to this pin.
22	RES	Reset input/output: goes low when power supply is less than approximately 4.2 volts, causing the BASIC Stamp to reset. Can be driven low to force a reset. This pin is internally pulled high and may be left disconnected if not needed. Do not drive high.
23	VSS	System ground: (same as pin 4) connects to power supply's ground (GND) terminal.
24	VIN	Unregulated power in: accepts 5.5 - 15 VDC (6-40 VDC on BS2-IC rev. e), which is then internally regulated to 5 volts. May be lef unconnected if 5 volts is applied to the VDD (+5V) pin.

Table 8. Basic Stamp II Pin Configuration



Connecting the BSII to the Serial Port

5.6.2. Program

The BS-II can be programmed easily with a very easy BASIC-like language called the PBasic. The 'P' stands for Parallax, the makers of the Stamps.

The BS-II has 16 I/O Pins. For the AGV vehicle, the following assignments were made:

BIT	I/O	Use
D0	Input	Mode Selection M0
D1	Input	Mode Selection M1
D2	Output	Left Motor 'A'
D3	Output	Left Motor 'B'
D4	Output	Left Motor 'D'
D5	Output	Right Motor 'A'
D6	Output	Right Motor 'B'
D7	Output	Right Motor 'D'
D8	Output	Mux Select
D9	Output	Rest Flag
D10	Input	Check Flag
D11	Input	Left Emitter Detector
D12	Input	Right Emitter Detector
D13	Input	Left Ultrasonic Receiver
D14	Input	Right Ultrasonic Receiver
D15	Output	Tone Generation

Table 9. Basic Stamp II Pin Assignments

Besides the above I/O pins, pin 2, SIN (Serial In) is used to receive the serial data in wireless communication mode.

The modes can be selected by externally setting M0 and M1 according to:

M1	M0	Mode
0	0	Image Processing Mode
0	1	Emitter Detector Mode
1	0	Ultrasonic Mode
1	1	Wireless Control Mode

Table 10. Mode Selection

The program stored in the BS-II is as follows:

```
'{$STAMP BS2}

'************************************** Pin Assignments ***
'*****
'MUX Line
'*****
high 8            '0=Computer : 1=Basic Stamp

'******
'Mode Selection Pins
'D1 D0 = Mode
' 0  0 = Image Processing control
' 0  1 = Emitter Detector control
' 1  0 = Ultrasonic control
' 1  1 = Wireless control
'******
INPUT 0   'D0
INPUT 1   'D1

'******
'Ultrasonic sensor input
'******
INPUT 14  'Left
INPUT 13  'Right

'*****
'Motor Outputs
'*****
low 2             'Left Motor A
low 3             'Left Motor B
low 4             'Left Motor D
low 5             'Right Motor A
low 6             'Right Motor B
low 7             'Right Motor D

'*****
'Reset pin
'*****
high 9            'Low to clear. Must be held high at start
                  'so that computer can set the flag
'*****
'Flag bit for fault tolerance
'*****
input 10

'*****
'Emitter Detector Sensor data
```

```
'*****
input 11  'Left Sensor
input 12  'Right Sensor

'*****
'Tone Generation - for debuggin and alarm purpose
'*****
output 15 'FREQ-OUT

'**************************************** Main Program ***
'** uC reset tone **
freqout 15, 200, 1092, 1000
pause 50
freqout 15, 200, 2092, (2092-8)
pause 50
freqout 15, 200, 1092, 1000
'**

Command VAR BYTE  'To store the serial data in Wireless Mode

mainLoop:
   IF IN1 = 0 AND IN0 = 0 THEN imageProcessing
   IF IN1 = 0 AND IN0 = 1 THEN emitterDetector
   IF IN1 = 1 AND IN0 = 0 THEN ultrasonic
   IF IN1 = 1 AND IN0 = 1 THEN wireless

'** Independent modules
'*******************************

imageProcessing:
   IF IN10 = 0 THEN flagNotSet

   'Flag Set:
           low 8          'Mux select low - select computer.
           low 9          'Reset the flag
           high 9  'Let Computer Set Flag

           'pause for 1 second and play tones at the mean time

           '** Image Processing One Cycle Complete tone **
           freqout 15, 150, 800
           freqout 15, 150, 1200
           freqout 15, 150, 1000
           freqout 15, 150, 1600
           freqout 15, 250, 1400

           '**
           goto mainLoop

   flagNotSet:
           high 8  'Select Basic Stamp
           gosub CStop    'Send data to stop
goto mainLoop

'*******************************
emitterDetector:
   high 8         'Mux select high - select Basic Stamp.

   IF IN11 = 1 THEN lineOnLeft   'Gives greater preference to the Left Line.
   IF IN12 = 1 THEN lineOnRight

   gosub CFront
goto mainLoop


   lineOnLeft:
           gosub CFrontLeft
   goto mainLoop

   lineOnRight:
          gosub CFrontRight
goto mainLoop

'******************************

ultrasonic:
   high 8         'Mux select high - select Basic Stamp.

   IF IN14 = 0 AND IN13 = 0 THEN noObstacle
   IF IN14 = 0 AND IN13 = 1 THEN obstacleOnRight
   IF IN14 = 1 AND IN13 = 0 THEN obstacleOnLeft
   IF IN14 = 1 AND IN13 = 1 THEN obstacleOnLeftAndRight
goto mainLoop                    ' Mrs. Justin Case

   noObstacle:
          gosub CFront
   goto mainLoop

   obstacleOnRight
          gosub CStop
          freqout 15, 250, 500
          gosub CBack
          freqout 15, 500, 400
          gosub CZTRRight
          freqout 15, 1000, 600
   goto mainLoop

   obstacleOnLeft
          gosub CStop
          freqout 15, 250, 500
          gosub CBack
          freqout 15, 500, 400
          gosub CZTRLeft
          freqout 15, 1000, 600
   goto mainLoop

   obstacleOnLeftAndRight
          gosub CStop
          freqout 15, 250, 500
          gosub CBack
          freqout 15, 500, 400
          gosub CZTRLeft
          freqout 15, 1000, 600
   goto mainLoop

'******************************
wireless:
   high 8         'Mux select high - select Basic Stamp.

   SERIN 16, 17197, [DEC Command]       '1200 Baud 8 bits no parity inverted
                                                'Once the AGV mode is changed, one
more serial data must be sent
                                                'or the interface resetted, as the
program stops on this line.
   'The two MSBs give the speed. D7=A D8=B
   'The four LSBs give the Direction

   if Command = %01000001 then BackLeft01
   if Command = %01000010 then Back01
   if Command = %01000011 then BackRight01
   if Command = %01000100 then ZTRLeft01
   if Command = %01000101 then sStop01
   if Command = %01000110 then ZTRRight01
   if Command = %01000111 then FrontLeft01
   if Command = %01001000 then Front01
   if Command = %01001001 then FrontRight01

   if Command = %10000001 then BackLeft10
   if Command = %10000010 then Back10
   if Command = %10000011 then BackRight10
   if Command = %10000100 then ZTRLeft10
   if Command = %10000101 then sStop10
   if Command = %10000110 then ZTRRight10
   if Command = %10000111 then FrontLeft10
   if Command = %10001000 then Front10
   if Command = %10001001 then FrontRight10

   if Command = %11000001 then BackLeft11
   if Command = %11000010 then Back11
   if Command = %11000011 then BackRight11
   if Command = %11000100 then ZTRLeft11
   if Command = %11000101 then sStop11
   if Command = %11000110 then ZTRRight11
   if Command = %11000111 then FrontLeft11
   if Command = %11001000 then Front11
   if Command = %11001001 then FrontRight11
goto mainLoop

'*********** 01
BackLeft01:
   gosub CBackLeft01
goto mainLoop

Back01:
   gosub CBack01
goto mainLoop

BackRight01:
   gosub CBackRight01
goto mainLoop

ZTRLeft01:
   gosub CZTRLeft01
goto mainLoop

sStop01:
   gosub CStop
goto mainLoop

ZTRRight01:
   gosub CZTRRight01
goto mainLoop

FrontLeft01:
   gosub CFrontLeft01
goto mainLoop

Front01:
   gosub CFront01
goto mainLoop

FrontRight01:
   gosub CFrontRight01
goto mainLoop

'************ 10
BackLeft10:
   gosub CBackLeft10
goto mainLoop

Back10:
   gosub CBack10
goto mainLoop

BackRight10:
   gosub CBackRight10
goto mainLoop

ZTRLeft10:
   gosub CZTRLeft10
```

```
goto mainLoop

sStop10:
   gosub CStop
goto mainLoop

ZTRRight10:
   gosub CZTRRight10
goto mainLoop

FrontLeft10:
   gosub CFrontLeft10
goto mainLoop

Front10:
   gosub CFront10
goto mainLoop

FrontRight10:
   gosub CFrontRight10
goto mainLoop

'********** 11

BackLeft11:
   gosub CBackLeft
goto mainLoop

Back11:
   gosub CBack
goto mainLoop

BackRight11:
   gosub CBackRight
goto mainLoop

ZTRLeft11:
   gosub CZTRLeft
goto mainLoop

sStop11:
   gosub CStop
goto mainLoop

ZTRRight11:
   gosub CZTRRight
goto mainLoop

FrontLeft11:
   gosub CFrontLeft
goto mainLoop

Front11:
   gosub CFront
goto mainLoop

FrontRight11:
   gosub CFrontRight
goto mainLoop

'****************************** Common Motor Control Modules
'********* 11
CBackLeft:
   low 2
   low 3
   low 4
   high 5
   high 6
   high 7
return
```

```
CBack:
   high 2
   high 3
   low 4
   high 5
   high 6
   high 7
return

CBackRight:
   high 2
   high 3
   low 4
   low 5
   low 6
   low 7
return

CZTRLeft:
   high 2
   high 3
   low 4
   high 5
   high 6
   low 7
return

CStop:
   low 2
   low 3
   low 4
   low 5
   low 6
   low 7
return

CZTRRight:
   high 2
   high 3
   high 4
   high 5
   high 6
   high 7
return

CFrontLeft:
   low 2
   low  3
   low  4
   high 5
   high 6
   low  7
return

CFront:
   high 2
   high 3
   high 4
   high 5
   high 6
   low 7
return

CFrontRight:
   high 2
   high 3
   high 4
   low 5
   low  6
   low  7
return

'********** 01
CBackLeft01:
   low 2
   low 3
   low 4
   high 5
   low 6
   high 7
return

CBack01:
   high 2
   low 3
   low 4
   high 5
   low 6
   high 7
return

CBackRight01:
   high 2
   low 3
   low 4
   low 5
   low 6
   low 7
return

CZTRLeft01:
   high 2
   low 3
   low 4
   high 5
   low 6
   low 7
return

CZTRRight01:
   high 2
   low 3
   high 4
   high 5
   low 6
   high 7
return

CFrontLeft01:
   low 2
   low  3
   low  4
   high 5
   low 6
   low  7
return

CFront01:
   high 2
   low 3
   high 4
   high 5
   low 6
   low 7
return

CFrontRight01:
   high 2
   low 3
   high 4
   low 5
   low  6
   low  7
return

'********** 10
CBackLeft10:
   low 2
   low 3
   low 4
   low 5
   high 6
   high 7
return

CBack10:
   low 2
   high 3
   low 4
   low 5
   high 6
   high 7
return

CBackRight10:
   low 2
   high 3
   low 4
   low 5
   low 6
   low 7
return

CZTRLeft10:
   low 2
   high 3
   low 4
   low 5
   high 6
   low 7
return

CZTRRight10:
   low 2
   high 3
   high 4
   low 5
   high 6
   high 7
return

CFrontLeft10:
   low 2
   low  3
   low  4
   low 5
   high 6
   low  7
return

CFront10:
   low 2
   high 3
   high 4
   low 5
   high 6
   low 7
return
```

```
CFrontRight10:
   low 2
   high 3
   high 4
   low 5
   low  6
   low  7
return
```

5.7. Image Processing Mode

In the image processing mode, the computer grabs an image at the beginning of the loop, processes the image, calculates and decides the states (one out of the seven states possible) of the left and right drive motors, and sends the data out to the parallel port at the end of the loop. It uses seven of the data bits of the parallel port (pin 2 to pin 8)

Data Bit	Command
D0	Left Motor 'A'
D1	Left Motor 'B'
D2	Left Motor 'D'
D3	Right Motor 'A'
D4	Right Motor 'B'
D5	Right Motor 'D'
D6	Set Flag

Table 11. Parallel Port Pin Assignments

In the above table, A, B, and D have the usual meaning as explained earlier.

5.8. Ultrasonic Mode

The AGV is made to go forward and avoid obstacles in this mode of operation. It uses the technology of bats to locate the obstacle in front. A 40 KHz ultrasonic transmitter receiver set is used as the sensor. The transmitter and the receiver were kept in parallel, so that the receiver receives the tone, if an obstacle nearby reflects the tone.

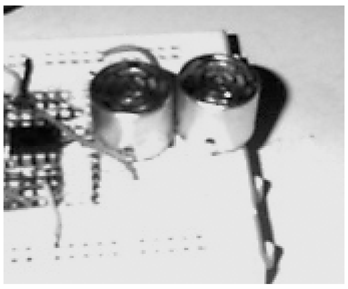


Fig 39. The Ultrasonic Transmitter Receiver Pair Arrangement

5.8.1. Ultrasonic Tone Generation

The transmitter/receiver has the best performance at 40 KHz. Even a drift a 1Khz may prove critical for its operation. A Wien Bridge circuit is used to generate the 40KHz tone.

5.8.2. Signal Conditioning

The transducer used is an active transducer. The received signal has a 3V peak-to-peak voltage when the ultrasonic sound is reflected from a short distance. But the signal lacked power, i.e. the output impedance of the transducer is very high. So an infinite gain amplifier is used to increase the signal current level. It is then fed into a buffer in order to remove the loading effect.

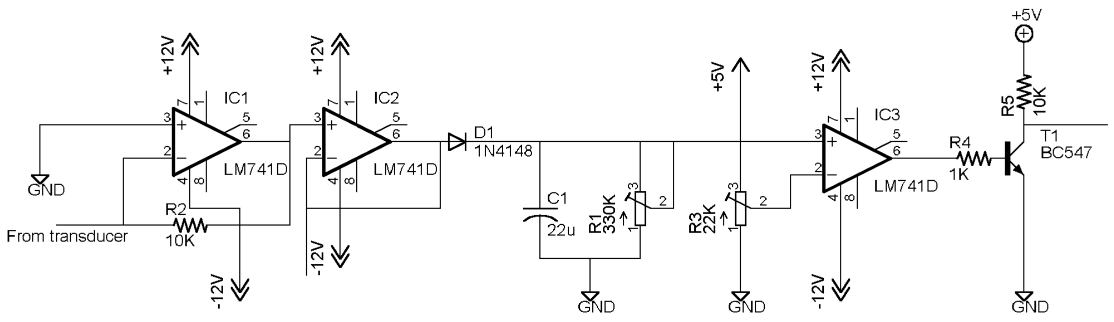


Fig 40. Ultrasonic Receiver Signal Conditioning

If the amplifier stage is not to be used and the output of the transducer is to be directly given to the buffer, the signal will die out due to the low power of the signal, causing zero output.

A signal averager is connected to the output of the buffer. When the output of the buffer exceeds 0.6 volts the capacitor charges instantly through the diode. Then as the output of the buffer goes below 0.6V the capacitor discharges through the pot (R1) set at 100K. Any other value of the resistance can be chosen for the discharging time by varying the pot.

Then the comparator stage compares the output level of the averager circuit.

Thus, if any obstacle comes in front of the vehicle, the receiver receives the signal and the output of the comparator is pulled low. The output of the signal conditioning circuit is +5V when there is no obstacle, and 0V when there is an obstacle. Two such pairs of transmitter and receiver are kept at the left and right of the front of the vehicle. The logic levels are fed to the Stamp, and the Stamp tries to avoid the obstacle by backing in a direction such that the obstacle is avoided. When backing up, the tone generator circuit of the Stamp produces three tones of 500Hz, 400Hz, and 600Hz for 250ms, 500ms, and 1s while stopping, backing up, and turning respectively. The tones alert the user that there is an obstacle in the path. The vehicle then tries again to go forward.

5.9. Emitter Detector Mode

In this mode, the AGV is guided along a black line in a white floor by means of infrared Light Emitting Diodes and photodiodes. Two sets of such IR LED/photodiode are placed at left and right of a PCB with a width of double the line width.

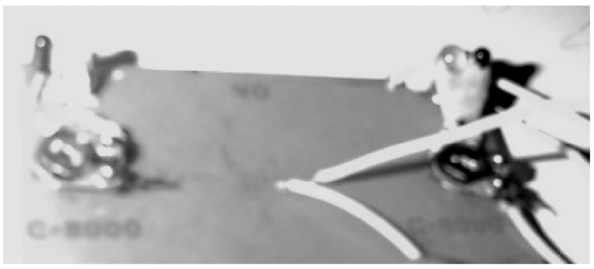


Fig 41. Emitter Detector Sets.

When the vehicle is following a line (a black thick line on a white surface) correctly, due to the arrangement, both the emitter-detector set is above the white surface and thus the photodiode receives the IR light from the IR LED as it gets reflected from the white surface. So the diode starts to conduct causing the output to be equal to the supply voltage.

Now, as the vehicle starts to move away from the line, the emitter-detector set comes above the black surface. Since the surface is black, the photodiode does not conduct. Hence the output drops to zero.

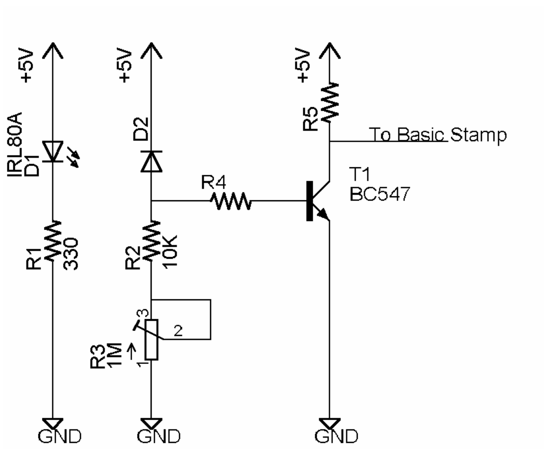


Fig 42. Infrared Emitter Detector Arrangement

This information is fed to the Basic Stamp II, and it decides the correct way of travel.

Note that the photodiode is placed reverse biased. If light falls on the photodiode, the transistor T1 turns on, making the input to the BS-II E/D input pin high.

In this way, a pre-laid line is followed with the help of two emitter-detector sets.

5.10. Wireless Control Mode

In this mode of operation, a remote user can control the vehicle without any wired link. The command for the vehicle is sent by means of asynchronous serial communication between the computer and the Basic Stamp-II. The BSII uses the SERIN command to recognize the serial data. (See Appendix)

5.10.1. Level Shifting

The serial data out of the RS-232C COM Port has +15V -15V voltage levels. These voltage level is changed to an inverted TTL because the AM Transmitter to be used needs TTL levels for its proper operation.

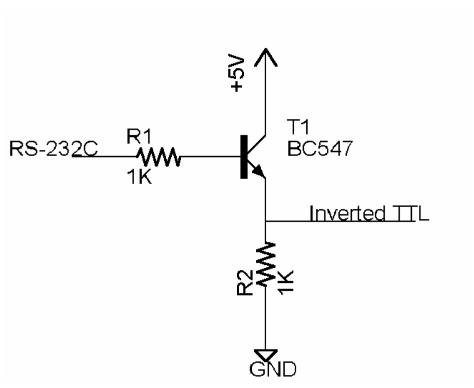


Fig 43. RS-232C to Inverted TTL Level Shifter

5.10.2. AM Transmission and Reception

AM Transmission and Reception were done by means of a ready-made tx/rx set AM-RT4-418 (transmitter) and AM-HRR-418 (receiver). It has a range of 70 meters and it operated at 418 MHz. The input and output to the tx/rx is TTL voltage level.

5.11. Power Supply

The maximum approximate power consumption of the AGV is about 180 watts. This would include 80 watts for the on board computer and the camera, 50 watts for each of the two drive motors. This power should be delivered by two independent 12V 75Ah batteries, one for the two motors, and the other for the computer and the camera. If the batteries are to be kept in parallel, the power supply for the computer would not be regulated.

With this power arrangement, simple calculations reveal that the vehicle would have a running period of more than eight hours with fresh batteries. After that the vehicle should stop doing its assigned job and return back to its base station for recharging of the batteries.

The on board Computer requires power supply either in two forms - AC power when using the Power Supply Unit , or regulated DC voltages of different levels.

Using the Power Supply Unit assembled with the computer, we would require an inverter (DC to AC). A Land Matic® 150 watt DC to AC Inverter is planned to be used. The Land Matic® Inverter would also supply power to the camera's adapter.

A more efficient design of the power supply would be not to use the Power Supply Unit (PSU) of the computer and the AC to DC adapter of the camera. However different levels of regulated DC voltages should be delivered. The different DC levels for the operation of the computer are +12, -12, +5, -5, and Ground. For the video camera, if the SONY HandyCam is to be used, it would require 7.5V DC.

To obtain these regulated DC outputs from the 12V battery, IC Voltage Regulators (like LM317) could be used.

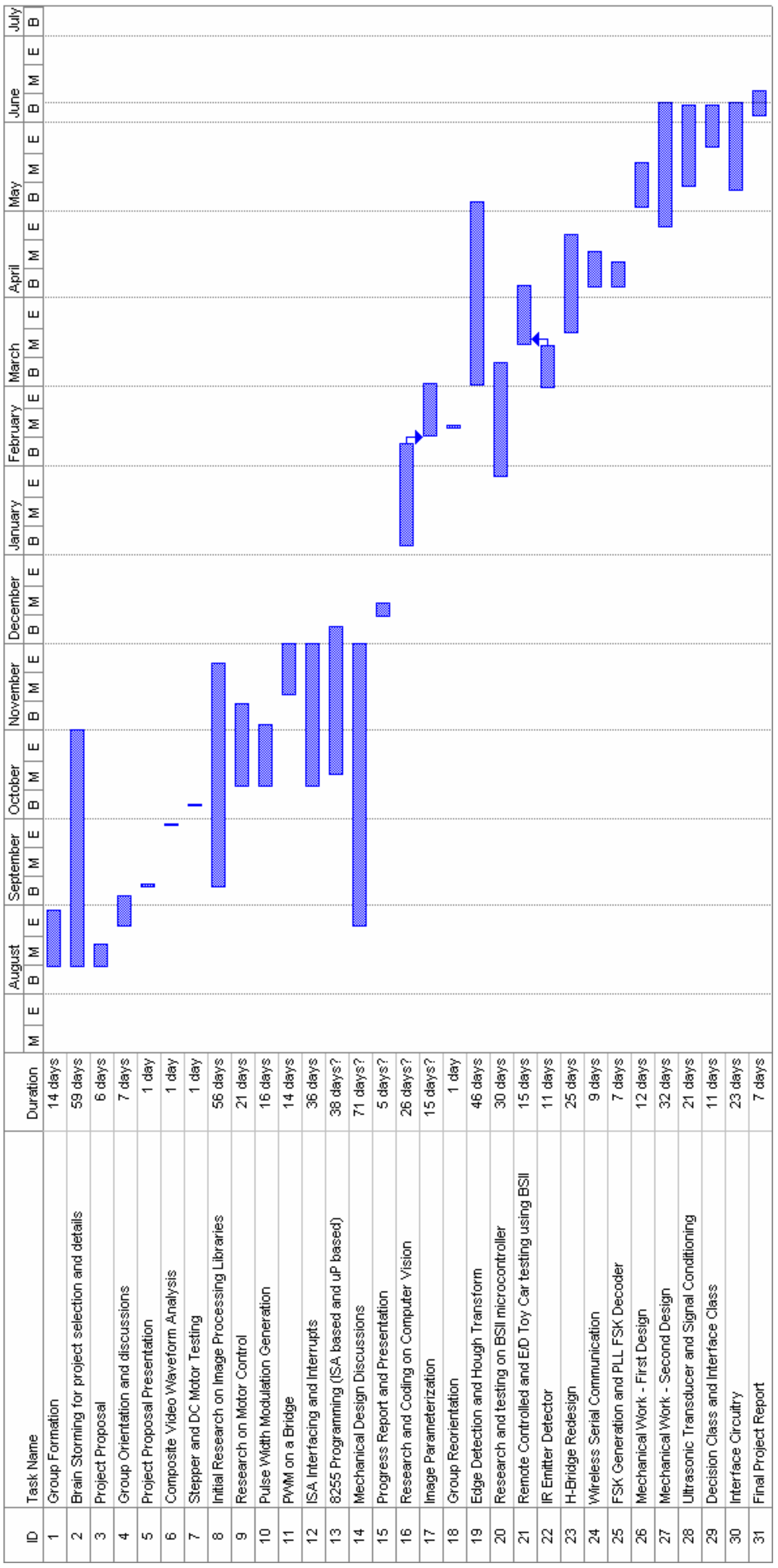
6. The Product

6.1. Introduction

The Final Product of the AGV would be a programmable vehicle that could be assigned for any job. The basic input to the vehicle would be vision to make it autonomous. What the vehicle would do depending upon the input vision depends on how the user would program the vehicle as.

AGVs can have uses in offices, factories, and hospitals to transport medium weight papers, materials and stuff from one place to the other repeatedly, avoiding obstacle, or following a line.

6.2. Gantt chart



ID	Task Name	Duration
1	Group Formation	14 days
2	Brain Storming for project selection and details	59 days
3	Project Proposal	6 days
4	Group Orientation and discussions	7 days
5	Project Proposal Presentation	1 day
6	Composite Video Waveform Analysis	1 day
7	Stepper and DC Motor Testing	1 day
8	Initial Research on Image Processing Libraries	56 days
9	Research on Motor Control	21 days
10	Pulse Width Modulation Generation	16 days
11	PWM on a Bridge	14 days
12	ISA Interfacing and Interrupts	36 days
13	8255 Programming (ISA based and uP based)	38 days?
14	Mechanical Design Discussions	71 days?
15	Progress Report and Presentation	5 days?
16	Research and Coding on Computer Vision	26 days?
17	Image Parameterization	15 days?
18	Group Reorientation	1 day
19	Edge Detection and Hough Transform	46 days
20	Research and testing on BSII microcontroller	30 days
21	Remote Controlled and E/D Toy Car testing using BSII	15 days
22	IR Emitter Detector	11 days
23	H-Bridge Redesign	25 days
24	Wireless Serial Communication	9 days
25	FSK Generation and PLL FSK Decoder	7 days
26	Mechanical Work - First Design	12 days
27	Mechanical Work - Second Design	32 days
28	Ultrasonic Transducer and Signal Conditioning	21 days
29	Decision Class and Interface Class	11 days
30	Interface Circuitry	23 days
31	Final Project Report	7 days

6.3. Conclusion and Recommendation

Doing a combined project as the AGV has made mixed impressions on everyone in the team. It has made us realize the value of team work, and to respect each other's engineering field. Moreover, all of us have been familiarized with each other's engineering fields.

As we are building a programmable robot, AGV is only the first stage. We would highly recommend the continuation of this project for the coming batches using the same base vehicle with new codes and new implementations. This would help build a robotics community in Kathmandu University.

We hope for a successful future of the AGV.

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- A K JAIN, FUNDAMENTALS OF DIGITAL IMAGE PROCESSING, PRENTICE HALL OF INDIA PRIVATE LIMITED, NEW DELHI.

8. Appendix

8.1. Mechanical Drawings:

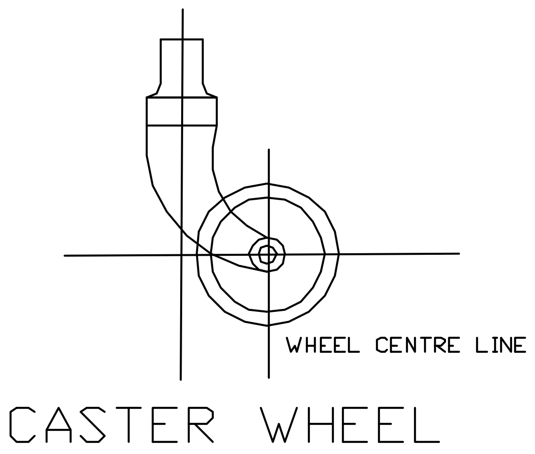

Fig 44. Caster Wheel

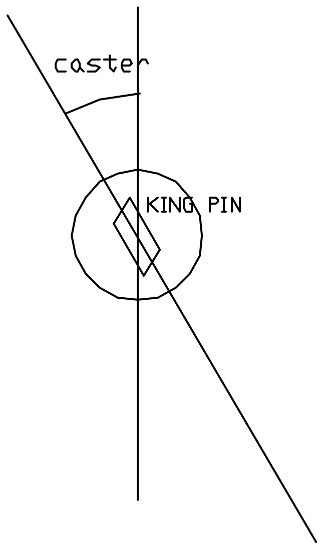

Fig 45. Caster Angle

.

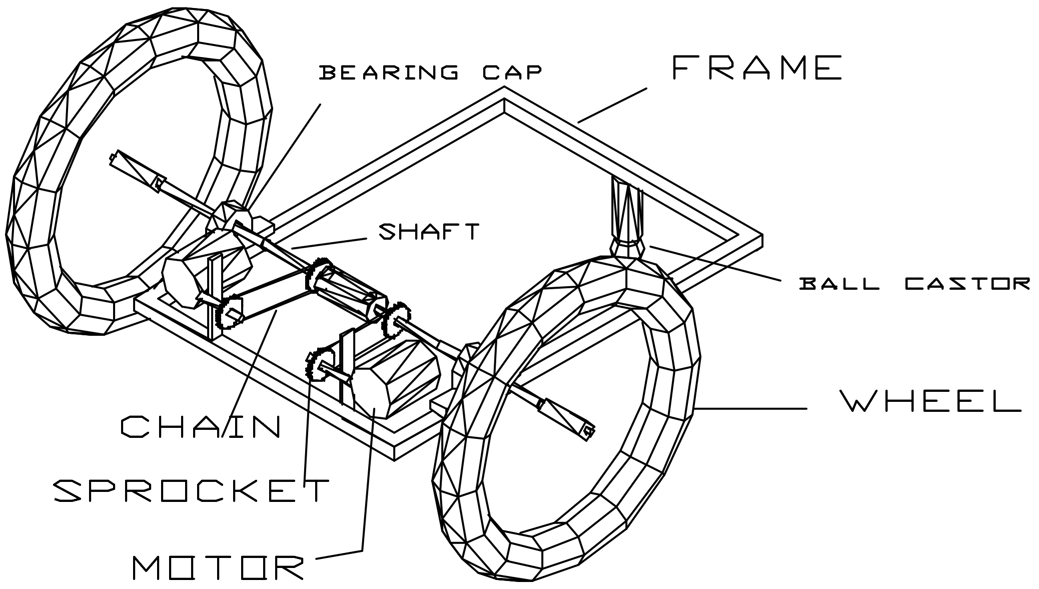

Fig 46. FINAL DESIGN OF THE VEHICLE

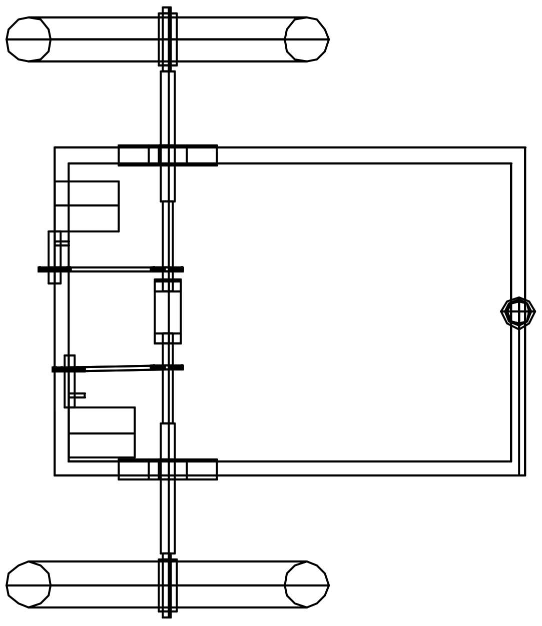

Fig 47. TOP VIEW OF THE VEHICLE

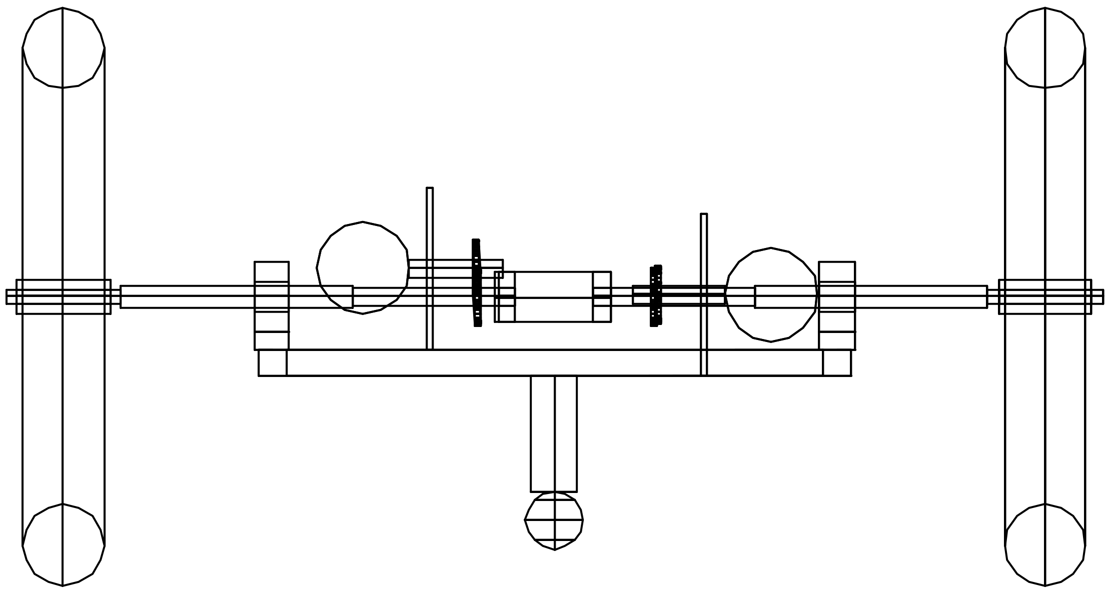

Fig 48. FRONT VIEW OF THE VEHICLE

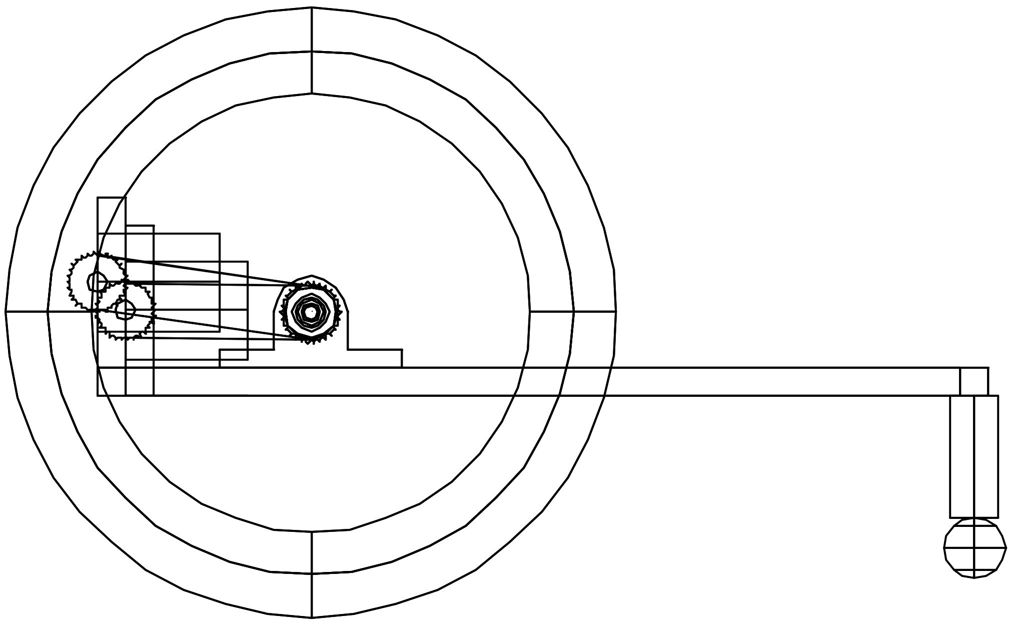

Fig 49. LEFT VIEW OF THE VEHICLE

8.2. Image Processing Code in VC++ using VisionSDK

```
/**
*  Project: Autonomous Guided Vehicle
*  Kathmandu University, Nepal.
*
*/

// Main.cpp: (A Console Program)
//
//////////////////////////////////////////////////////////////////////

#include "Agv.h"

int main()
{
   unsigned long int times=0;
   //Instantiate our AGV Class
   CAgv myAgv;

   //File Name to output debug BMPs
   char *szFile="File";

   /* The Control Loop */
   while(!kbhit())               //this should be infinite
          myAgv.doLoop(2000, szFile, times++); //the main loop is there!

   return 0;
}
```

```
// Agv.h: interface for the CAgv class.
//
//////////////////////////////////////////////////////////////////////

#if !defined(AFX_AGV_H__B3AE4DC9_4AA0_44A7_8CA9_A091E1B5A26E__INCLUDED_)
#define AFX_AGV_H__B3AE4DC9_4AA0_44A7_8CA9_A091E1B5A26E__INCLUDED_

#if _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000

#include <exception>//Exception Handling
#include <stdexcept>//Exception Handling
#include <windows.h>//DWORD in popDelay.
#include <math.h> //all the mathematics
#include <conio.h>       //for printer port access.

/***************************
   Constant Definitions

***************************/
#define PI 3.1415926535
#define LPT1 0x378

/* **************************
    Forward Declarations
   i.e. class prototypes
*****************************/
class CProcess;
class CDecision;
class CInterface;


/********************
   The AGV Class
********************/
class CAgv
{
public:
   CAgv();
   virtual ~CAgv();

   /*
          doLoop is the main control loop element.
   */
   void doLoop(DWORD popDelay, char *szFileName, unsigned long int times);


private:
   CProcess* m_pProcess;
   CDecision* m_pDecision;
   CInterface* m_pInterface;

friend CProcess;  /* CProcess may require access to m_pInterface */
friend CDecision; /* CDecision Requires access to m_pProcess */
friend CInterface; /* CInterface Requires access to m_pDecision */
};

#endif // !defined(AFX_AGV_H__B3AE4DC9_4AA0_44A7_8CA9_A091E1B5A26E__INCLUDED_)
```

```
// Agv.cpp: implementation of the CAgv class.
//
//////////////////////////////////////////////////////////////////////
#include "Process.h"
#include "Decision.h"
#include "Interface.h"

#include "Agv.h"

//////////////////////////////////////////////////////////////////////
// Construction/Destruction
//////////////////////////////////////////////////////////////////////


CAgv::CAgv()
{
   m_pProcess = new CProcess(this);
   m_pDecision = new CDecision(this);
   m_pInterface = new CInterface(this);
}

CAgv::~CAgv()
{
   delete m_pProcess;
   delete m_pDecision;
   delete m_pInterface;
}

void CAgv::doLoop(DWORD popDelay, char *szFileName, unsigned long int times)
{
// char *szFile="";

   m_pProcess->popImage(popDelay);
/*
   sprintf(szFile, "%s CAP %3d.bmp",szFileName,times);
   printf("\nWriting: %s\n",szFile);
   m_pProcess->WriteCapImageToFile(szFile);
*/
   m_pProcess->getSubImage(10); //5% on all sides
   m_pProcess->edgeDetectCapImage(20);
/*
   szFile="";
   sprintf(szFile, "%s EDGE %3d.bmp",szFileName,times);
   printf("\nWriting: %s\n",szFile);
   m_pProcess->WriteEdgeImageToFile(szFile);
*/
   m_pProcess->HoughTransformCapImage();
/*
   szFile="";
   sprintf(szFile, "%s HOUGH %3d.bmp",szFileName,times);
   printf("\nWriting: %s\n",szFile);
   m_pProcess->WriteHoughImageToFile(szFile);
*/
   m_pProcess->setLineDescriptor(m_pProcess->getEdgeImageHeight()/2+5);
   //fill the lineDescriptor variable.

   //argument=Hough Threshold
   //just checking
/* for(int n=0; n<m_pProcess->getNumberOfLines(); n++)
          printf("Line:%d \t Radius:%d \t Angle:%d \n",
                                                       n,
                                                       m_pProcess->line[n].r,
                                                       m_pProcess-
>line[n].theta);  //line should be protected?
*/
   m_pDecision->decideNext();
   m_pInterface->sendData();

// printf("\n %X sent to LPT1\n", m_pInterface->getDataOut());
```

```
   if (m_pInterface->getDataOut()==64)
           printf("\n%d. STOP\n\n", times);
   if (m_pInterface->getDataOut()==71)
           printf("\n%d. RIGHT\n\n",times);
   if (m_pInterface->getDataOut()==95)
           printf("\n%d. STRAIGHT\n\n",times);
   if (m_pInterface->getDataOut()==88)
           printf("\n%d. LEFT\n\n", times);
}
```

```
// Decision.h: interface for the CDecision class.
//
//////////////////////////////////////////////////////////////////////

#if !defined(AFX_DECISION_H__B71845A0_FA57_4A90_86DA_9C59D475C519__INCLUDED_)
#define AFX_DECISION_H__B71845A0_FA57_4A90_86DA_9C59D475C519__INCLUDED_

#if _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000

class CAgv; //Forward Declaration

enum motorState {OFF, CW, CCW}; //PWM states should be added later
                                                       //     for fine control


/*
LINE_LEFT =              //
                   //
                   ||
                   ||


LINE_RIGHT =  \\
                    \\
                     ||
                     ||
*/
//enum typeOfLine {NO_LINE, SINGLE_LINE, LINE_LEFT, LINE_RIGHT};

class CDecision
{
public:
   CDecision(CAgv *pAgv);
   virtual ~CDecision();

// void classifyLine();

   void decideNext();

   motorState getRightMotorState();
   motorState getLeftMotorState();

private:
   CAgv* m_pAgv; //so that Decision Objects can access Agv Object

// typeOfLine lineType;

   motorState leftMotorState, rightMotorState;
   double radius;
   double theta;

};

#endif //
!defined(AFX_DECISION_H__B71845A0_FA57_4A90_86DA_9C59D475C519__INCLUDED_)
```

```
// Decision.cpp: implementation of the CDecision class.
//
//////////////////////////////////////////////////////////////////////

#include "Process.h"
#include "Decision.h"
#include "Interface.h"
#include "Agv.h"

//////////////////////////////////////////////////////////////////////
// Construction/Destruction
//////////////////////////////////////////////////////////////////////

CDecision::CDecision(CAgv *pAgv):m_pAgv(pAgv) //initilazation list
{
   leftMotorState=OFF;
   rightMotorState=OFF;
   radius=0;
   theta=0;
}

CDecision::~CDecision()
{

}

void CDecision::decideNext()
{
   int image_width=m_pAgv->m_pProcess->getEdgeImageWidth();

   if (!m_pAgv->m_pProcess->getNumberOfLines())
   {
          leftMotorState=OFF;
          rightMotorState=OFF;
          return;
   }

   for(int n=0; n<m_pAgv->m_pProcess->getNumberOfLines(); n++)
   {
          radius+=m_pAgv->m_pProcess->line[n].r;
          theta+=m_pAgv->m_pProcess->line[n].theta;
   }
   radius/=m_pAgv->m_pProcess->getNumberOfLines(); //average them
   theta/=m_pAgv->m_pProcess->getNumberOfLines();

   if (theta>5 && theta<=90)
   {
          //Move Right
          leftMotorState=CCW;
          rightMotorState=OFF;
   }

   if (theta>90 && theta<355)
   {
          //Move Left
          leftMotorState=OFF;
          rightMotorState=CW;
   }

   if (theta<=5 || theta>=355)
   {
          if ( radius> image_width/2 + 0.15*image_width )
          {
                 //Move Right
                 leftMotorState=CCW;
                 rightMotorState=OFF;
          }
          else if ( radius< image_width/2 - 0.15*image_width )
          {
                 //Move Left
```

```
                    leftMotorState=OFF;
                    rightMotorState=CW;
            }
            else
            {
                    //Move Straight
                    leftMotorState=CCW;
                    rightMotorState=CW;
            }
    }


}

motorState CDecision::getLeftMotorState()
{
    return leftMotorState;
}

motorState CDecision::getRightMotorState()
{
    return rightMotorState;
}

/*void CDecision::classifyLine()
{
    lineType=SINGLE_LINE;
    /* Add more later*/
//}*/
```

```
// Interface.h: interface for the CInterface class.
//
//////////////////////////////////////////////////////////////////////

#if !defined(AFX_INTERFACE_H__21A4DDF9_66FD_445C_BFB8_78CACDDCFD40__INCLUDED_)
#define AFX_INTERFACE_H__21A4DDF9_66FD_445C_BFB8_78CACDDCFD40__INCLUDED_

#if _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000

class CAgv; //Forward Declaration

class CInterface
{
public:
   CInterface(CAgv *pAgv);
   virtual ~CInterface();

   void sendData();//To LPT Port
   int getDataOut();//To display in console

private:
   CAgv* m_pAgv; //so that Decision Objects can access Agv Object
   unsigned char dataOut;//8 bit - 0 to 255
};

#endif //
!defined(AFX_INTERFACE_H__21A4DDF9_66FD_445C_BFB8_78CACDDCFD40__INCLUDED_)
```

```
// Interface.cpp: implementation of the CInterface class.
//
//////////////////////////////////////////////////////////////////////

#include "Process.h"
#include "Decision.h"
#include "Interface.h"
#include "Agv.h"

//////////////////////////////////////////////////////////////////////
// Construction/Destruction
//////////////////////////////////////////////////////////////////////

CInterface::CInterface(CAgv *pAgv):m_pAgv(pAgv) //initilazation list
{
   dataOut=0x00;
}

CInterface::~CInterface()
{

}

/**
*  Assuming D2D3 is for Left motor and D1D0 is for Right Motor
*  00 = stop; 01=CW; 10=CCW; 11=NEVER DO THIS.
*/
void CInterface::sendData()
{
   switch(m_pAgv->m_pDecision->getLeftMotorState()){

   case OFF:
          dataOut = 0x00;        //00 xxx 000
          break;
   case CW:
          dataOut = 0x03;        //00 xxx 011
          break;

   case CCW:
          dataOut = 0x07;        //00 xxx 111
          break;
   default:
          dataOut = 0x00;        //00 xxx 000
          break;
   }

   switch(m_pAgv->m_pDecision->getRightMotorState()){

   case OFF:
          dataOut |= 0x00;       //00 000 xxx
          break;
   case CW:
          dataOut |= 0x18;       //000 011 xxx
          break;

   case CCW:
          dataOut |= 0x38;    //00 111 xxx
          break;
   default:
          dataOut |= 0x00;       //00 000 xxx
          break;
   }

   _outp(LPT1,dataOut);

   /* Clock at D6 -Positive Edge- */
   dataOut |= 0x40;                              //01 XXX XXX

// for (int delayTime=400; delayTime>5; delayTime--)
//        printf("S");
```

```
   _outp(LPT1,dataOut);
}

int CInterface::getDataOut()
{
   return (int) dataOut;
}
```

```
// Vision.h: interface for the CVision class.
//
//////////////////////////////////////////////////////////////////////

#if !defined(AFX_VISION_H__42BC1143_4816_4E52_996A_21E9CDAC9DF2__INCLUDED_)
#define AFX_VISION_H__42BC1143_4816_4E52_996A_21E9CDAC9DF2__INCLUDED_

#if _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000

#include <windows.h>
#include <VisImSrc.h>    //The MS-VisionSDK Library

/**
   CVision deals with video capture and writing images to disk.
   CVision is independent of CAgv
*/
class CVision
{
public:
   int getEdgeImageHeight();
   int getEdgeImageWidth();
   CVision();
   virtual ~CVision();

   void popImage(DWORD delay);

   void getSubImage(double percentage);
   void WriteCapImageToFile(char* szFileName);
   void WriteSubImageToFile(char* szFileName);
   void WriteEdgeImageToFile(char *szFileName);
   void WriteHoughImageToFile(char *szFileName);

protected:
   CVisGrayByteImage m_capImage;
   CVisGrayByteImage m_subImage;
   CVisGrayByteImage m_edgeImage;
   CVisGrayByteImage m_HoughImage;

private:
   CVisImageSource imgsrc;
   CVisSequence<CVisGrayBytePixel> sequence;
};

#endif // !defined(AFX_VISION_H__42BC1143_4816_4E52_996A_21E9CDAC9DF2__INCLUDED_)
```

```
// Vision.cpp: implementation of the CVision class.
//
//////////////////////////////////////////////////////////////////////

#include "Vision.h"
#include <exception>
#include <stdexcept>

//////////////////////////////////////////////////////////////////////
// Construction/Destruction
//////////////////////////////////////////////////////////////////////

CVision::CVision()  //initialization list
{
   imgsrc = VisFindImageSource("");
   if (imgsrc.IsValid())
          sequence.ConnectToSource(imgsrc, true, false);
   else
          throw("Exception - CVision::CVision(CAgv p*Agv) - Image Source not
Valid");
}

CVision::~CVision()
{
   sequence.DisconnectFromSource();
}

void CVision::popImage(DWORD delay)
{
          if(!sequence.Pop(m_capImage, delay))
          {
            sequence.DisconnectFromSource();
            throw("Exception - CVision::Popimage()");
          }
}

void CVision::getSubImage(double percentage)
{
   int wOffset=floor(percentage*m_capImage.Right()/100);
   int hOffset=floor(0.1*m_capImage.Bottom());

   m_subImage=m_capImage.SubImage(m_capImage.Left() + wOffset/2,
                                                          m_capImage.Top()  +
hOffset/2,
                                                          m_capImage.Right()-
wOffset/2,
                                                          m_capImage.Bottom()-
hOffset/2);
   m_subImage.ResetOrigin(0,0);
}

void CVision::WriteCapImageToFile(char *szFileName)
{
   try{
          m_capImage.FWriteFile(szFileName);
   }
   catch(exception e){
          printf(e.what());
   }
}

void CVision::WriteSubImageToFile(char *szFileName)
{
   try{
          m_subImage.FWriteFile(szFileName);
   }
   catch(exception e){
          printf(e.what());
   }
}
```

```
void CVision::WriteEdgeImageToFile(char *szFileName)
{
   try{
           m_edgeImage.FWriteFile(szFileName);
   }
   catch(exception e){
           printf(e.what());
   }
}

void CVision::WriteHoughImageToFile(char *szFileName)
{
   try{
           m_HoughImage.FWriteFile(szFileName);
   }
   catch(exception e){
           printf(e.what());
   }
}



int CVision::getEdgeImageWidth()
{
   return (m_edgeImage.Right()-m_edgeImage.Left());
}

int CVision::getEdgeImageHeight()
{
   return (m_edgeImage.Bottom()-m_edgeImage.Top());
}
```

```
// Process.h: interface for the CProcess class.
//
//////////////////////////////////////////////////////////////////////

#if !defined(AFX_PROCESS_H__CA3F39C4_BF70_42AE_867A_EBC1C308F536__INCLUDED_)
#define AFX_PROCESS_H__CA3F39C4_BF70_42AE_867A_EBC1C308F536__INCLUDED_

#if _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000

#include "Vision.h"
#include "Agv.h"

//class CAgv;  agv.h is already included.

class CProcess  : public CVision
{
public:

   CProcess(CAgv *pAgv);
   virtual ~CProcess();

   void edgeDetectCapImage(int gradientThValue);
   void HoughTransformCapImage();

   struct lineDescriptor{
          int theta;
          int r;
   }line[40];     //line whould be protected. But how to get line?

   void setLineDescriptor(int HoughThresh);
   int getNumberOfLines();

private:
   CAgv* m_pAgv; //To access the AGV Object
   int numberOfLines;
};

#endif //
!defined(AFX_PROCESS_H__CA3F39C4_BF70_42AE_867A_EBC1C308F536__INCLUDED_)
```

```
// Process.cpp: implementation of the CProcess class.
//
//////////////////////////////////////////////////////////////////////

#include "Process.h"
#include "Decision.h"
#include "Interface.h"

//////////////////////////////////////////////////////////////////////
// Construction/Destruction
//////////////////////////////////////////////////////////////////////

CProcess::CProcess(CAgv *pAgv):CVision()
{
   m_pAgv=pAgv;
}

CProcess::~CProcess()
{
}

void CProcess::edgeDetectCapImage(int gradientThValue)
{
   double gradientX, gradientY, gradient;
   int j,k;
/* // SOBEL
   int maskX[3][3]={1, 2, 1, 0, 0, 0, -1, -2, -1};
   int maskY[3][3]={1, 0, -1, 2, 0, -2, 1, 0, -1};
*/
   // ROBERTS
   int maskX[2][2]={-1, -1, 1, 1};
   int maskY[2][2]={-1, 1, -1, 1};


   m_edgeImage=m_subImage;

   for(k=m_subImage.Top()+1; k<m_subImage.Bottom()-1; k++)
           for(j=m_subImage.Left()+1;j<m_subImage.Right()-1; j++)
           {
/*                 //SOBEL
                   gradientX=
                                   maskX[0][0]*m_subImage.Pixel(j-1,k-1) +
                                   maskX[0][1]*m_subImage.Pixel(j-1,k) +
                                   maskX[0][2]*m_subImage.Pixel(j-1,k+1) +
                                   maskX[1][0]*m_subImage.Pixel(j,k-1) +
                                   maskX[1][1]*m_subImage.Pixel(j,k) +
                                   maskX[1][2]*m_subImage.Pixel(j,k+1) +
                                   maskX[2][0]*m_subImage.Pixel(j+1,k-1) +
                                   maskX[2][1]*m_subImage.Pixel(j+1,k) +
                                   maskX[2][2]*m_subImage.Pixel(j+1,k+1) ;

                   gradientY=
                                   maskY[0][0]*m_subImage.Pixel(j-1,k-1) +
                                   maskY[0][1]*m_subImage.Pixel(j-1,k) +
                                   maskY[0][2]*m_subImage.Pixel(j-1,k+1) +
                                   maskY[1][0]*m_subImage.Pixel(j,k-1) +
                                   maskY[1][1]*m_subImage.Pixel(j,k) +
                                   maskY[1][2]*m_subImage.Pixel(j,k+1) +
                                   maskY[2][0]*m_subImage.Pixel(j+1,k-1) +
                                   maskY[2][1]*m_subImage.Pixel(j+1,k) +
                                   maskY[2][2]*m_subImage.Pixel(j+1,k+1) ;
*/
                   //Roberts
                   gradientX=
                                   maskX[0][0]*m_subImage.Pixel(j,k) +
                                   maskX[0][1]*m_subImage.Pixel(j,k+1) +
                                   maskX[1][0]*m_subImage.Pixel(j+1,k) +
                                   maskX[1][1]*m_subImage.Pixel(j+1,k+1);

                   gradientY=
                        maskY[0][0]*m_subImage.Pixel(j,k) +
                        maskY[0][1]*m_subImage.Pixel(j,k+1) +
                        maskY[1][0]*m_subImage.Pixel(j+1,k) +
                        maskY[1][1]*m_subImage.Pixel(j+1,k+1);

                gradient=pow(pow(gradientX/2,2)+pow(gradientY/2,2),0.5);
                if (gradient>gradientThValue)
                        m_edgeImage.Pixel(j,k)=255;
                else
                        m_edgeImage.Pixel(j,k)=0;

        }

   for(j=m_subImage.Left();j<m_subImage.Right(); j++)   //Fill the bottom border
black
   {
        m_edgeImage.Pixel(j,m_subImage.Top())=0;
        m_edgeImage.Pixel(j,m_subImage.Bottom()-1)=0;
   }

   for(k=m_subImage.Top();k<m_subImage.Bottom(); k++)   //Fill the right border
black
   {
        m_edgeImage.Pixel(m_subImage.Left(),k)=0;
        m_edgeImage.Pixel(m_subImage.Right()-1,k)=0;
   }
}

void CProcess::HoughTransformCapImage()
{
   double theta_for_maxR=atan2(m_edgeImage.Bottom(),m_edgeImage.Right());
   double max_HT_Rad=m_edgeImage.Right()*cos(theta_for_maxR*PI/180)
                                                  +
m_edgeImage.Bottom()*sin(theta_for_maxR*PI/180);
   CVisGrayByteImage HT(2*max_HT_Rad,360);      //twice to cover the negative
regions too
   int theta, i, j;
   float rad;
   int round_rad;
   for(i=m_edgeImage.Top(); i<m_edgeImage.Bottom(); i++)
        for(j=m_edgeImage.Left();j<m_edgeImage.Right(); j++)
                if(m_edgeImage.Pixel(j,i)>0)
                {
                        for(theta=0;theta<360;theta++)
                        {
                                rad=j*cos(theta*PI/180) + i*sin(theta*PI/180);
                                round_rad=ceil(rad)+max_HT_Rad;//position r as an
index to array
                                HT.Pixel(round_rad, theta)+=1; //increase the
accumulator
                        }
                }
   m_HoughImage=HT;
}

void CProcess::setLineDescriptor(int HoughThresh)
{
   int i,j;
   double theta_for_maxR=atan2(m_edgeImage.Bottom(),m_edgeImage.Right());//from
dr/d(theta)=0
   double max_HT_Rad=m_edgeImage.Right()*cos(theta_for_maxR*PI/180)
                                                  +
m_edgeImage.Bottom()*sin(theta_for_maxR*PI/180);
   numberOfLines=0;
   for(i=m_HoughImage.Top(); i<m_HoughImage.Bottom(); i++)
        for(j=m_HoughImage.Left();j<m_HoughImage.Right(); j++)
                if(numberOfLines<40)
                        if(m_HoughImage.Pixel(j,i)>=HoughThresh)
                                if(j>=max_HT_Rad) //taking for posisitve R only,
ignore the mirrors
```

```
                                    {
                                            line[numberOfLines].r=j - max_HT_Rad;
   //reposition r
                                            line[numberOfLines++].theta=i;
                                    }

   int temp_no_of_lines=numberOfLines;
   for(int k=0; k<temp_no_of_lines;k++)
   {

   }
}


int CProcess::getNumberOfLines()
{
   return numberOfLines;
}
```

8.3. Wireless Serial Communication for Remote Control Code in VB

```
Private Sub Form_Load()
    If MSComm1.PortOpen = False Then MSComm1.PortOpen = True
End Sub

Private Sub Form_Unload(Cancel As Integer)
    If MSComm1.PortOpen = True Then MSComm1.PortOpen = False
End Sub

Private Sub Form_KeyDown(KeyCode As Integer, Shift As Integer)

    Select Case KeyCode

    'KEYPAD (123456789)- Full Speed (11)
        Case 35:        'BackLeft 11
            botMove (192 + 1)
        Case 40:        'Back 11
            botMove (192 + 2)
        Case 34:        'BackRight 11
            botMove (192 + 3)
        Case 37:        'ZTRLeft 11
            botMove (192 + 4)
        Case 12:        'Stop 11
            botMove (192 + 5)
        Case 39:        'ZTRRight 11
            botMove (192 + 6)
        Case 36:        'FrontLeft 11
            botMove (192 + 7)
        Case 38:        'Front 11
            botMove (192 + 8)
        Case 33:        'Front 11
            botMove (192 + 9)

    ',./l;'p[] - 85% Speed (10)
        Case 188:        'BackLeft 11
            botMove (192 + 1)
        Case 190:        'Back 11
            botMove (192 + 2)
        Case 191:        'BackRight 11
            botMove (192 + 3)
        Case 76:        'ZTRLeft 11
            botMove (192 + 4)
        Case 186:        'Stop 11
            botMove (192 + 5)
        Case 222:        'ZTRRight 11
            botMove (192 + 6)
        Case 80:        'FrontLeft 11
            botMove (192 + 7)
        Case 219:        'Front 11
            botMove (192 + 8)
        Case 221:        'Front 11
            botMove (192 + 9)

    'zxcasdqwe - 75% Speed (01)
        Case 90:        'BackLeft 11
            botMove (64 + 1)
        Case 88:        'Back 11
            botMove (64 + 2)
        Case 67:        'BackRight 11
            botMove (64 + 3)
        Case 65:        'ZTRLeft 11
            botMove (64 + 4)
        Case 83:        'Stop 11
            botMove (64 + 5)
        Case 68:        'ZTRRight 11
            botMove (64 + 6)
        Case 81:        'FrontLeft 11
```

```
            botMove (64 + 7)
        Case 87:        'Front 11
            botMove (64 + 8)
        Case 69:        'Front 11
            botMove (64 + 9)

    End Select

End Sub
Private Sub botMove(moveCode As Integer)
    MSComm1.Output = Str(moveCode) & "!"
End Sub
```