Design, Improvement, Modification & Fabrication of Mechanisms and Control Systems of Robots for ABU ROBOCON

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Abstract

Bangladesh is a developing country. The industries in this country are not well organized and thus far from using robots in the production lines. Nonetheless there are a wide number of areas where robots are used. For this reason the scarcity of necessary equipments to build is severe in our country. Overcoming these restrictions robotics projects is done. In this project, some special purpose robots were built to compete in the Robocon 2008. The concept of mechanical engineering, electronic control and system thinking in the design and fabrication of automatic robots was combined and coordinated. These automated machines could pick some objects carry through a predefined path and place them in desired location. All these tasks have pragmatic applications on the industry in common repetitive works. As these robots were made for an International competition so main intention (purpose) was precision and reliability rather than implementing innovative and cutting-edge ideas. The mechanical structure of all the robots was mainly made of aluminum. Steel was used in some places for structural strength and rigidity. Most of the motors were dc gear motors. The latest available advanced control mechanism incorporating microcontrollers, PWM, timers, counters, interrupts is used in this project. Apart from the robots for competition an additional experimental robot was fabricated to implement some new mechanical design concepts.

Although the main purpose of the project was to manufacture robots for an international competition there were researches going to improve the robots continuously. It could be expect that in near future Bangladesh would among those countries manufacturing world standard robots. It could be said that the design and fabrication of these robots are utilization appropriate technology and an indication of the countries success in the Robotics.

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FOREWORD

Asia-Pacific Broadcasting Unit (ABU) each year arranges robot competitions in the Asia region under the name ABU ROBOCON. The goal of this competition is to increase the creativity and thus improve the skills to design and manufacturing of robots in this region. Participating in this competition has provided the scope of getting familiar with technology, cultures and exchange ideas among the students in this region. This competition has also increased the enthusiasm and eagerness of the students to take part in competitions.

Last year the competition was organized in India. The contest theme is based on Indian mythology related to Lord Krishna (a Hindu deity) and the festival of Dahi-Handi, celebrated annually in northern part of India. Born as a prince and brought up into a cowherd family, **Krishna** is often referred to as "**Govinda**".

As a children, **Govinda** and his friends used to raid kitchens in search of milk, butter (Makhkhan) and cheese (Paneer). They also used to tease young girls (Gopis) carrying pots (Matka) filled with water, milk, butter, or cheese on their heads. A common practice in rural India is to suspend these pots (containing Cheese, Butter and Milk) from beams high in the ceiling out of reach of cats.

During the day when the men were busy in the fields and the women folk busy with outdoor chores, the naughty and adventurous **Govinda** along with his band of friends would form a human pyramid to reach these pots and help themselves to the contents.

The robots for this contest can be termed to as special purpose robots as those were to be made to carry out some well defined jobs inside a certain place for which definite layout of the place was supplied. For ensuring the proper working of the robots and to understand their working efficiency, a game field was needed inside or around the lab but unfortunately it was a very costly project to build such a game field. So, as the need for such a place was quite remarkable, some individual components of the game field such as the mat of the floor, a portion of the tower etc were built.

The practice sessions were carried out on this mock field. All the robots were built using the raw materials available in the local market. A severe lacking of proper motors needed for the definite jobs was faced. It was impossible to find a motor with the necessary specifications even at a higher price. So, the motors were chosen at first from the second hand motor shop and then design the machines accordingly. The sensors were also made using own resources as they were not available, too.

So, under such consequences, building such high-tech machines in this country to compete with the other much developed country’s robots was dependent on the available appropriate technology to a great extent. It was a tough job indeed but it helped to realize the real situation of the technology in Bangladesh which must be improved for the overall development of this country.

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Chapter 1 Robots

A robot is a virtual or mechanical artificial agent. In practice, it is usually an electro-mechanical system which, by its appearance or movements, conveys a sense that it has intent or agency of its own. The word robot can refer to both physical robots and virtual software agents, but the latter are usually referred to as bots. There is no consensus on which machines qualify as robots, but there is general agreement among experts and the public that robots tend to do some or all of the following: move around, operate a mechanical limb, sense and manipulate their environment, and exhibit intelligent behavior, especially behavior which mimics humans or other animals.

1.1 Robots Characteristics

While there is no single correct definition of "Robot", a typical robot will have several or possibly all of the following properties.

- It is artificially created.
- It can sense its environment, and manipulate or interact with things in it.
- It has some ability to make choices based on the environment, often using automatic control or a preprogrammed sequence.
- It is programmable.
- It moves with one or more axes of rotation or translation.
- It makes dexterous coordinated movements.
- It moves without direct human intervention.
- It appears to have intent or agency.

The last property, the appearance of agency, is important when people are considering whether to call a machine a robot, or just a machine

For robotic engineers, the physical appearance of a machine is less important than the way its actions are controlled. The more the control system seems to have agency of its own, the more likely the machine is to be called a robot. An important feature of agency is the ability to make choices.

- A clockwork machine is never considered a robot.
- A remotely operated vehicle is sometimes considered a robot (or telerobot). The manual machine manufactured could also be called as telerobot.
- A machine with an onboard computer, which could drive in a programmable sequence, might be called a robot.
- A self-controlled machine which could sense its environment and make driving decisions based on this information would quite likely be called a robot.
- A sentient machine which can make decisions, navigate freely and converse fluently with a human is usually considered a robot.

1.2 *Laws of Robotics*

Over the years man has dreamed a machine similar to human beings. Many stories, dramas, science fictions has been written and read. Among them Isaac Asimov has gone so far that he addressed for three rules for a machine to be named as robot. Three Laws of Robotics are a set of three rules which are as follows:

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

- A robot must obey orders given to it by human beings, except where such orders would conflict with the First Law.

- A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Although all the characteristics and rules mentioned above doesn't comply with the robots manufactured there are significant characteristics and developed AI (artificial intelligence) which could lead to call those as robots.

1.3 *Degrees of Freedom*

This term degrees of freedom or DOF is widely used to describe the motions in a robot. The robots have to locate some points or locations in space in real world. The ways according to which a robot can locate or reach at a point could be named as the degrees of freedoms of a robot. The mechanical parts of a robot usually are incorporated with this term. In mechanics, degrees of freedom (DOF) are the set of independent displacements and/or rotations that specify completely the displaced or deformed position and orientation of the body or system. This is a fundamental concept relating to systems of moving bodies in mechanical engineering and robotics.

A particle that moves in three dimensional spaces has three translational displacement components as DOFs, while a rigid body would have at most six DOFs including three rotations. A system with several bodies would have a combined DOF that is the sum of the DOFs of the bodies, less the internal constraints they may have on relative motion. A mechanism or linkage containing a number of connected rigid bodies may have more than the degrees of freedom for a single rigid body. Here the term degrees of freedom are used to describe the number of parameters needed to specify the spatial pose of a linkage.

The number of DOF that a manipulator possesses is the number of independent position variables that would have to be specified in order to locate all parts of the mechanism. In other words, it refers to the number of different ways in which a robot arm can move. In the case of typical industrial robots, because a manipulator is usually an open kinematic chain, and because each joint position is usually defined with a single variable, the number of joints equals the number of degrees of freedom.

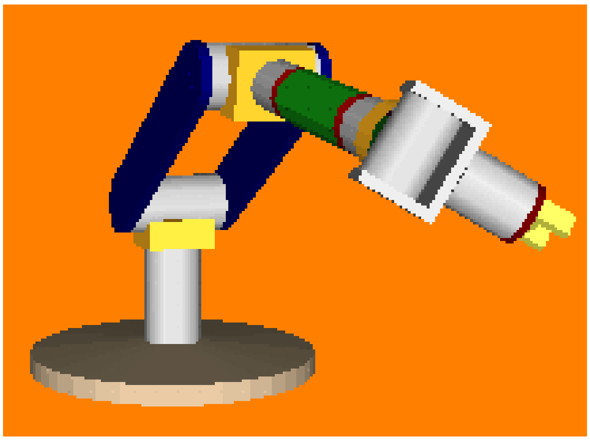


Figure 1-1 Seven Degrees of freedom

A specific type of linkage is the open kinematic chain, where a set of rigid links are connected at joints; a joint may provide one DOF (hinge/sliding), or two (cylindrical). Such chains occur commonly in robotics, biomechanics and for satellites and other space structures. A human arm is considered to have seven DOFs. A shoulder gives pitch, yaw and roll, an elbow allows for pitch, and a wrist allows for pitch, yaw and roll. Only 3 of those movements would be necessary to move the hand to any point in space, but people would lack the ability to grasp things from different angles or directions. A robot (or object) that has mechanisms to control all 6 physical DOF is said to be holonomic. An object with fewer controllable DOF than total DOF is said to be non-holonomic, and an object with more controllable DOF than total DOF (such as the human arm) is said to be redundant.

In mobile robotics, robot can reach any position and orientation in 2-D space, so it needs 3 DOFs to describe its pose, but at any point, it can move only by a forward motion and a steering angle. So it has two control DOFs and three representational DOFs - i.e. it is non-holonomic.

In three dimensions, the six DOFs of a rigid body are sometimes described using these nautical names:

- Moving up and down (heaving also named elevation);
- Moving left and right (swaying also named reach);
- Moving forward and backward (surging also named as base travel);
- Tilting forward and backward (pitching);
- Turning left and right (yawing);
- Tilting side to side (rolling).

Chapter 2 Mechanical Systems

Among the several important systems that could be employed to manufacture a robot Mechanical systems handles the structures, motion designing etc. A mobile robot requires movement and orientation in several directions. Along with this it also requires some gripping actions. These are the concerns of the Mechanical Systems. In the next few paragraphs involvements of mechanical engineering would be described.

2.1 Gripping System

The robots took part in the contest like ABU ROBOCON always has to handle some object of several shapes. For this purpose several types of gripper is used. Grippers that are commonly used in the manufacturing of the robots could be broadly classified as follows:

- String Pulley Gripper
- Gear operated Gripper
- Mechanical Link Gripper

2.1.1 String Pulley gripper:

In this type of gripper system channel stock of desired length is chosen and they are supported by bearing at a point. On the bearing support the channel stock can rotate freely. At one end of the channel stock it is spring loaded which provides necessary gripping forces and prevents the objects from slipping down from the grip

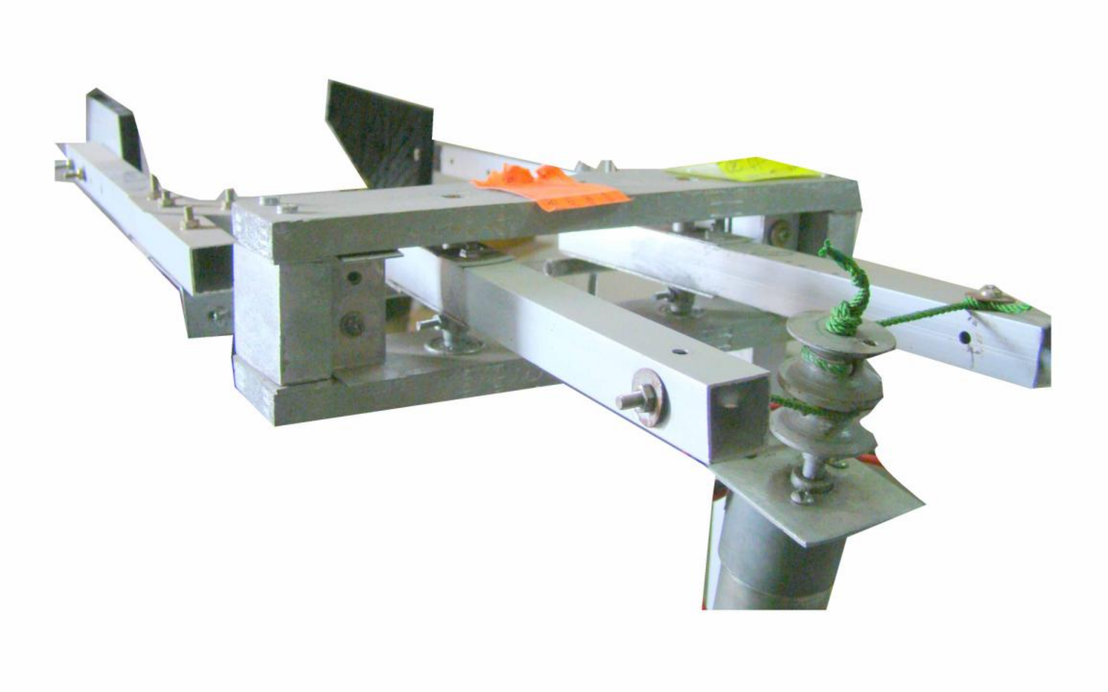


Figure 2-1 Gripper Mechanism of String Pulley System

of the robot. On the other end motor is equipped to drive the gripper system. The distance of the motor from the sliding axis was calculated such that the moment due to motor weight about sliding axis overbalances the moment caused by the gripping arm weight and the weight of the object which should be picked. The motor is coupled with a two slot pulley where two set of string can wind simultaneously. The strings are connected to the end of the channel stock. So while the motor is rotating the string winds in the pulley thus creates a tension force in the end of the channel stock causing the gripper jaw to open. While the motor rotates in the reverse direction the tension force reduces on the string. The spring loaded on the front side of the gripper allows sufficient force to be developed to release and unwind the string. If the pulley diameter was big then the gripper can be opened and closed quickly. But the problem is we needed the arms to remain in open condition without any power to the motor to protect the motor to be stalled.. In that case the torque created by the spring force on the arms should be overbalanced by the motor starting torque. If the pulley diameter is very big then the motor resisting torque creates less resisting force on the wire. in that case the arms don't remain in full open condition and closes spontaneously when there is no power in motor. Thus the gripping system of string pulley gripper works.

Benefits

This type of gripper system is rigid and provides necessary spring forces to firmly hold and grip the objects. So there is little possibility of slipping the object from the gripper.

Limitations

The noticeable drawback of this type of gripping system is the presence of string pulley. As long as there is presence of string pulley there are possibilities of over winding and tearing of strings. This type of failure may occur frequently if extra care is not taken. Another problem is the usage of high torque motor is necessary for this type of system.

Modifications:

By designing the better pulley and using the proper springs it is possible to improve the performance of this type of gripping system.

2.1.2 Gear operated Gripper

This type of gripper uses two spur gears on which gripper jaws are set. One of the gears is powered using a motor which may be named as driver gear. The other one is driven. The driven gear rotates in opposite direction with the meshed one. While the gear rotates the point on each gear moves away from each other and comes closer as the direction of their rotation is reversed. This methodology is employed in this type of gripping system. As shown in figure jaws are set on these two gears. So when the gear rotates the jaws rotates with them providing necessary gripping forces. A spring

Figure 2-2 Gear Operated Gripping Mechanism

may be used to increase the gripping force. But in most cases the single motor used provides necessary gripping system.

Benefits:

This type of gripper is easy to manufacture, less machining is required and also weighs less and also strings and pulleys are eliminated. Resilience is very high and possibility of failure is nil in this type of gripping system.

Limitations:

Depending on the gear dimension the gripping capacity varies. While larger gears are used the motor of high torque rating is required. As the motor is mounted only one gear the weight is not balanced in this type of system.

Modifications:

Better designing of mounting, coupling and setting would lead this system to perfection

2.1.3 Mechanical Link Gripper

To eliminate the usage of high torque rated motor and string pulley this is an efficient system to be employed. This gripper system uses several mechanical links to provide the necessary gripping force. The figure explains well the construction of this type of gripper. There are three links of which the larger one is coupled with motor which rotates with motor. The movement of the larger link incorporates the movements of the other two links. These two links are connected to the gripper jaws. So while motor rotates the gripper jaws actuate. Thus the gripping action took place. The designing of the link depends on the amount of gripping forces required.

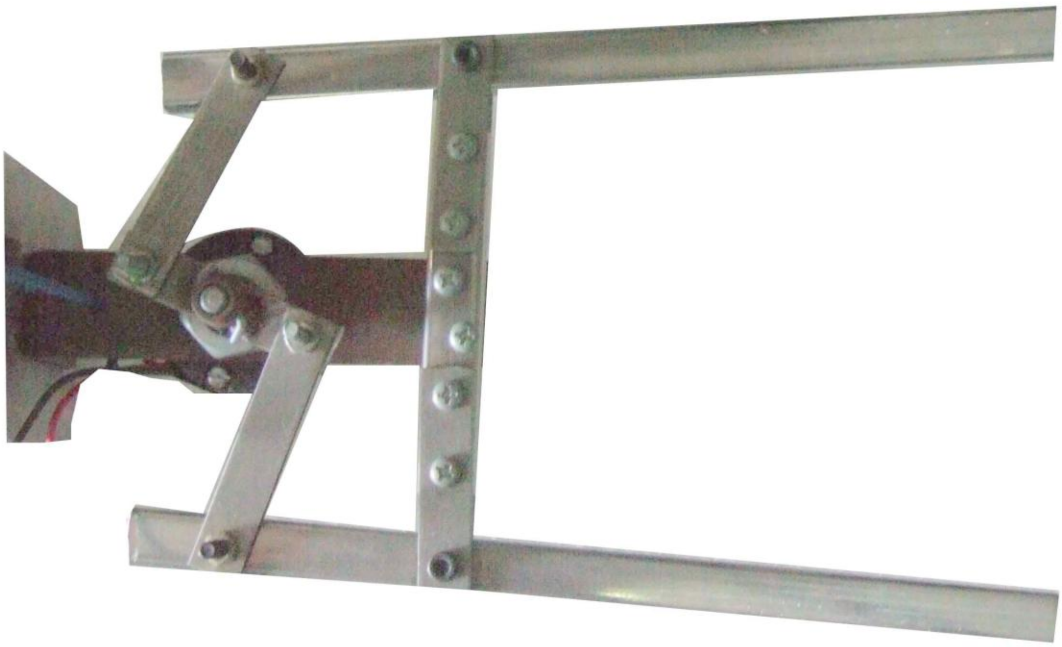


Figure 2-3 Mechanical Link Gripper

Benefits

The leaping advantage of this system is that the motor required to operate don't requires high torque rating. Spring, pulley and string are eliminated and thus reliance is increased. This type of system is also lighter in weight which is an important concern for the robots taking part in the competition.

Limitations:

Usage of limit switch and better controlling is necessary to control the gripping action. If sufficient controlling and feedback system is not provided this type of gripper system may return to its open position.

Modifications:

The improvement of designing and fabrication is necessary to reduce the dependability on the controlling system.

2.2 Driving system

Of the several Mechanical systems used in the robots driving system could be named as the most important. As the robots manufactured for the contest is mobile and autonomous the responsibility of making the robot mobile is performed by the driving system. Several driving system was tried during the analysis and fabrication of this driving system.

According to the needs driving system may use one motor to up to three motors. Usually number of motors varies according to the steering capability and steering systems used in the driving system. These could be classified according to:

- Single motor drive system
- Two motor Drive system
- Single motor drive system with Stepper motor steering.

2.2.1 Single Motor Drive System

The single motor drive systems are the one which uses only one motor. While it is ensured that the robot should only have the straight motion, then this is the case where one motor can be used. This is also reliable as because there is nearly no scope of deviating from the target. By designing properly the driving wheels it is possible to follow straight line as long as curved line incorporating the instantaneous center of rotation. In the 2008 contest the usage of instantaneous center was perfectly used by the Indian Nirma Institute of Technology.

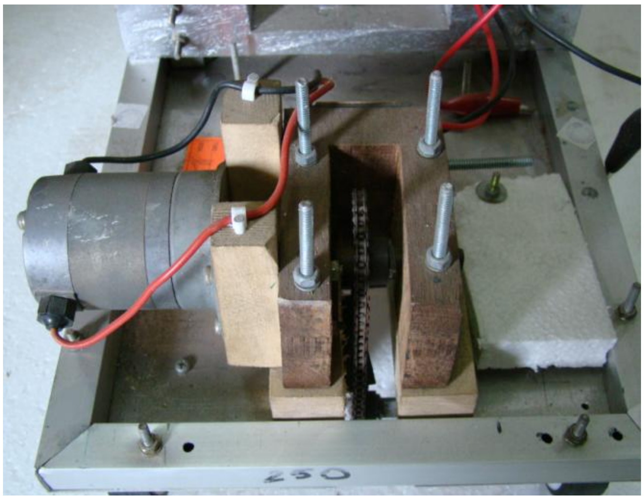


Figure 2-4 Single motor Drive system

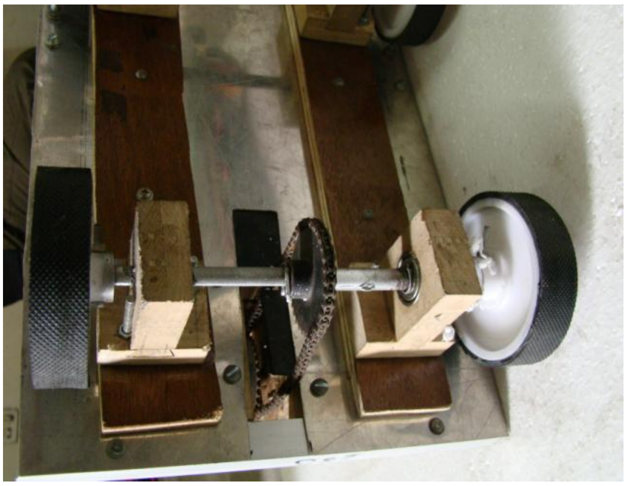


Figure 2-5 Chain Sprocket drive

Usually one single motor is not used to power only one wheel which would introduce slippage on the other while causing the robot to deviate from the actual destination. So usually power is transferred to one single shaft from the motor of which driving wheels are mounted on both ends. This ensures equal power distribution on both of the wheel and thus slippage is avoided.

2.2.2 Two motor Drive system

While using two independent motor to control the steering of robot drive system it is expected that the two motors are of similar specifications. Their performances, current rating, voltage rating, rpm etc should be similar. This could be possible if motors are brought from the manufacturer. But for our country it is difficult for to find such type of motors. So motors of nearly closer characteristics are used instead. This introduces a problem of straight line travel for the robots.

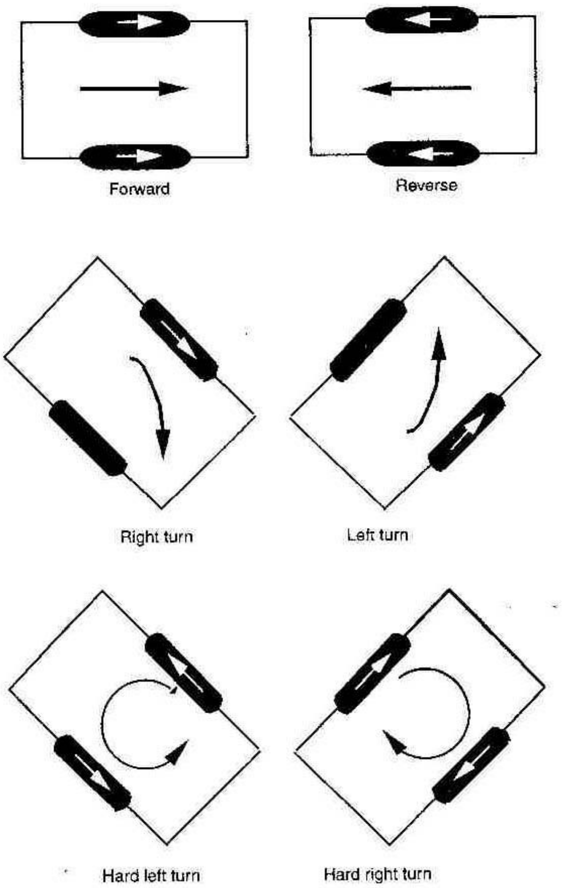


Figure 2-6 Steering of Driving System

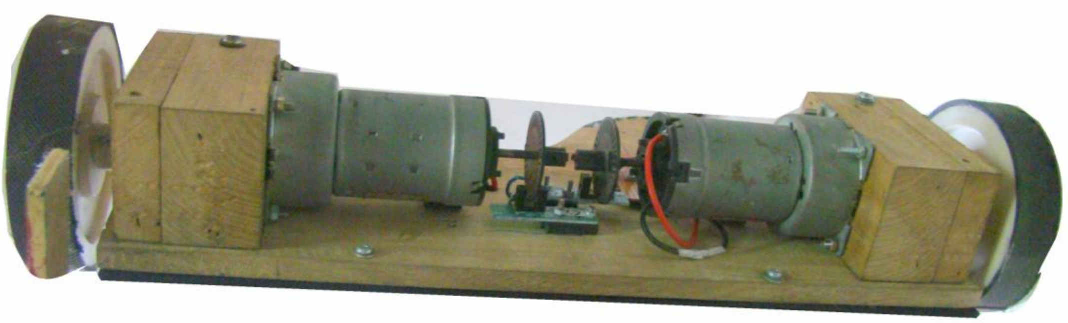


Figure 2-7 Motor Mounting System

Usually this type of drive system consists of two motors mounted with their axis on a straight line. Generally the motors are required to carry heavy load of about 10 to 15 kg. So the power required is usually high. This requires the motors to be mounted properly to provide cooling. Otherwise this would increase the temperature of the motors and thus deteriorates the performance of the motors over time. While mounting the motors these factors should be kept in mind. To keep the motors on a single straight line several designs of mounting two motors in one block was tried. Later motor mounted using built in bearing holder was use to serve the purpose.

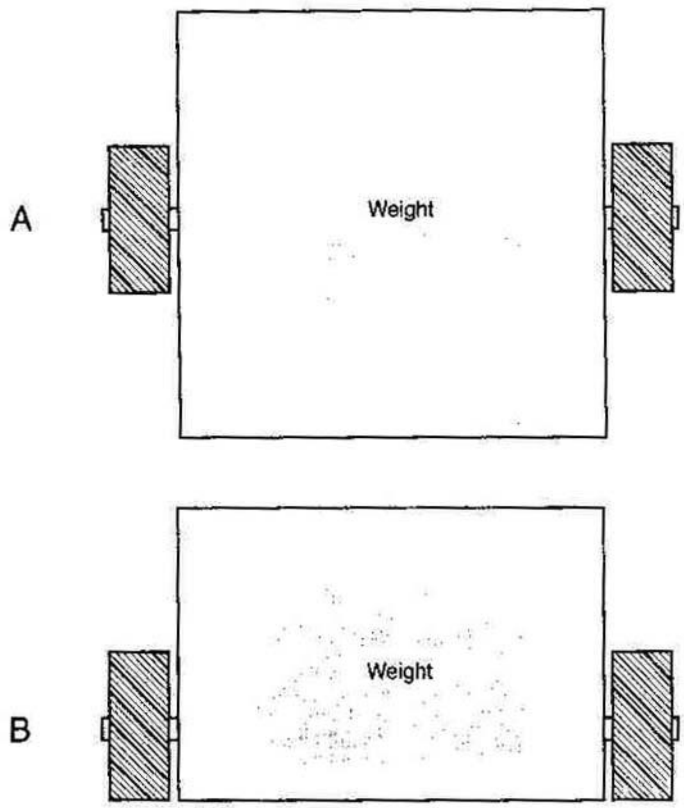


Figure 2-8 Caster requirement
A - Two Casters are necessary B - One caster is sufficient

The controlling the direction of this system is done by controlling the independent motors. While both motors run in forward direction the robot advances forward and when they both run in reverse direction the robots moves backward. When right turn is required then left motor runs in forward leaving the other in neutral state. While left turns are necessary right motor runs in forward leaving the other neutral. Right turn could also be made by running the right motor backward and for the left turn vice versa.

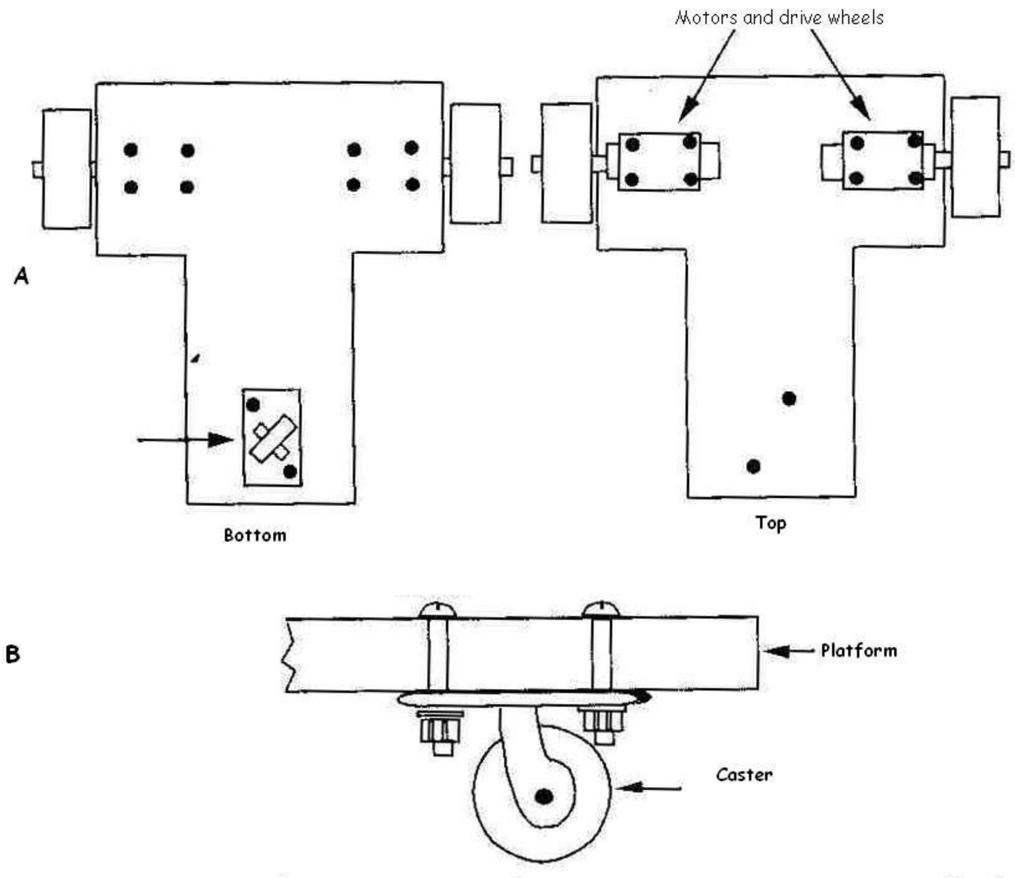


Figure 2-10 Mounting of Casters

In this type of system the use of caster or supporting wheel is must to provide necessary stability. It is obvious that a robot base couldn't be stable on only two wheels. At least three is necessary. One caster or two could be used with the two

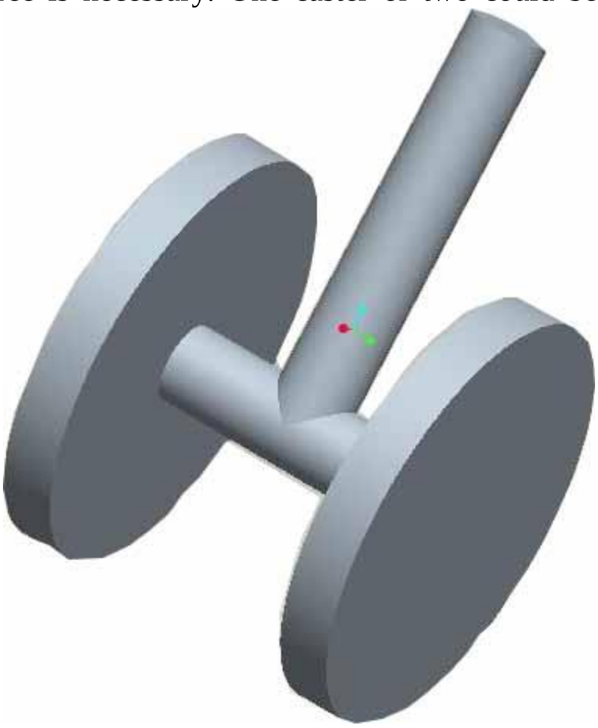


Figure 2-9 Differential Caster

driving wheels. The number casters to be used depend on the positions of the driving wheels. The image shows the numbers of caster to be used for the driving wheels set at the middle and for the driving wheels set at front or at rear end depending on the distribution of load.

The using of caster has some drawback. The accuracy of reaching the destination for a robot largely depends on the initial positions of the casters used. So every time the casters are to be positioned on their desired situation to make the robots perform efficiently. To reduce this problem usage of differential casters machined from BUET was tried. In this system two wheels of same diameter was machined from nylon cylinder. Then these two wheels are set on housing. The two wheels are mounted on two separate bearing connected by a shaft. Thus the wheels are free to rotate on the axis of the shaft. As the wheel are fixed they need not to be aligned and thus reduce the align problem of the caster. This is a very efficient system while the robots are running on low speed. But as the robots starts moving fast they start to skid as they are positioned closely. So this problem removes the presence of this type of casters from the robots used in the contest

2.2.3 Single motor drive system with Stepper motor steering.

Another efficient type of driving system is single motor drive stepper motor steering system. In this case only one motor is used to power the drive wheels. Two motors

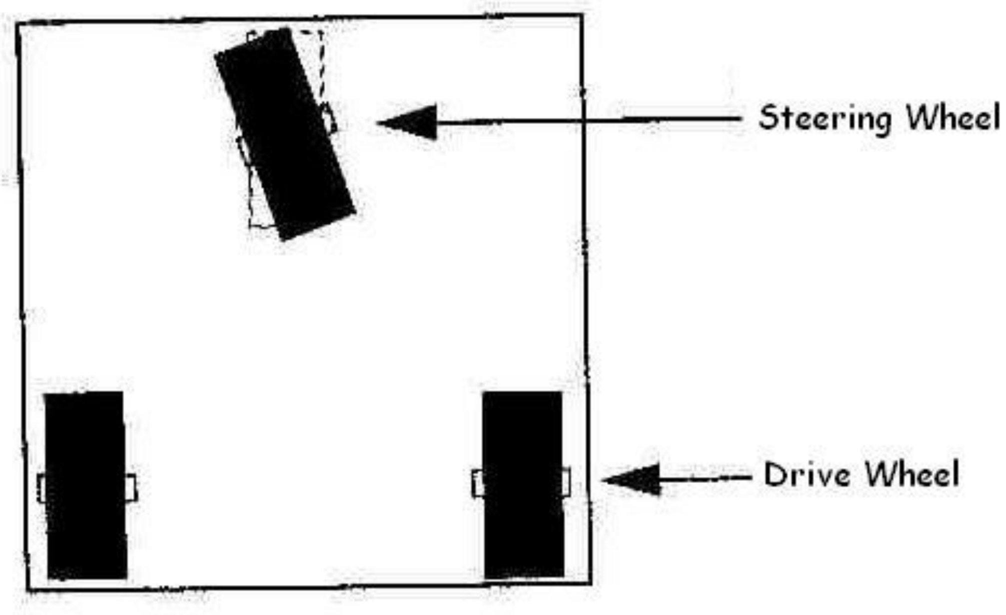


Figure 2-11 Steering in Front wheel

may also be used but this incorporates problem of synchronizing of the motors. The mounting of the driving motor is as the same as the single motor drive system. The most sensitive system is the steering system. Here front wheel are just like the wheel casters as described on the previous paragraph. Other types of steering wheels may be used. One vertical shaft is welded on the horizontal shaft. This passes through one bearing and then afterwards connects with a stepper motor. As the stepper motor rotates it provides necessary steering action and leads the robot to the desired locations. Several problems were faced while using this steering system. The program code written to control the steering should be perfect otherwise it would cause great deviations. Moreover the angular errors even if was not more that fraction of degrees results several feet of deviation which may lead the robotics system to complete failure. So the controlling of the steering in this system is the most difficult and important part.

2.3 *Sliding system*

Sliding system is one of the basic systems of a robot. The robots that are manufactured for the contest should have some vertical axis movement to provide the necessary elevation for the robots. While working on the sliding system several different styles and systems were tried

These are as follows:

- Four rod - pulley system
- Two rod circular sliding system
- Polar elevation
- Rectangular support roller sliding system

2.3.1 Four rod pulley system:

Four rod made by stainless steel is used to support the slider. Four pulleys are used with the slider to slide over the circular rod. In this case pulley diameter is crucial. The grooves cut on the pulley should be so that it is perfectly meshed with the stainless steel rod. That was so tough job because of the availability and capability of machining facilities in BUET. One string was used to pull the slider. The string was

Figure 2-13 Pulley mounted

Figure 2-12 Four Rod Slider

pulled by a motor of very high torque. Four Stainless Steel pipes are supported at the top and at the bottom to hold them rigid. There is pulley holder designed to mount the pulleys on them. It is so designed that the spacing between the pulley is exactly as that

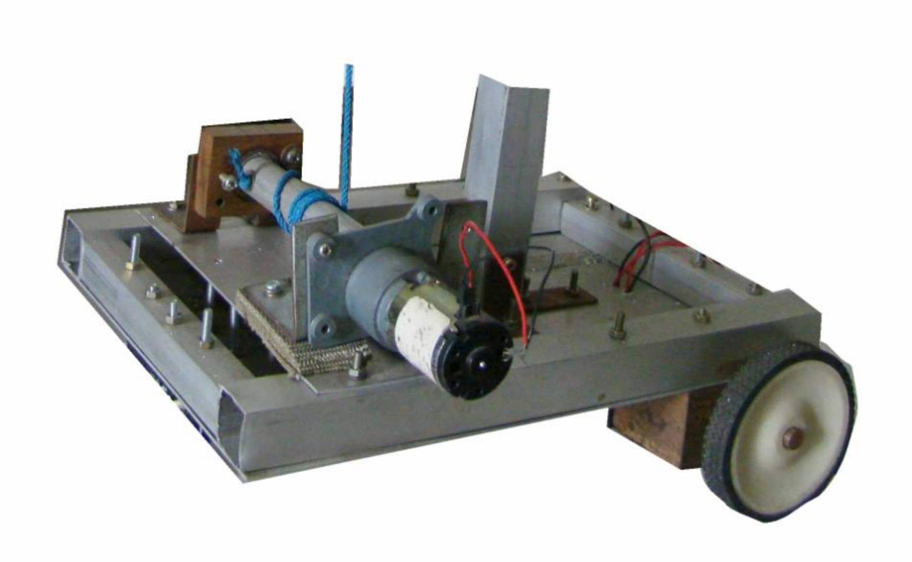


Figure 2-14 Slider pulley mounted on Motor

of the spacing between the outer end of the steel pipes. The motor is set on the base so that the motor can pull the string from the base through another pulley mounted at the top support.

A shaft mounted on the motor is used over which the string will wind spirally and pull the sliding system. The speed of the lifting of the slider depends on the diameter of the shaft. As motor speed was so slow the shaft should be made as large as possible in diameter which also increases the required motor torque. So an optimum safe diameter for shaft is chosen.

Benefits:

The system is a reliable one as long as weight and size is of no concern. This runs smoothly with no jamming which provide free fall using the gravity feed. On the rising period the pulley rolls over the pipes and less force is required by the motor due to the lower amount of frictional forces.

Limitations:

In this system the rolling pulley holder should be rigid enough to hold those pulleys at place. Otherwise pulleys may be displaced causing problem in sliding upward and downward direction. Also sudden collapse of the sliding system may occur if one or more pulleys came apart from their place.

Modifications:

If the pulley holder could be manufactured by casting then it would be much more reliable reducing the possibilities of system collapse due to the razing of the pulley.

2.3.2 Two rod circular sliding system:

In this system two stainless steel pipes are used and circular slide ways are used to slide over the circular pipes. The sliding mechanism could be machined in built with another system such as gripping system or anything else. Sliders built of aluminum bars of two separate pieces. In between the bars wooden blocks and rubber pads are used as sandwich to ensure the surface contact. Circular pipes of closer diameter can also be used instead of wooden blocks. Holes of diameter closer to the circular pipes are drilled on the aluminum bars. Through these holes circular pipes are passed through which are then supported using wooden or aluminum blocks at the top and at the bottom. Usually at the top block the pulley is mounted through which the nylon string passes and is then winded on the aluminum pulley mounted on a motor. While the motor turns it winds strings on its coupled pulley and thus the slider is rise up, while motor turns in the opposite direction it loosens the string and the slider moves downward with the assistance of gravity feed.

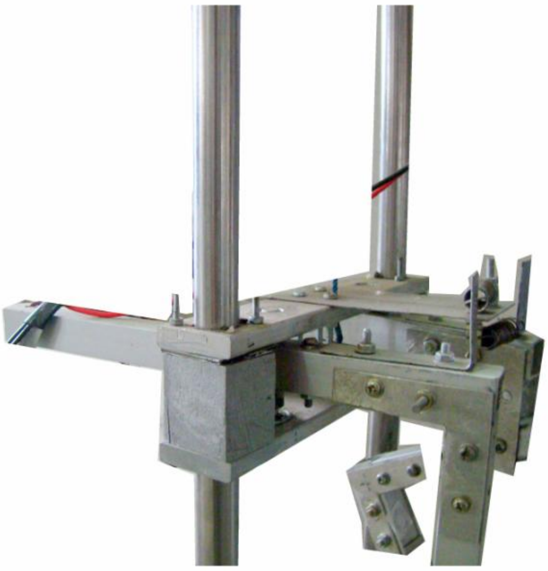


Figure 2-15 Sliding System

Advantages:

In comparison to the four pipe and pulley sliding system this system is far easier, handy, lighter and also reliable. The displacement of slider pulley is completely reduced in this type of system as it doesn’t use slider pulleys

Limitations:

The clearance between the pipe and slide way is very important. This clearance should be as less as possible. If the clearance is more the slide way would get line contact rather than surface contact because of uneven loading. As a result the pipe exerts an opposite force on the slider causing the slider to be jammed. This increases the required motor power. So the clearance should be as small as possible.

For circular slide ways wooden piece is used as sandwich in between the aluminum bars to ensure surface contact. But if top quality woods are not used then the wooden sandwiches swell out with changing environmental conditions and cause extra amount of frictional forces. (Moisture contents in the environment etc.). This makes the allowance selection difficult. This also limits the minimum clearance. So to ensure the desired clearance stainless steel pipe is suitable instead of wooden block.

Modifications:

If proper and accurate machining is possible then the circular sliding system using only one pipe would be possible which would reduce the weight and size significantly and would definitely serve as better system.

Figure 2-16 Polar Elevation

2.3.3 Polar Elevation System:

Polar elevation system provides elevation using polar coordinate. There is a platform where usually the gripping system is mounted. This platform is connected on a hinge support. The other part of the hinge support is connected on a fixed channel stock. The other end is pulled down using a motor, pulley and string. Usually the downward movement of the platform is given by the gravity feed. When the platform is required to rise in the upward direction then the motor is run in a direction to wound the string on the pulley which shortens the free length of the string and the platform goes up. The motor power is limited by the length of the platform and the position of the C.G. because as the C.G. is positioned far from the hinge point the torque required by the motor to raise the platform is high.

Benefits:

- Several advantages that are noticeable in this system are:
- Less weight
- Easy and not compact design
- Easy machinability
- Components required is less
- Reliability is better
- Controlling is easier

Limitations:

This system faced the following problem while it was in action.

- As the polar elevation is required perfect calculation and design is required to locate a certain point in space
- String pulley is less reliable as there are possibilities of over wounding on the pulley.
- The elevation height is much more less than the channel stock used to support the gripping platform.

Further modifications:

The sliding system uses two circular guide ways to ensure the stability. The unavailability of proper and accurate machining restricts to use of only one circular guide. If proper machining could be done then the clearance between the circular guides would be necessarily small enough to prevent the lateral movement of the sliding system which would be more efficient system to be used on the robots.

2.3.4 Rectangular support roller sliding system

Of the various sliding systems used in the robots and the researches done on the sliding system this is at present the best to serve the purpose to provide the elevation of the robots for the contest. Several designs were tried before reaching this outcome.

This type of sliding system uses one channel stock on which several rollers roles from aluminum enfold where the rollers are mounted. Minimum of three rollers on the two opposing sides are required to ensure the stability. One roller on one side and the other two on the other side should prevent the contact between enfold and

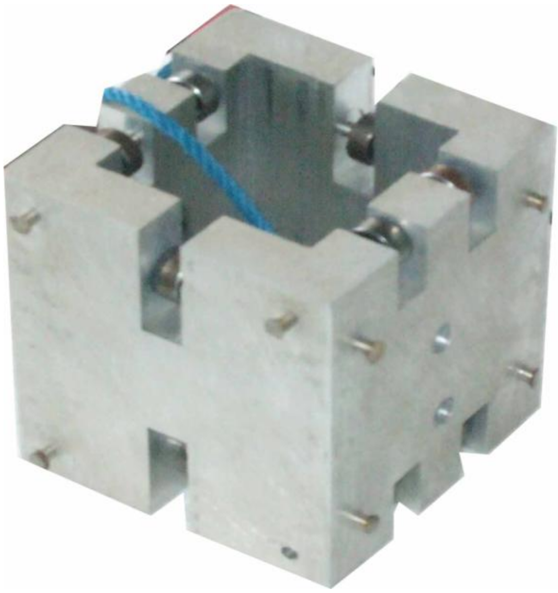


Figure 2-17 Rectangular Slider

channel stock and thus prevent friction between them. There are necessary space on the enfold to mount other systems like gripping system. The mounted systems like gripping system is hanged using nylon string through a pulley and at last that string is wounded on a pulley. This pulley is driven by a motor to rise and lower that mounted system. Generally that system goes up using the tension forces created by the motor on the pulley and lowered by using gravity feed and loosening the tension on the string simultaneously.

Benefits:

Several benefits of this type of systems are
Weight is reduced as reduced number of support to slide.
Improved stability rather than that of circular guide slide systems.
Motor of less torque rating is required to drive the system.
Less space is required to which is a feat of smaller and handy robots.

Limitations:

The limitations of this type of systems are:
Due to continuous use of this system the channel stock and roller may wear out and thus increase the clearance which would lead to unstable situation.
String and pulley used in this system is not reliable as there are possibilities for the string to miss the winding.

Further modifications:

To remove the limitations of wearing out of the system either by spring loaded enfold may be used or stainless steel roller and channel stock might be used. The string pulley system is unreliable and it could be replaced by rack pinion system if better machining is possible.

Chapter 3 Manufactured Robots

The driving system, sliding system and gripping system was developed and analyzed to build mechanical parts of the autonomous and manual mobile robots for the ABU Robot contest. As those three systems are responsible for the performance of the robots in the contest the reliability and ease of operations of these systems would be nearly perfect with no margin of failure. They have to run perfectly every time they are required. Three robots were manufactured of them two participated in the ABU robot contest and the last one was manufactured to test the modifications done on the previous systems. Three robots were

- Manual Machine
- Career BOT
- Ilk BOT (Didn't participate in the ABU robot contest 2008)

3.1 Manual Machine

In the ABU robot contest each year there is only one manual machine which is allowed to be driven by an operator through remote control. There are several rules

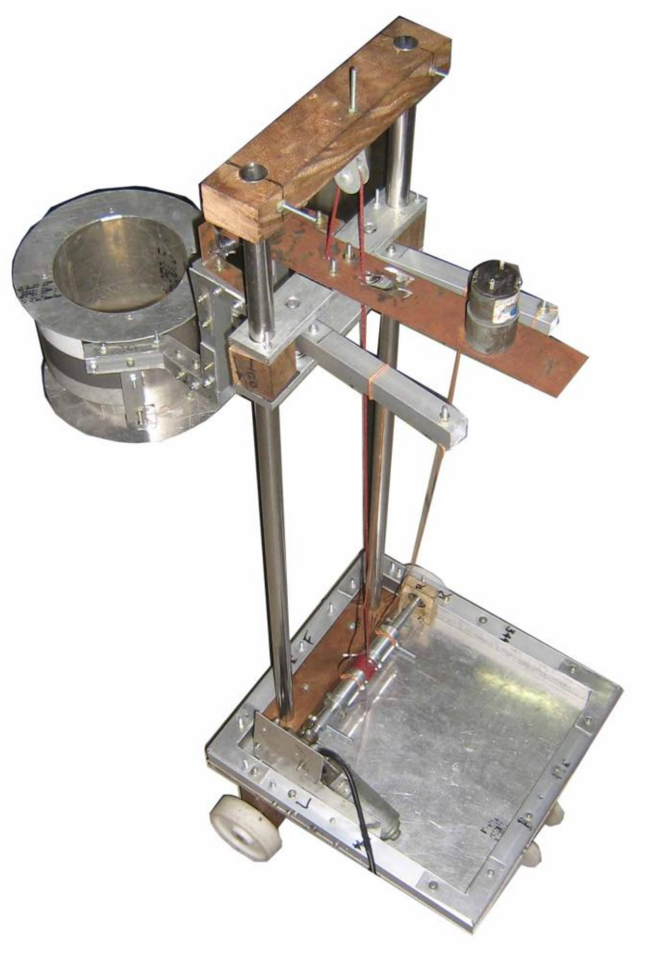


Figure 3-1 Manual Machine

and restrictions for the manual machine used in the contest. Appendix (Rules and regulations ABU ROBOCON 2008) is referred for further information.

The Manual machine contains one of each of the driving system, sliding system and gripping system. Two motors for driving system and one each for each of the sliding and gripping system were used in this robot. So there are total of 4 motors to be controlled.

The driving system used was front wheel driven with motor mounted at the front end of the driving base. Two identical motor was required for the straight travel of the robot while drive system is powered with both of the motor. But due to the unavailability of identical similar motor in Bangladesh; motors of different performances were used. This results in slightly left skid while following a straight line.

Circular guide way system was used to provide the vertical movement of the robot. This provides the “Elevation” of the robot. On the circular guide way sliding system for the manual machine positive vertical movement is provided by pulling a string using a motor mounted on the base of the robot. Negative vertical movement is provided using gravity feed while the motor is releasing the string wound on a pulley. Greases may be used to provide for smooth sliding.

Gripping system used on this machine contains some exceptions on its PVC build gripper jaw. The contest requires this robot to grip circular objects named as “Motka”. Particularly this is the main reason why circular PVC pipe instead of conventional channel stock is used to manufacture the gripper jaw of the manual machine. Moreover the jaw of this machine should have to be fit into 400mm of space to allow scoring 2 “Motka” inside a 500mm box. The weight limitations also lead to use some lighter materials to be used. So in sum up of these entire problems the final outcome was a PVC build gripper jaw. Gripper system was designed in such a system that it was able to place objects on the ground and not disturbing the stability of the objects to be placed. Rest of the gripping system was conventional that was described earlier on the gripper section. Here four rolling contact bearings were used and the inner race was rotating with outer race stationary.

Specifications:

Dimension	950×490×970 mm
Elevation	700 mm
Gripping capacity was	200mm
Power Supply:	12V and 6A.
PWM	Not Used.
Remote Controller	8 buttons.
Breaking System Used:	Regenerative Type.
Weight:	9 kg (with battery)

3.2 Carrier BOT

For the 2008 contest this was the heaviest robot and posses a bit of strange characteristics too. According to the theme one robot must have to carry another robot

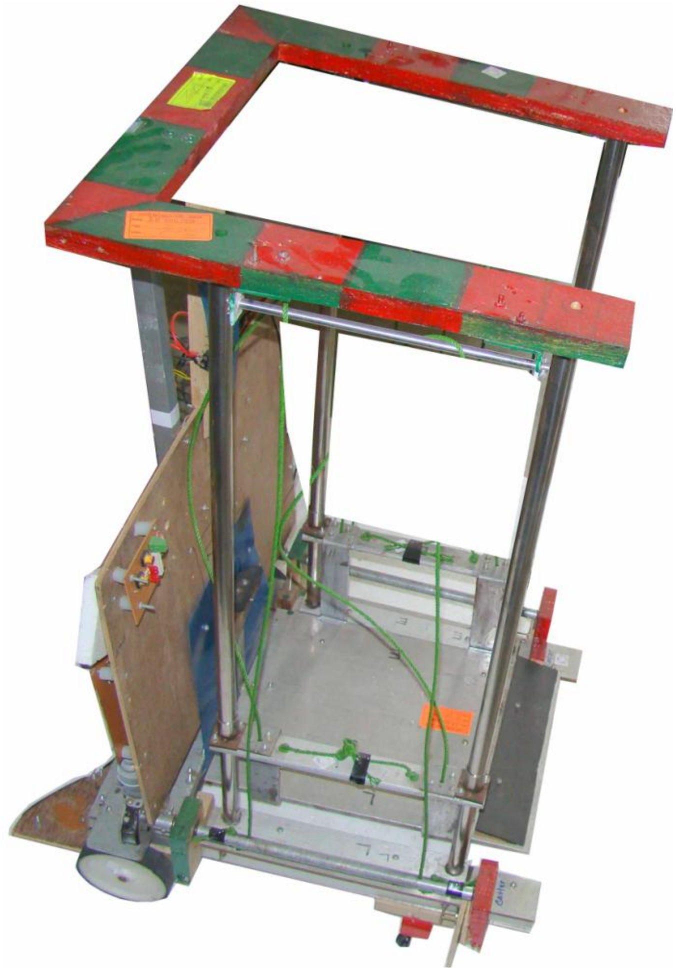


Figure 3-2 Carrier BOT

to a tower to score. This was the robot used to carry another robot on its platform to the desired place and raise that robot to the desired height.

The driving system for this robot is same as that of the Manual Machine. Motors were mounted on the front end. Two casters were used to support the rear end. Encoders were equipped to ensure the straight travel and ensure the detection of the desired place. The drive system of this robot is capable of providing corrective measure if the drive system deviates from its path.

Sliding system of this robot may be called the combinations of the two circular guide ways. Circular pipes of nearly equal diameter were used to acquire surface contact in between the slider and supporting pipe. To rise the slider two sets of string instead of one was used to distribute the tension properly and equally over the slider. The sliding system of this robot caused problem with the synchronization of the two sets of motor. This problem was due to the usage of different types of motors. The synchronization of these two motor was done by calibrating the diameter of the shaft mounted on the motor. By varying the diameter of the shaft which winds the string over them, the two motors of different performance was synchronized.

Specifications:

Dimension:	640×490×920 mm
Elevation:	650 mm
Power Supply:	12V and 6A.
PWM:	Used on both driving motors
Breaking System:	Regenerative Type.
Weight:	13 kg (with battery)

3.3 Ilk BOT:

To improve the performance of Bangladesh team several researches are done on various systems like driving system, gripping system, sliding system etc. This robot is an example of the usage of these experimental systems. The gripping system and elevation was replaced by completely new gear operated gripping system and polar elevation system. The driving system was similar to those of the conventional type which have been used previously.

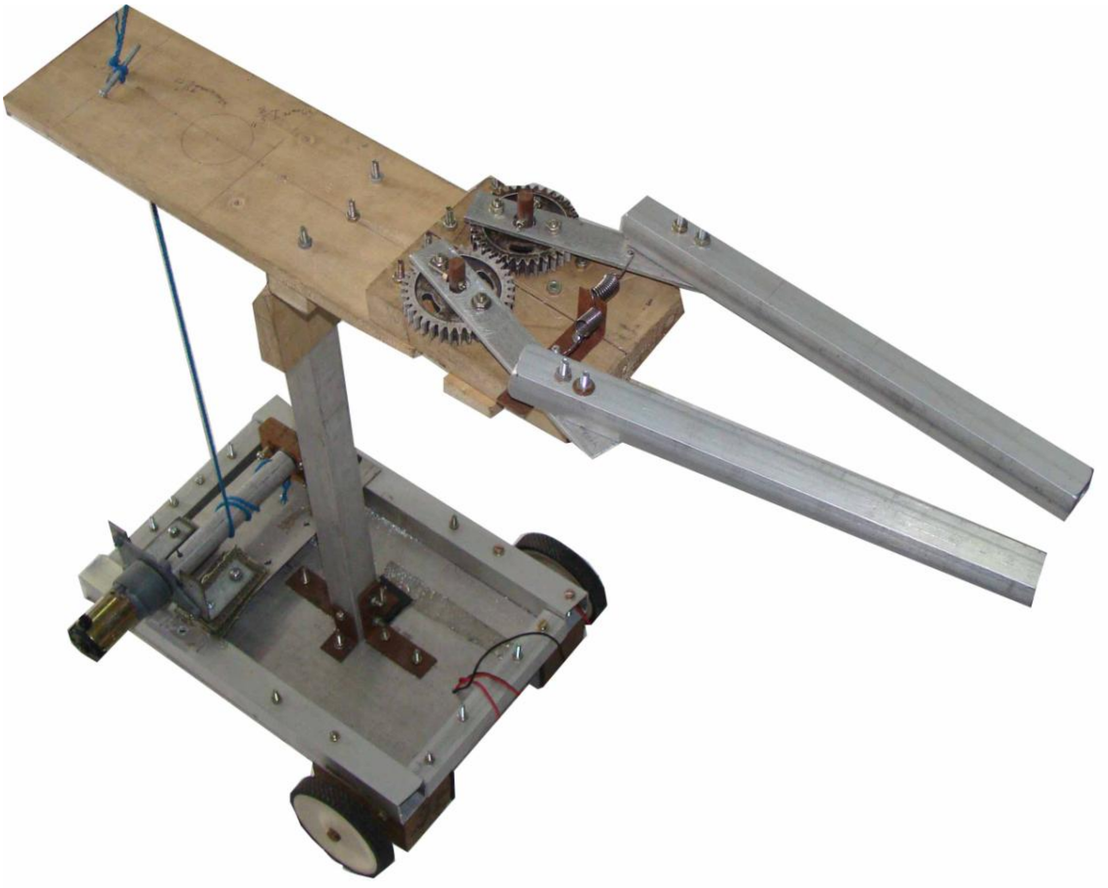


Figure 3-3 Ilk BOT

The gripping system uses two spur gears to provide necessary motion. One gear is driven with a motor which drives another gear. Channel stocks are connected to these gears using shafts which are the necessary part of the gripper jaw. These jaws may be spring loaded which requires motor with high torque. If no spring is used the motor torque required is less but the possibility of slipping the gripped object is increased. One important benefit of using this type of system is that it uses one spring rather than that of the conventional one used in the robots of Bangladesh team.

In this robot slider is reduced and thus the construction and operation to provide the elevation is hereby significantly simplified. The system is easy to manufacture and requires less force with comparatively lower torque rated motor. To perfectly locate a point in the space proper calculations and manufacturing of the system is expected. The driving system of this robot is very much simple as like manual machine. No encoder is equipped on the driving system of this robot. The robot will move according to the program code written. This makes this robot a bit inefficient as no feedback for its driving system is provided. Nonetheless, if the program code is perfect and the perfect values of the variables are to be found by several trials this could also act as an efficient system.

Specifications:

Dimension:	300×210×520 mm
	800×300×820 mm
Gripping Capacity	0~370 mm
Elevation:	220~820 mm (polar elevation 90 Degrees)
Power Supply:	12V and 6A.
PWM:	Used on both driving motors
Breaking System:	Regenerative Type.
Weight:	7 kg (with battery)

Chapter 4 Control systems

The name implies the usefulness of this system. The robots build and manufactured should be controlled with several electronics systems to interact on the real world. How the robots are to be started, how they are to be powered, how they have to respond etc everything to be controlled are done using several control system. It was the motors which endows the robots movement. These motors are electrical equipment which are to be controlled with several electrical and electronics system. Furthermore there are several sensors which are to be powered using the control systems. So in a nutshell it could be said that the control system drives the mechanical parts of the robots and helps them to identify as a robot otherwise they will stand still as like a truss structures.

4.1 Direction Control of Motor

Motors are controlled by simple H-Bridge circuits. The basic of H-Bridge circuit is fairly simple. The function of this circuit is to reverse the direction of flow whenever signal is received. To build this system four SPDT switches or one DPDT switch may be used. The following diagram clearly represents the H-Bridge circuit.

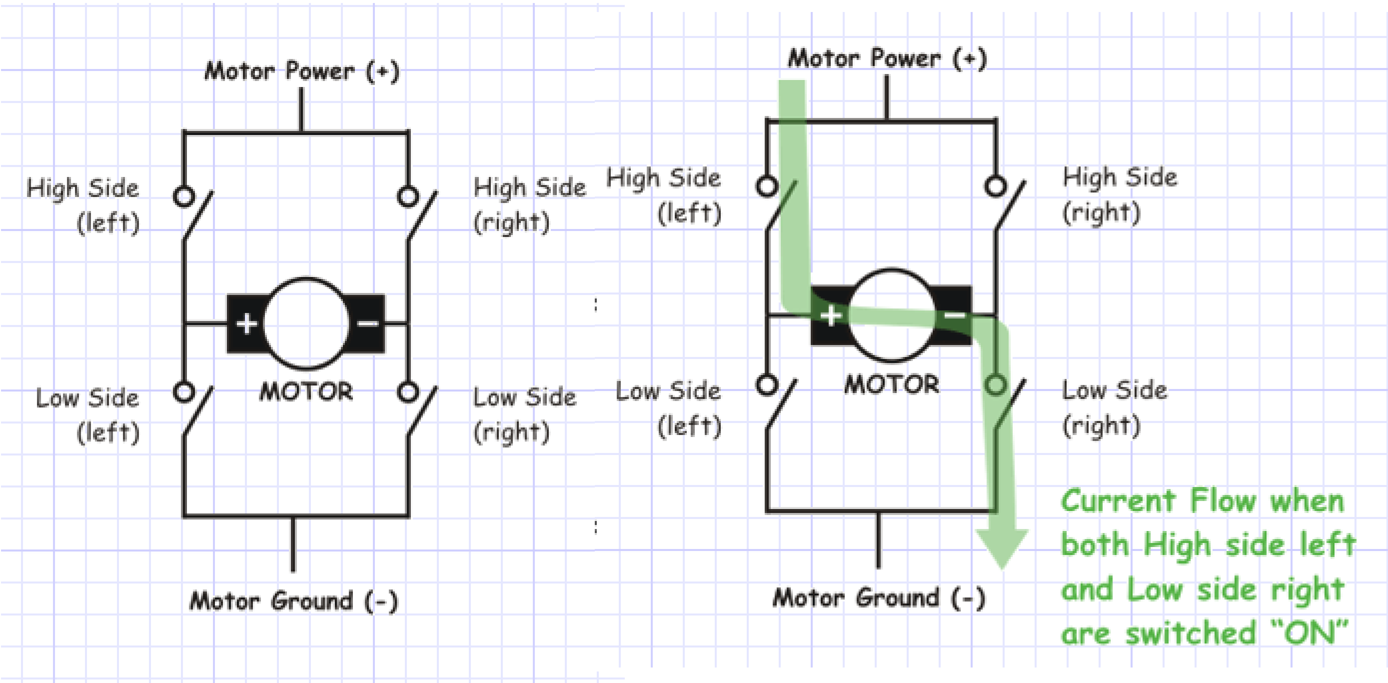


Figure 4-1 Motor Control Circuit

According to the figure the motor creates the horizontal line of the "H" and the four relays constitutes the vertical lines of the "H". The power and ground are not included into the constitution of "H". Four relays are named as High side (Left & Right) and Low side (Left & Right).

When High side (left) relay and Low side (right) relay is switched on then the circuit is on and current flow from the high side to the ground causing the motor to run in a direction. To run the motor in reverse direction the relays of alternating sides

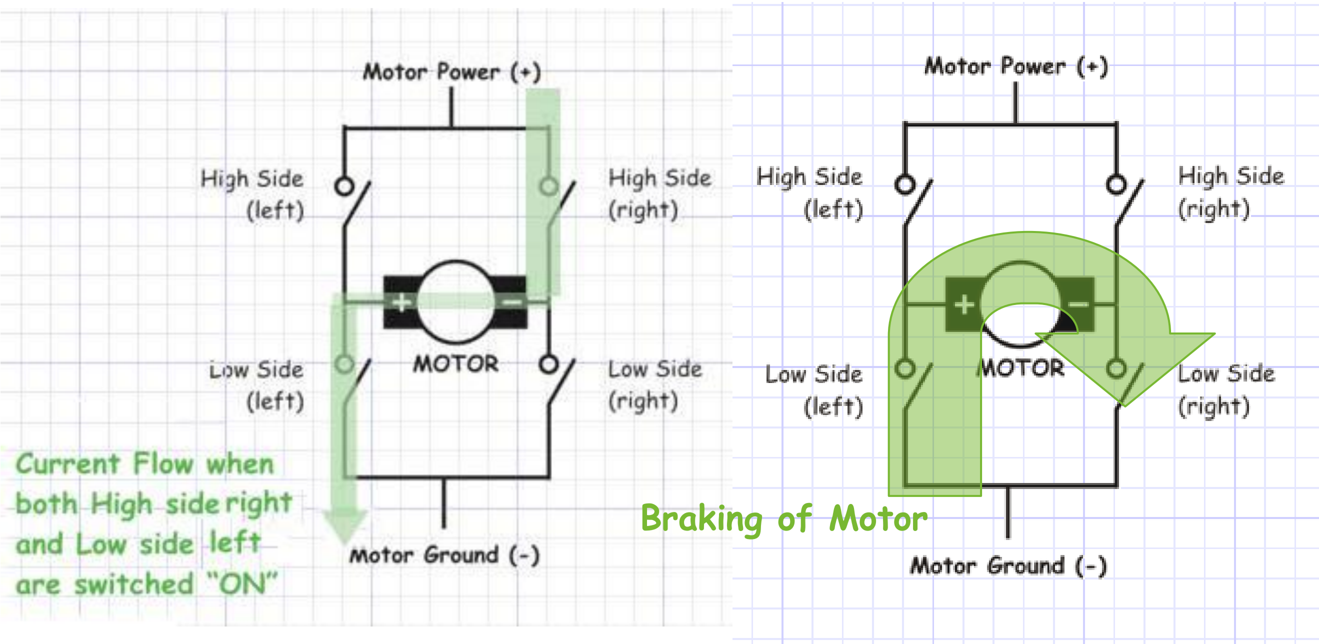


Figure 4-2 Motor Reversing and Dynamic Braking

should be energized. That is; the High side (right) and the Low side (left) relays should be energized. This would allow current from high side to the low (ground) side but facing the motor in reverse direction. So the motor would run in reverse direction.

4.2 Braking of Motor

In the regenerative braking the motor both end of the motor should have to be shorted. This is called regenerative braking of motors. In this case the motor will stop earlier than it would if it is allowed to stop on its own. While the motor is running and the power is suddenly removed the motor will continue running because of its inertia. This will then act as a generator producing electricity in the reverse direction of what was supplied to the motor. While the motor ends are shorted this electricity would pass through the motor and cause the motor to stop earlier.

The following table would provide necessary information about controlling the motor.

High Side Left	High Side Right	Lower Left	Lower Right	Quadrant Description
On	Off	Off	On	Motor goes Clockwise
Off	On	On	Off	Motor goes Counter-clockwise
On	On	Off	Off	Motor "brakes" and decelerates
Off	Off	On	On	Motor "brakes" and decelerates

To brake the motor plugging may also be used. This would stop the motor earlier than that of regenerative braking. But this requires accurate time control otherwise the motor would start rotating in reverse direction. Motor plugging is nothing but reversing the direction of flow to make the motor run in reverse direction. Depending on the speed of the motor the reversing flow time would vary. So the speed at which the motor is rotating is also required to be tracked down. So while plugging is incorporated the controlling should be better.

Another method of braking the motor is the usage of dynamic braking. This method use heat dissipater to waste out the extra amount of power generated by the motor while working as generator. As a heat dissipater small bulbs or high resistors may be used across the motor. This method is quite efficient one but not capable of providing quick stop as that of the regenerative braking.

4.3 Speed Control of Motor

It is necessary to control the speed of the motors used in robots in order to

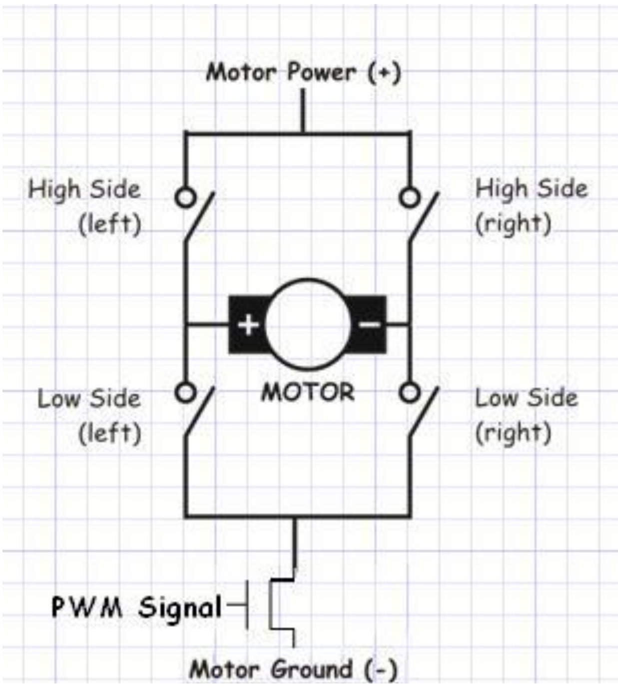


Figure 4-3 Speed control of Motor

control the actions of the robots. There are several methods to control the speed of the motors; usually PWM (pulse with modulation) is used to control the speed of the motor in robotics projects. The figure illustrates the speed control of motor using PWM.

4.3.1 Pulse with modulation:

The speed of a DC motor is directly proportional to the supply voltage, so if the supply voltage is reduced from 12V to 6V, the motor will run at half the speed. By varying the average voltage sent to the motor it is possible to reduce the effective voltage from 12V to 6V. This could be done simply by adjusting the voltage sent to the motor, but this is quite inefficient to do. A better way is to switch the motor's supply on and off very quickly. If the switching is fast enough, the motor doesn't notice it, it only notices the average effect. This on off should be in the ranges of milliseconds. This switching is done by using power MOSFETs (Metal-Oxide-

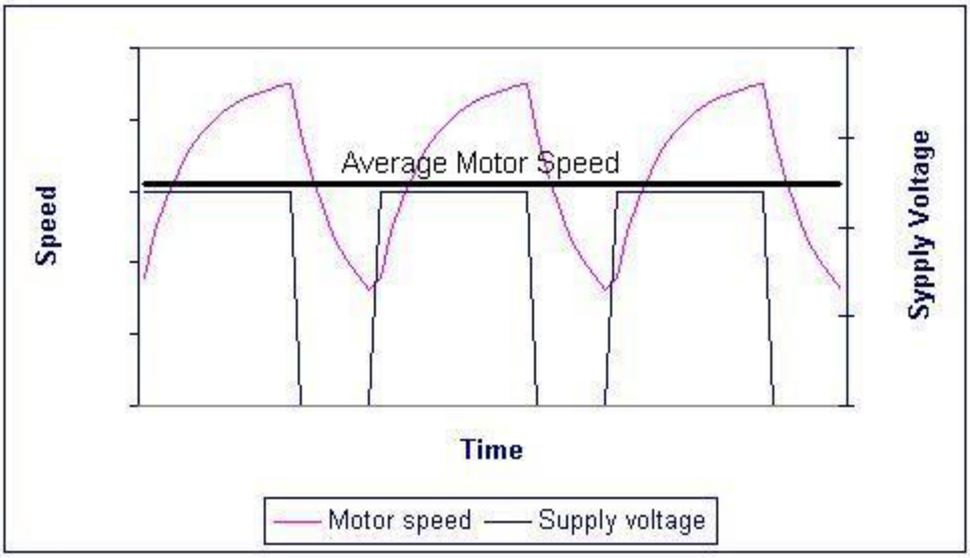


Figure 4-4 Speed variation of Motor with PWM

Semiconductor Field Effect Transistor). This is a device that can turn very large currents on and off under the control of a low signal level voltage. The time that it takes a motor to speed up and slow down under switching conditions is dependent on the inertia of the rotor (basically how heavy it is), and how much friction and load torque there is. The graph shows the speed of a motor that is being turned on and off fairly slowly.

Calculating the frequency:

There are several factors that could be taken into consideration to calculate the frequency of PWM. Some important points that should be taken into consideration are

Each switching on and off of the speed controller MOSFETs results in a little power loss. Therefore the greater the time spent switching compared with the static on and off times, the greater will be the resulting 'switching loss' in the MOSFETs.

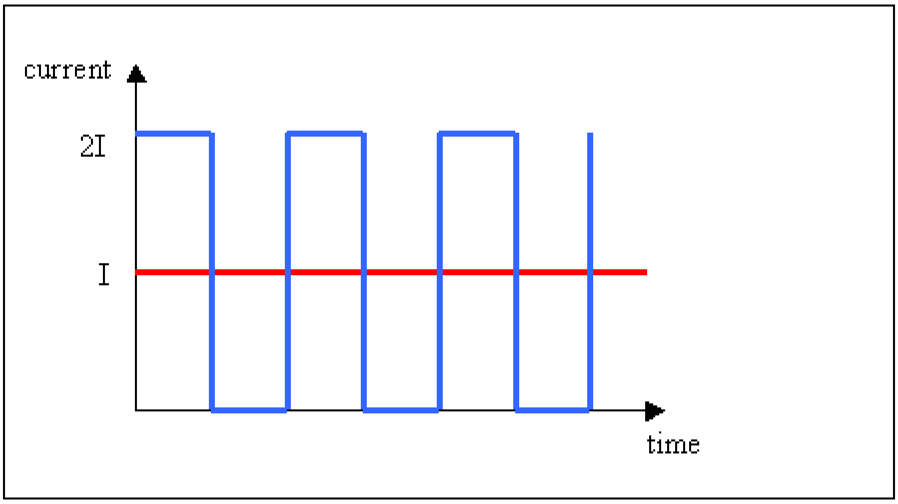


Figure 4-5 Power loss in PWM

However, when the power dissipation in the stray resistances in our motor and speed controller, for the DC case:

$$\text{Power Loss} = I^2R$$

and for the switching case, the average power loss is

$$\text{Power Loss} = 2I^2R$$

So in the switching waveform, twice as much power is lost in the stray resistances.

The higher the switching frequency, the more stable is the current waveform in the motors. This waveform will be a spiky switching waveform at low frequencies, but at high frequencies the inductance of the motor will smooth this out to an average DC current level proportional to the PWM demand. This spikyness will cause greater power loss in the resistances of the wires, MOSFETs, and motor windings than a steady DC current waveform.

Another factor for choosing the PWM frequency is the percentage of current fluctuation allowed. As the frequency of voltage rises from zero to the maximum current also goes up and as the voltage moves to zero the current decreases to zero value. But if the PWM of voltage don't allow sufficient time for the power supply to saturate the current supply then it would be some loss. To reduce the loss the frequency should be such that it uses sufficiently all of the power supplied by the battery. Following figure would represent better explanation

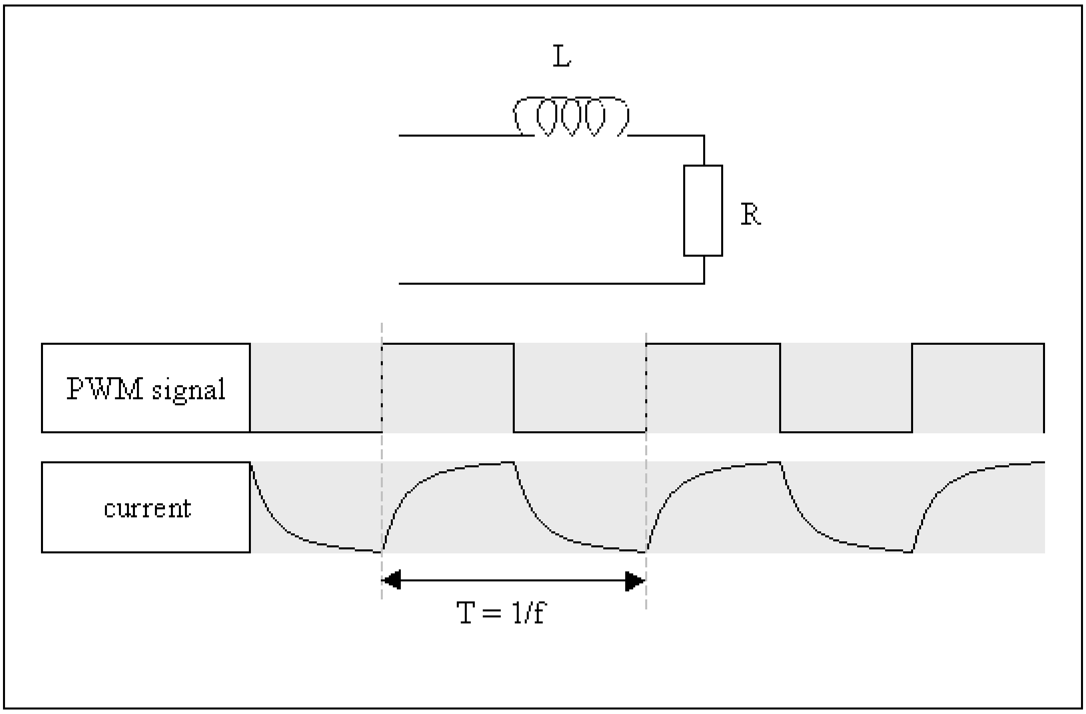


Figure 4-6 Effect of PWM on supply current

The switching is done using MOSFETs. For controlling of high powered DC motors it draws a significant amount of current. Not surprisingly the power handled is high which indicates great amount of power loss. This power loss is represented as high heat dissipation.

4.4 Reducing the heat in the MOSFETs

When the MOSFETs are on and current is flowing through them in forward direction, they have a very low resistance and are dissipating hardly any heat at all. However, when the current is flowing in reverse direction, there is a fixed voltage across them. This causes quite a large power dissipation (volts × amps). A feature of MOSFETs is that they will conduct current from source to drain as well as drain to source, as long as the voltage difference is greater than 10-12 volts. Therefore, if the MOSFETs that are carrying reversed current through diodes placed around them and diodes turned on, then they will dissipate a lot less heat. The heat will be dissipated in the wires and the motor itself instead.

Advantages of PWM systems

1. The output transistor is either on or off, not partly on as with normal regulation, so less power is wasted as heat and smaller heat-sinks can be used.
2. With a suitable circuit there is little voltage loss across the output transistor, so the top end of the control range gets nearer to the supply voltage than linear regulator circuits.
3. The full-power pulsing action will run motors at a much lower speed than an equivalent steady voltage.

Disadvantages of PWM systems

1. Without adding extra circuitry, any motor speed signal is lost, as the fan electronics' power supply is no longer continuous.
2. The 12V "kicks" may be audible if the motor is not well-mounted, especially at low revs. A clicking or growling vibration at PWM frequency can be amplified by case panels.
3. Some authorities claim the pulsed power puts more stress on the motor bearings and windings, shortening its life.

4.5 Encoders

To track the speed of the motor there is need of a device that will measure the speed of the motor shaft. The best way to do this is to fit an optical encoder. This

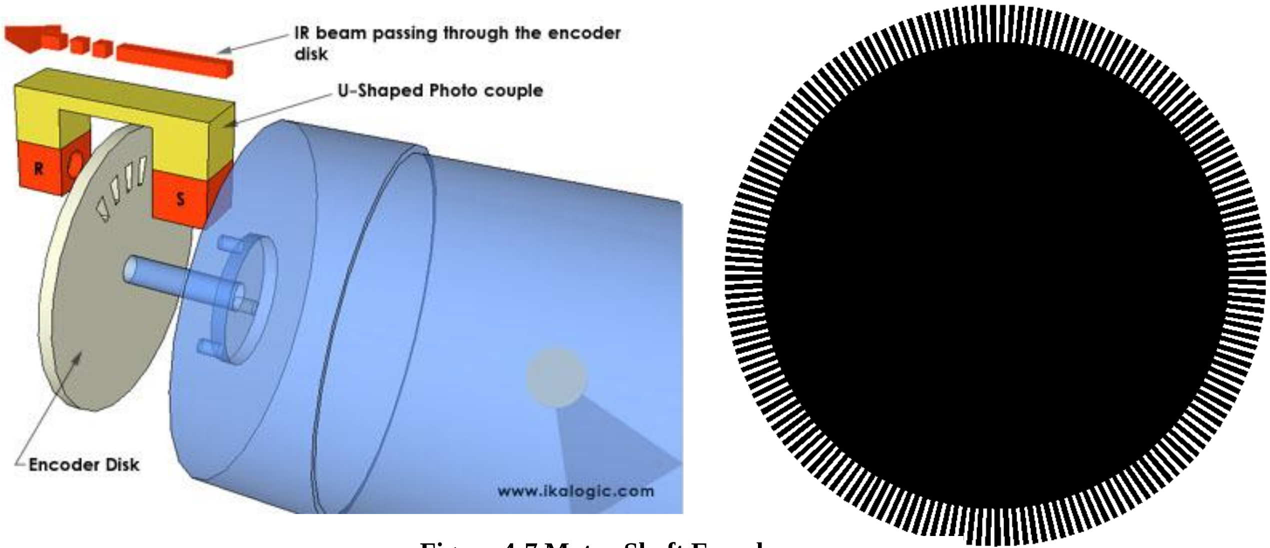


Figure 4-7 Motor Shaft Encoder

shines a beam of light from a transmitter across a small space and detects it with a receiver the other end. If a disc is placed in the space, which has slots cut into it, then the signal will only be picked up when a slot is between the transmitter and receiver. There are several types of encoders. In the robots for the 2008 contest encoder package from HP was used.

4.6 Synchronization of driving motors

To stop a robot swerving in an arc when straight travel is wanted, it is needed to have feedback control of the motor speeds. This means that the actual speed of each wheel is measured, and compared with all the other wheels. Obviously to go in a straight line, the motor speeds must be equal. However, this does not necessarily mean that the speed demand for each motor should be the same. The motors will have different amounts of friction, and so a ‘stiffer’ motor will require a higher speed demand to go as fast as a more free-running motor.

A block diagram of an analogue feedback speed controller is shown below

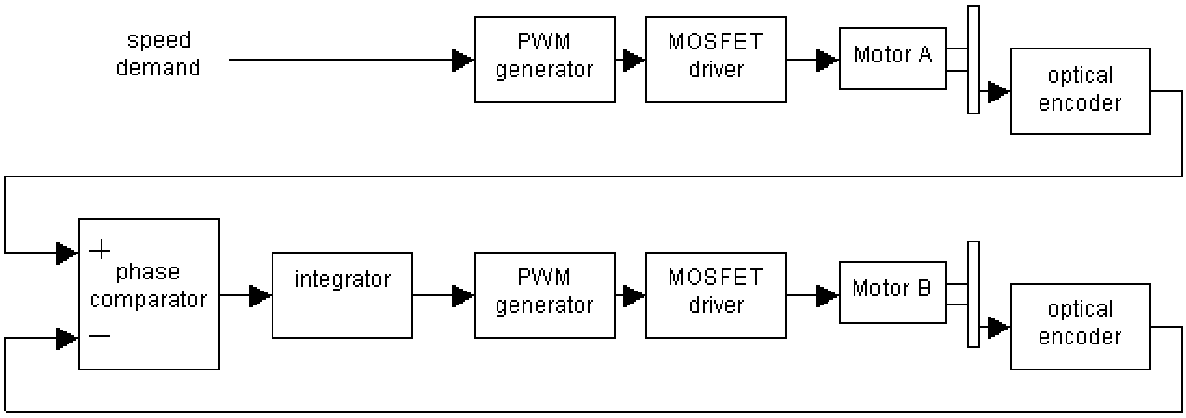


Figure 4-8 Block Diagram of Feedback motor speed and direction control

The speed demand is a DC voltage, which is fed to the PWM generator for motor A. This drives motor A at a speed dependant on the demand voltage. The speed of motor A is sampled using an optical encoder. This has a frequency output, which is proportional to the speed of the motor.

If it is assumed that motor B is already running at some speed, then the optical encoder on its shaft will be producing a frequency also. The phase comparator compares the two frequencies, effectively comparing the speeds of the two motors. Its output is a signal which gets larger as the two input frequencies get further apart. If the two frequencies are the same, it has a zero output.

The integrator adds the output of the phase comparator to whatever its output was before. For example, if the integrator output was previously 3 volts, and its input is 0 volts, then its output will be 3 volts. If its input changed to –1 volts, then its output would change to 2 volts.

Let’s assume that motor B is running slower than motor A. Then the output of the phase comparator will be positive, and the output of the integrator will start to rise. The speed of motor B will then increase. If it increased to a speed greater than that of motor A, then the output of the phase comparator would become negative, and the output of the integrator would start to fall, thereby reducing the speed of motor B. In this manner, the speed of motor B is kept the same as the speed of motor A, and the robot will go in a straight line (as long as its wheels are of the same size).

This method can be expanded to use any number of wheels. One motor will always be the directly driven one (in this case motor A), and the others will have their speed locked to this one. Note that if the directly driven motor is faster, or more free-running, than the others, then when it is driven at its fastest speed (the PWM signal is always ON), then the other motors will never be able to keep up, and the robot will still swerve. It is best, therefore, to directly drive the slowest motor.

An analogue feedback speed controller such as this is quite difficult to make, and keep stable. It is easier to perform this function using software in an onboard microcontroller. In this project PIC18 series microcontroller is used.

4.7 Controller

Controller could be said as the brain of the robot. Robots judge the environments asses the sensor inputs and take necessary decisions to act as a robot using controller. As a controller microcontroller, computer, microprocessor with other devices could be used. Among them as a controller microcontrollers are widely used.

In this project microcontroller from PIC microchip PIC18F452 has been used. Along with this microcontroller crystal of 4MHz was used. This is necessary as crystal is not included with PIC packages. The pin configuration of the microcontroller is as follows.

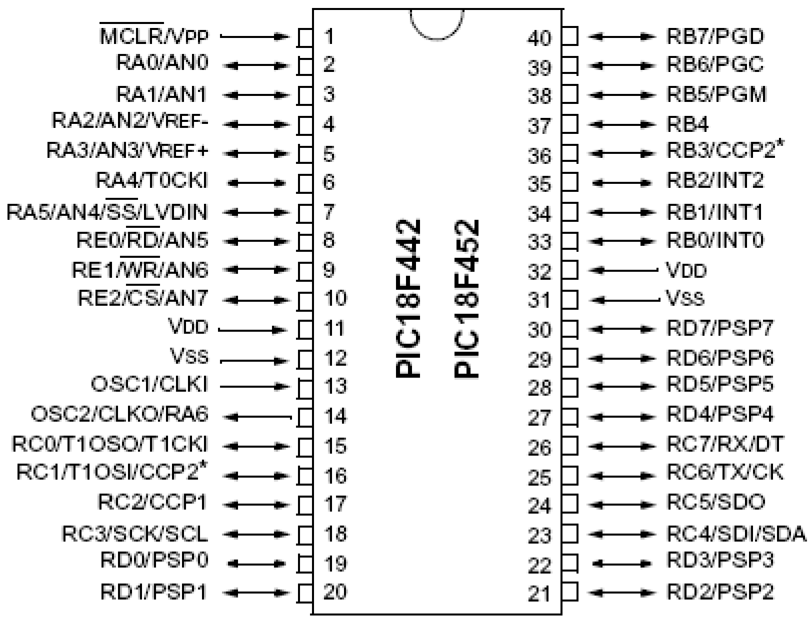


Figure 4-9 PIC microcontroller

Several features of microcontroller that are used to program the robots are as follows:

- Input and Output
- Reset
- PWM
- Timer
- Interrupts

4.7.1 Input and Output

Input and output ports directly react with outer world. When a microcontroller I/O pin is set at input mode and a voltage over 3V is applied it reads it as an input. If I/O pin is set on output state then microcontroller would give constant 5V as an output. There are either five ports or three ports available. Ports contains 8~3 pins. Some pins of the I/O ports are multiplexed with an alternate function from the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin. Each port has three registers for its operation. These registers are:

- TRIS register (data direction register)
- PORT register (reads the levels on the pins of the device)
- LAT register (output latch)

The data latch (LAT register) is useful for read-modify-write operations on the value that the I/O pins are driving.

To define the pins or ports as input or output the TRIS register should be configured. Setting this register to high would set a port or pin as input port or pin. Setting it to low would let it be worked as output.

The PORT register reads the status of the pins, whereas writing to it will write to the port latch.

The Data Latch register (LAT) is also memory mapped. The Read-modify-write operation on the LATA register reads and writes the latched output value for PORTA.

4.7.2 Reset

To handle unexpected situations resets to the microcontrollers are necessary. There may be various types of resets. The PIC18F452 differentiates between various kinds of RESET:

- Power-on Reset (POR)
- MCLR Reset during normal operation
- MCLR Reset during SLEEP
- Watchdog Timer (WDT) Reset (during normal operation)
- Programmable Brown-out Reset (BOR)
- RESET Instruction
- Stack Full Reset
- Stack Underflow Reset

Though there are various types of resets available only Power-on-Reset and MCLR Reset were used. The first one resets the memory and registers while power comes to the microcontroller. The MCLR reset is active when this pin is grounded from 5V source.

4.7.3 Pulse With Modulation (PWM)

The microcontroller used has built in functions to generate PWM frequency as determined by the program code. To use the PWM CCP1CON/CCP2CON registers should be configured. The register mapping is as follows

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	DCxB1	DCxB0	CCPxM3	CCPxM2	CCPxM1	CCPxM0
bit 7							bit 0

Figure 4-10 Register for PWM configuration

To use the pins 16 and 17 the following settings should be done.

bit 7-6 **Unimplemented:** Read as '0'
bit 5-4 **DCxB1:DCxB0**: PWM Duty Cycle bit1 and bit0
bit 3-0 **CCPxM3:CCPxM0**: CCPx
11xx = PWM mode (x = could be any value)

PWM capability is provided through the use of Timer2 and the CCPR1 Registers as shown in figure below:

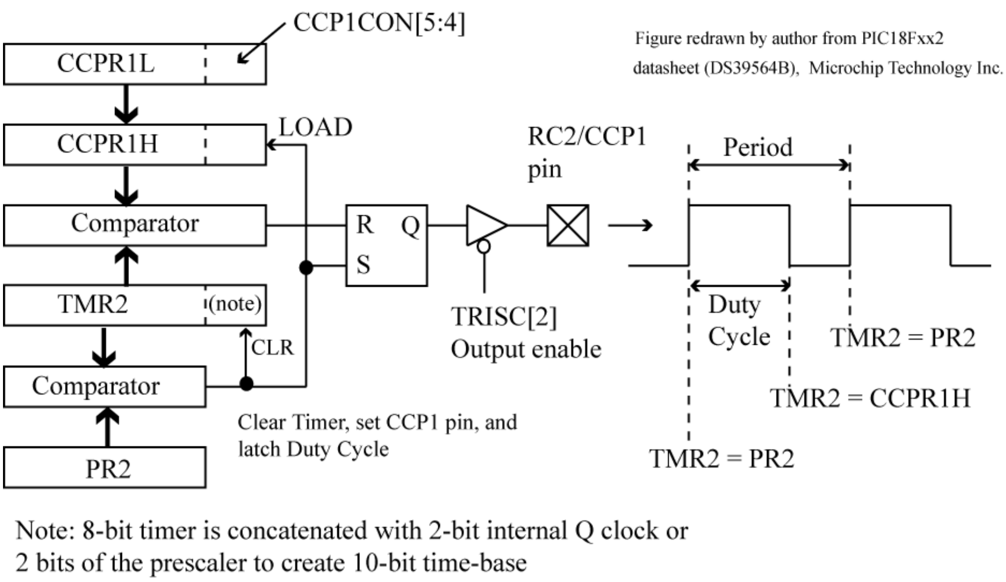


Figure 4-11 Registers used for PWM Generation

The PR2 register sets the period of the generated square wave, while the CCPR1H register provides the duty cycles. A match of the PR2 register and TMR2 values sets the CCP1 pin high, clears the TMR2 register, and transfers the CCPR1L value to CCPR1H to fix the duty cycle. A match of TMR2 with CCPR2H resets the CCP1 pin, thus terminating the high portion of the square wave. Both PR2 and the duty cycle are extended to 10 bits of precision; the PR2 register by using the 2 bit internal Q clock or 2 bits of the Prescaler and the duty cycle by using the CCP1CON[5:4] bits as the lower 2 bits of the 10 bit duty cycle value.

PWM Period = (PR2+1) * 4 * TOSC * TMR2_PRE

PWM Duty Cycle = (CCPR1L:CCP1CON[5:4])*TOSC*TMR2_PRE

%Duty Cycle = CCPR1L/(PR2+1)*(100%)

4.7.4. Timer

Timer is another useful feature used in microcontroller. In PIC18F452, there are 4 timers naming as Timer0, Timer1, Timer2, and Timer3. The different timers can be set as different bit mode. As an example, Timer0 can be set as 8 bit mode or 16 bit mode. The prescaler value of the timer sets the accuracy of the timer. The timer is usually used to measure the signal period. Each timer needed a clock pulse for the timing. These clocks can be divided into 2 divisions

- Timer with internal clock
- Timer with external clock

Measuring signal period is common problem in embedded systems. This can be measuring time between two events or measuring signal frequency f=1/T and so on. Measuring of time interval or period is based on comparing of event time t with discrete time usually produced by timer. This usually is done by filling the event time t with discrete time intervals Δt. According to this, discrete time signal period has to be much shorter than event time: Δt<< t. Then counting these short time intervals it can determine the event time.

In the project both the internal and external clock was used. Internal clock was used to count and measure the time passed. It measures the time and decides which actions to be performed.

In the external clock, external signals are used as a clock unit. The MCU counts the time taking that signal as a base. When certain counts are done necessary actions are taken according to the program code written.

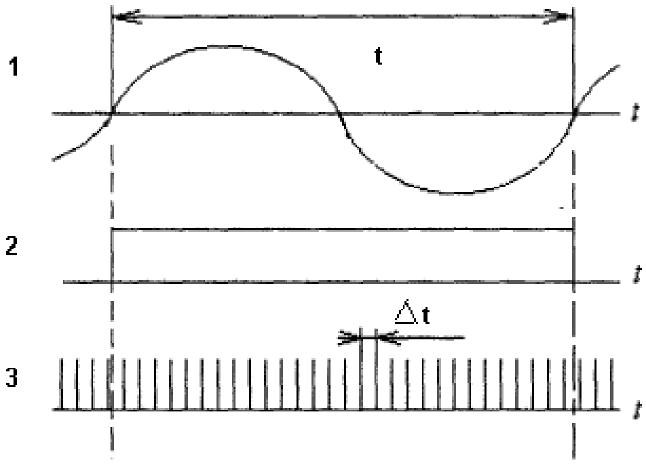


Figure 4-12 Effect of time intervals

In PIC18F452 the timers are able to provide the following functions

Timer0:

The Timer0 module has the following features:

- Software selectable as an 8-bit or 16-bit timer/ counter
- Readable and writable
- Dedicated 8-bit software programmable prescaler
- Clock source selectable to be external or internal
- Interrupt-on-overflow from FFh to 00h in 8-bit mode and FFFFh to 0000h in 16-bit mode
- Edge select for external clock

Timer1:

The Timer1 module timer/counter has the following features:

- 16-bit timer/counter (two 8-bit registers; TMR1H and TMR1L)
- Readable and writable (both registers)
- Internal or external clock select
- Interrupt-on-overflow from FFFFh to 0000h
- RESET from CCP module special event trigger

Timer2:

The Timer2 module timer has the following features:

- 8-bit timer (TMR2 register)
- 8-bit period register (PR2)
- Readable and writable (both registers)
- Software programmable prescaler (1:1, 1:4, 1:16)
- Software programmable postscaler (1:1 to 1:16)
- Interrupt on TMR2 match of PR2
- SSP module optional use of TMR2 output to generate clock shift

Timer3:

The Timer3 module timer/counter has the following features:

- 16-bit timer/counter (two 8-bit registers; TMR3H and TMR3L)
- Readable and writable (both registers)
- Internal or external clock select
- Interrupt-on-overflow from FFFFh to 0000h
- RESET from CCP module trigger

4.7.5. Interrupts

In robotics projects there might cases where signals from the environment may be received when it is not expected but that signal might be necessary to asses and take proper decisions. In the robots that were manufactured there are many touch sensors or limit switch sensors. If signals are received from them then necessary actions are required. These types of problem could easily be solved by interrupts.

An interrupt is an event in hardware that triggers the controller to jump from its current program counter to a specific point in the code. Interrupts are designed to be special events whose occurrence cannot be predicted precisely (or at all). The controller has many different kinds of events that can trigger interrupts, and for each one the controller will send the execution to a unique, specific point in memory. Each interrupt is assigned a word long segment at the upper end of memory. This is enough memory for a jump to the location in memory where the interrupt will actually be handled. Interrupts in general can be divided into two kinds.

- Maskable
- Non-maskable.

A maskable interrupt is an interrupt whose trigger event is not always important, so the programmer can decide whether the event should cause the program to jump to the ISR (interrupt service routine) or not.

A non-maskable interrupt (like the reset button) is so important that it should never be ignored. The controller will always jump to this interrupt when it happens.

Often, maskable interrupts are turned off by default to simplify the default behavior of the device. Special control registers allow non-maskable and specific non-maskable interrupts to be turned on.

There are several interrupt inputs. For this reason interrupts generally have a "priority;" when two interrupts happen at the same time, the higher priority interrupt will take precedence over the lower priority one. Thus if a peripheral timer goes off at the same time as the reset button is pushed, the processor will ignore the peripheral timer because the reset is more important (higher priority).

Interrupts shows generally 3 kinds of execution process.

i. Rising edge interrupt
ii. Falling edge interrupt
iii. Change mode interrupt

In PIC18F452, INT0, INT1, INT2 are the interrupts which are used either in rising mode interrupt or falling edge interrupt, while all RB port can be used as an interrupt port in change mode. In the change mode, either change of the state from zero to one or one to zero will cause interrupt. On the other hand rising edge and falling edge will call the interrupt function (ISR) when the rising edge and falling edge occurs respectively in the input.

When the interrupt first occurs on the controller there is a precise order of events that will occur. This process takes 6 instruction cycles to occur.

1. The current instruction completes.

2. The program counter as it is after the above instruction is pushed onto the stack. The stack is memory whose contents are kept in last in first out order. The stack pointer is always updated to point to the most recent element added to the stack. This allows the processor to call functions and track interrupts. When something is pushed onto the stack, the stack pointer is incremented and the pushed data is written to that location. When you copy out of the stack and decrement the stack pointer, this is called popping something off the stack.

3. The status register is pushed onto the stack.

4. The highest priority interrupt waiting to occur is selected.

5. Single source interrupts have their interrupt request flags reset automatically. Multiple source interrupt flags do not do this so that the interrupt service routine can determine what the precise cause was.

6. The status register is cleared. This will bring the processor out of any low-power modes. This also disables interrupts (the GIE bit) during the interrupt.

7. The content of the interrupt vector is loaded into the program counter. Specifically the processor executes the instruction at the particular memory location (the interrupt vector) for that interrupt. This should always be a jump to the interrupt service routine.

   The registers used in the interrupts are:

   - INT0IF
   - INT0IE
   - RBPU
   - INTEG0
   - IPEN
   - GIE
   - GIEL

Interrupts may be occurred internally and externally. Internal interrupts are those one which occurs when the microcontroller sets the bit for an internal interrupts. Several causes that could create internal interrupt are timer overflow, memory overflow etc. The overflow of T0CKI and T1CKI are the examples of internal interrupts.

External interrupts are those who occurred because of the external trigger on the desired pin of microcontroller. In the PIC 18F452 there are 3 pins for external interrupts. They are pin 0,1 and 2 of Port B.

Chapter 5 Computer Modeling and Simulation

Simulation is the imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviors of a selected physical or abstract system. Simulation is used in many contexts, including the modeling of natural systems or human systems in order to gain insight into their functioning. It would provide an ease if used properly in designing the robots. Other contexts include simulation of technology for performance optimization, safety engineering, testing, training and education. Simulation can be used to show the eventual real effects of alternative conditions and courses of action.
Key issues in simulation include acquisition of valid source information about the referent, selection of key characteristics and behaviors, the use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation outcomes.

A robotics simulator is used to create embedded applications for a specific (or not) robot without depending "physically" on the actual robot, thus saving cost and time. In some case, these applications can be transferred on the real robot (or rebuilt) without modifications. The term robotics simulator can refer to several different robotics simulation applications. For example, in mobile robotics applications, behavior-based simulators allow users to create simple worlds of rigid objects and light sources and to program robots to interact with these worlds. Behavior-based simulation allows for actions that are more biological in nature when compared to simulators that are more binary, or computational. In addition, behavior-based simulators can "learn" from mistakes and are capable of demonstrating the anthropomorphic quality of tenacity.

Modern simulators tend to provide the following features:

- Fast robot prototyping
- Using the own simulator as creation tool (Webots, R-Station, Marilou).
- Using external tools (Gazebo uses Blender).
- Physics engines for realistic movements. Most simulators use ODE (Gazebo, Marilou, Webots) or PhysX (Microsoft).
- Realistic 3d rendering. Standard 3d modeling tools or third party tools can be used to build the environments. (Pro Engineering, Solid Works)
- Dynamic robot bodies with scripting. URBI, MATLAB, Python languages used by Webots, Python used by Gazebo etc.

Among several available softwares for simulating the robotic systems “Pro Engineering” was used to design and analysis of several experimental system. The Manual machine and the Ilk BOT were modeled using Pro Engineering. The following figure was created using Pro Engineering and they were simulated for the prediction of several critical issues. The Manual Machine and the Ilk BOT was designed and simulated using this software. The final Image of these two robots gripper was as follows:

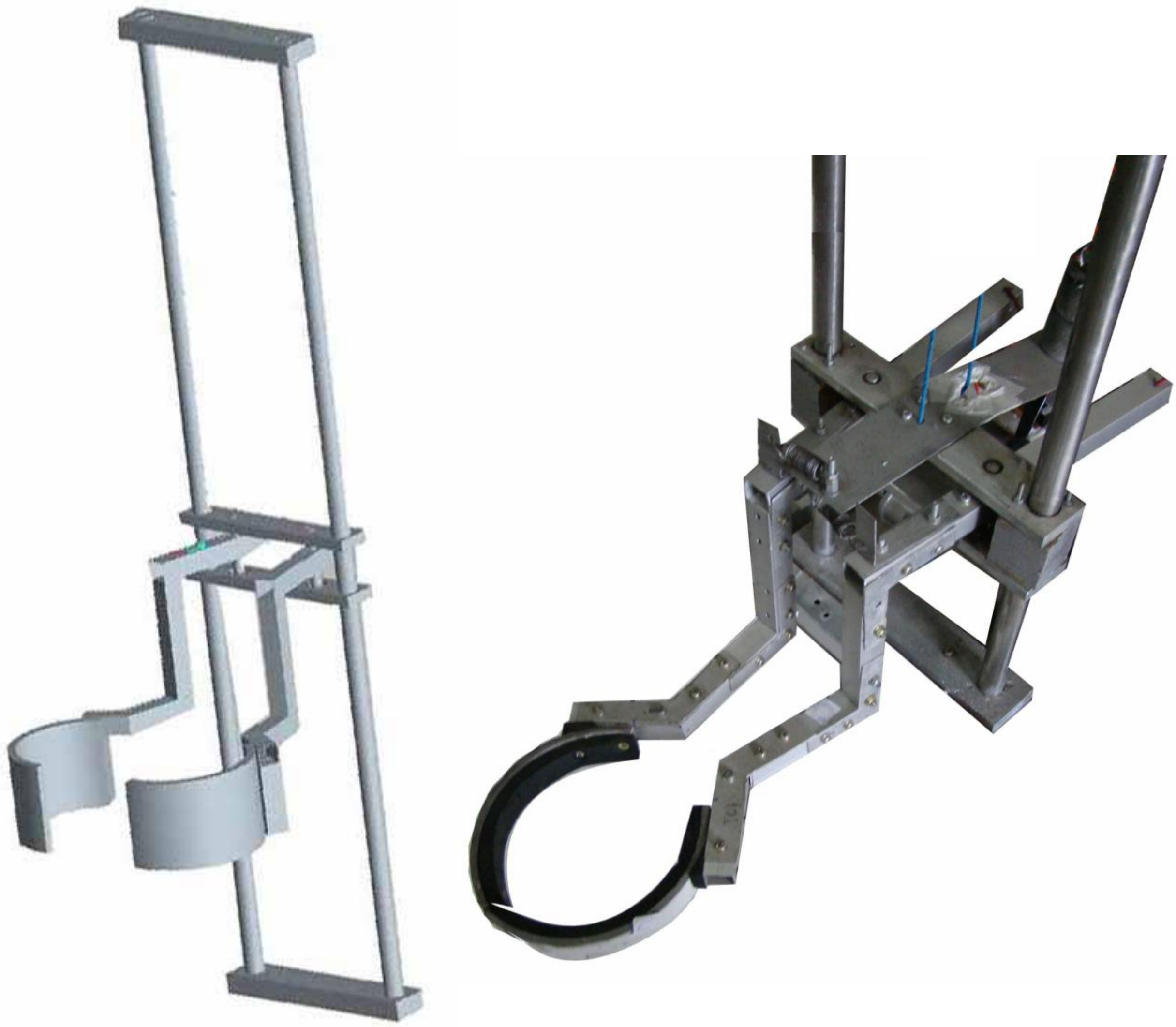


Figure 5-0-1 Pro Engineering Model and actual gripper of Manual machine

The figure above clearly illustrates the similarities between the software model and the actual model.

The Ilk BOT gripper was also designed and simulated. The image of the model and the actual assembly is as follows

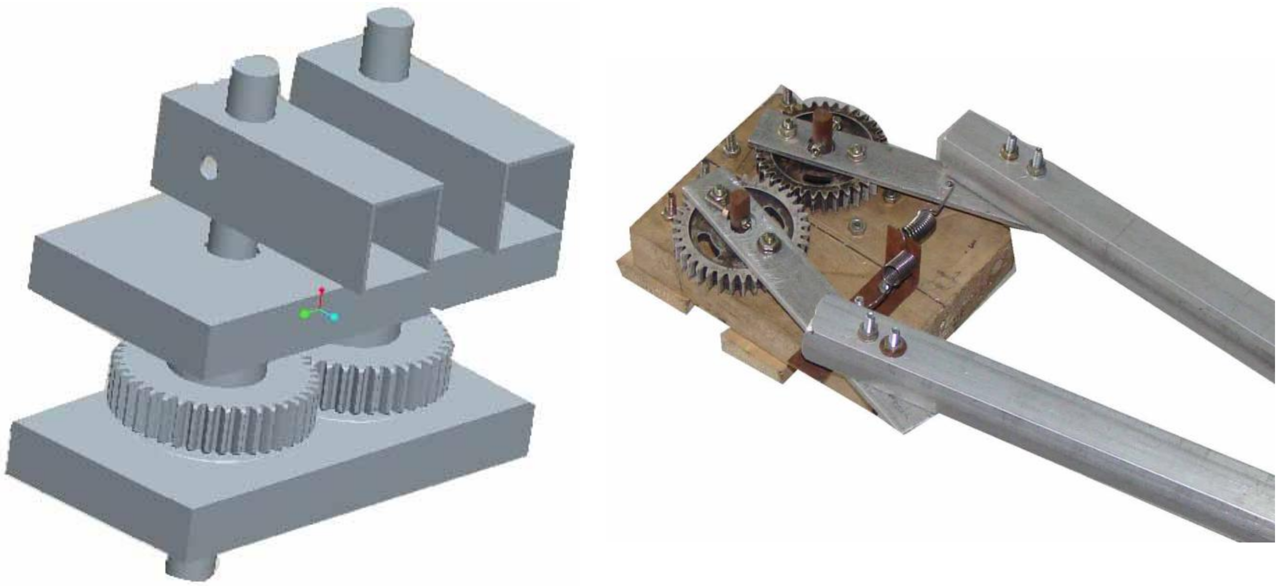


Figure 5-0-2 Gripper of Ilk BOT (Model and Actual system)

Several simulation results of the gripper system designed were found as follows:

	Property	Value
Material "AL2014"	Type	Isotropic
	Density	2.79355e-09 [tonne / mm^3]
	Young's Modulus	73084.4 [N / mm^2]
	Poisson's Ratio	0.33
	Conductivity	192.163 [N / (sec C)]
	Specific Heat	9.63753e+08 [mm^2 / (sec^2 C)]
	Thermal Expansion	2.304e-05 [/ C]
	Shear Stiffness	27475.3 [N / mm^2]
	Failure Criteria	None

Chapter 6 Performance Assessment

6.1 Manual Machine

In every contest of ROBOCON there was one manual machine. This should be operated by an operator. A controller was used to control the manual machine. The performance of the manual machine is some part dependent on the operator. If the other control system is good enough then it would be easier for the operator to operate that machine.

In the contest the manual machine is allowed to move in the manual area zone. This is not required to enter on the automatic zone. The task of manual machine is defined. It may interact with autonomous machine if required with some limitations.

The manual machine in the contest has to move some cylindrical objects with balls placed on it. So extra care should be taken so that jerking and vibration is within desired limit. Otherwise the ball placed over the cylindrical object may fall down. The manual gripper and movements was sufficiently desirable to provide the safety for scoring of robot.

As the robot used motors of low rpm on every system (rotation was only about 66rpm) there was little possibility of beating others using motors of 1000 rpm. The Manual machine has the capability of cleaning the game field within two minutes and thirty seconds of three minutes game while others clear the field within one minute. The performance of the robot was satisfactory but the due to the speed of the motor it was difficult for the team to compete the strongest team in the competition. Without this problem it was a perfect machine. The performance could be increased if motor with high rpm.

6.2 Ilk BOT

This robot was built as a part of the research on various systems used in the robots. Driving system, gripping system, sliding system of various new ways was designed and tried. The performance was satisfactory on every system.

Driving system uses driving motors at front end as well but the mounting of the motor was different. Different type of motor mounting system was used. Experimenting was done and researches were pursued to attain better result and performance.

In the gripper system a new technology with two spur gears was used to reduce the string pulley system. This also facilitates the usage of lower torque rated motors. Use of two springs was eliminated and the purpose was done with using only one spring. This also reduces the weight and dimensions of the robot gripper. The system was proved to be very efficient.

The polar elevation was tried in this robot instead of sliding system. If the system is properly designed it would also act as an efficient system. Though string pulley system was used there was no problem and probability of failure is less than that of other sliding system because the possibility of jamming is reduced.

Chapter 7 Further Developments

There are scope of developments in each systems used. Other system could also be introduced to improve the performance of the robots manufactured.

7.1 Mechanical Developments

Better mechanical systems, machining systems and materials could also be employed to improve the mechanical system. The basic systems used to manufacture the robots have vast area of developments.

The drive system determines the speed of the vehicle, gripper movement, the strength of the robot and dynamic performance.

Three common systems used in robotics are

- Electric System
- Hydraulic System
- Pneumatic System

Motor

The DC motors mounted on the machines were very slow and behaved unpredictably. Most of the motors were collected from rejected textile machinery and marine ships. If high-speed lightweight motors could be collected, the machine′s working cycle would be reduced. Servomotors provide easy control of speed. For higher speed, torque and better control BLDC motors can also be used.

Robot actuator needs to have enough power to accelerate /decelerate the links, carry the loads. In the manufactured robots electrical drive system was used. Electrical motors are controlled using the electronic circuit. Along with electric system pneumatic system could also be used. Hydraulic systems are generally for high powered devices. Using hydraulic system in robots like the one manufactured could be problematic because of the controlling system.

Pneumatic Control

In some cases robotic system could have operate more precisely and efficiently if pneumatic actuation which generates more power than conventional motor drives can be used. It could also be used to assist the electrical drive system. Using speedy motor may not also be the perfect solution because the mat on which robots move in the actual competition is slippery. So there are possibilities of losing control over a robot. Some of the advanced team in the competition uses pneumatic system to increase the drag force to maintain proper control of robots. Pneumatic Control consists of follows equipments

- Air Compression
- Compressed Air Conditioning
- Compressed Air Drying
- Air Distribution
- Air Circuit Construction
- Pneumatic Cylinders
- Air Motors
- Directional Control Valves
- Flow Controls
- Sensors
- Physical Principles
- Circuit Presentation and Analysis
- Step-Counter Circuits
- Cascade Circuits
- Combinational Circuits

Air Compressor is used to store energy as a compressed air in the pneumatic Cylinder and with the help of a solenoid valve the cylinder is closed. In a desire moment the valve is set open and the energy of the compressed air is released. This system is quicker and efficient if could have done properly.

7.2 Material

In design and fabrication of the robots basically aluminum was the main material. Sometimes mild steel was also used when strength is the concern. Aluminum has the best strength weight ratio among the monolithic metals and material available in local market.

In robot building weight has always been a matter to be concerned, so to lessen the weight; use of composites can be a very good option. Some composites have specific strength (ratio strength to density) almost ten times greater than that of aluminum. Those materials also hold high specific modulus. So weight could be minimized to a great extent.

7.3 Electrical Developments

Developments in the electrical controlling systems would make the robots smarter. Using of advanced sensors, controllers, components etc would also assist the robot to better interact with the environment and better program would provide better intelligence to that robots. According to the needs several electronics system that could be used is

- Ultra-sonic Sensor
- Vision Sensor

- Pneumatic Control
- Line Follower
- Advanced Motor control Circuit

7.3.1 Ultra-sonic Sensor

Ultrasonic sensors may be used for detection of blocks, measuring the distance and targeting the desired post. The Ultrasonic Distance Sensor measures the distance or presence of a target object by sending a sound wave above the range of hearing at the object and then measuring the time it takes for the sound echo to return. By

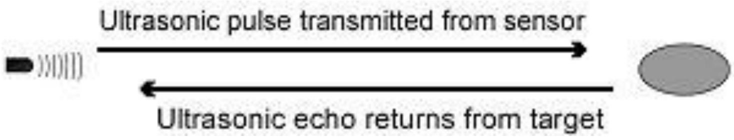


Figure 7-0-1 Ultrasonic Sensor working principle

knowing the speed of sound, the sensor can determine the distance of the object from the transducer element.

The Ultrasonic Distance Sensor is available in two different output type:

- Ultrasonic Sensor with Analogue Voltage Output
- Ultrasonic Sensor Digital Output

The sensor gives a voltage output proportional to the distance after the distance (time) is measured. Ultrasonic sensors are available in the local market at reasonable prices. This sensor gives voltage output from the range of 0~1mV depending on the sound wave received. This sensor should be programmed properly with a controller to produce necessary digital output to process signals.

7.3.2 Vision Sensor

Many of today's vision and recognition applications require the extraction of pertinent image features in real time, without necessarily having to acquire and process the whole image as traditional image processing systems. If the Robots have this kind of Vision sensor it would have the ability to sense objects more accurately on the fields. Robot can also sense opponent robots by vision sensors and can block them or could avoid collision with them.

During the past years, several optical sensors have been developed, which are capable of performing on-chip pre-processing tasks at the pixel level that dramatically simplify the extraction of the desired information. First implementations aimed at functionalities such as light adaptation and spatio-temporal filtering, properties similar to those found in the biological retina. The most recent generation of vision sensors introduces a variety of fundamentally new properties. They process the image information in a pixel-parallel way and can be programmed to represent process and extract the relevant image features, in real time.

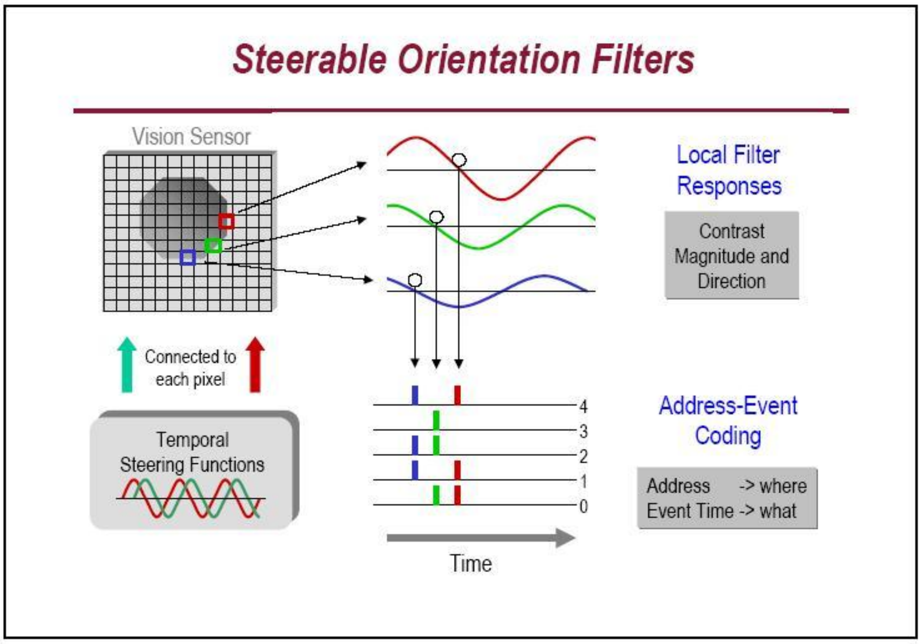


Figure 7-2 Vision Sensor working principle

64x64 and 128x128 pixel vision sensors have been designed and successfully integrated and characterized. They reliably represent image contrasts down to about one percent, over a range of more than six orders of magnitude in illumination intensity. They are highly flexible and can therefore be used for many real-time vision tasks, as required in robotics interfacing applications.

APPENDIX

The Objective

Two (2) opposing teams (a Red team and a Blue team) will operate Manual machines and Autonomous machines and attempt to get at the pots of butter placed at a height and remove the large cube of Butter (Makhkhan) from the bowls. A few of the machines would also attempt to “Steal” the Earthen Pots (Matkas) containing balls of Cheese (Paneer) being carried by the Young Girls (Gopis). Points are earned when the Butter is removed from the Bowls placed at a height.

Points could also be earned when a Pot and/or Cheese is transferred to a Basket. The team which picks up all the three butter cubes directly from the bowls and holds them in the air will be declared “GOVINDA” (the winner) and the game will be over.

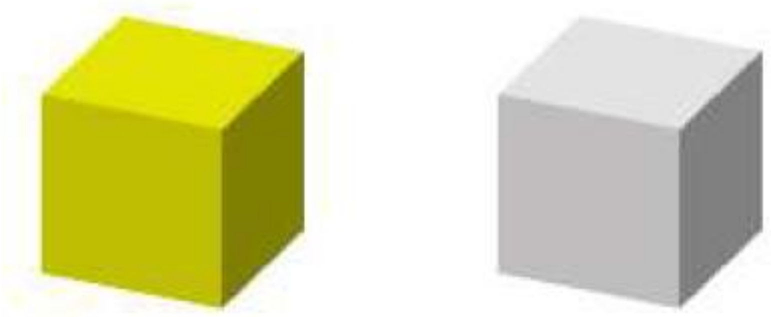
If no team becomes “GOVINDA”, the team which accumulates more number of points within the specified time of three (3) minutes will be declared as the winner.

Definition of words and their representation in the game

Words in bracket are translation in Hindi language

1) Butter (Makhkhan)

Butter is represented by a 200 mm cube of low density polystyrene painted Yellow for the Central Bowl. For the Side Bowl, the cube is of the same size and is painted White.

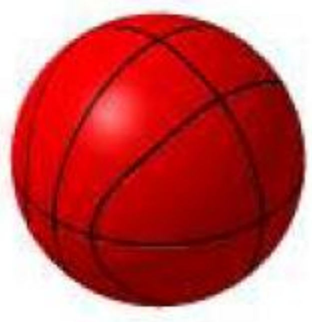


2) Earthen Pot (Matka)

A hollow thin walled cylindrical Pot made up of light weight plastic material with a wide mouth on the top.

3) Cheese (Paneer)

The Cheese is represented by a light weight miniature basket ball which rests on the mouth of the pot with most of it visible above.

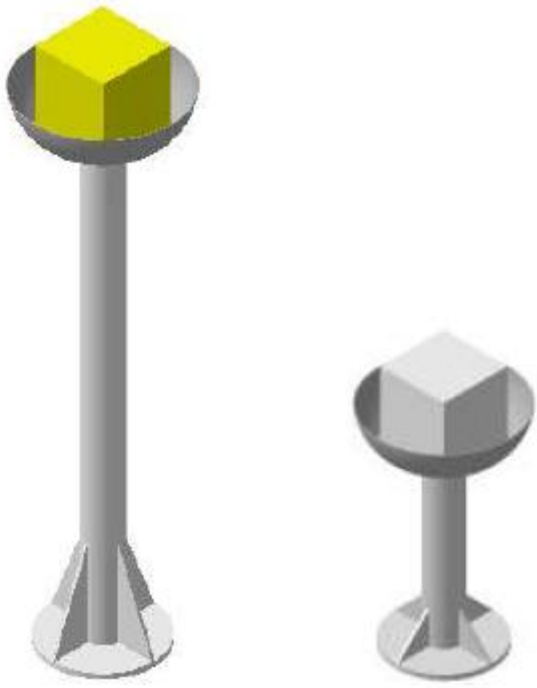


4) Central Bowl (Handi)

This Bowl is placed in the centre of the game field. Yellow colored Butter cube is placed in it.

5) Side Bowl

There are two (2) Side Bowls, one in each half of the game field. White colored Butter cubes are placed in these Bowls.



Central Bowl

Side Bowl

The Game Field with various Objects

The game is played on a game field (sized 14500 mm x 13000 mm), which is surrounded by a 100 mm high and 30 mm wide wooden wall. The floor of the game field is made of 2 mm thick vinyl sheet. The field consists of a Manual Area in pacific blue color, an Autonomous Area in green color and Common Areas colored red and blue for respective team.

Manual and Autonomous Areas

The Manual machines can move freely in the Manual Area but cannot enter the Autonomous Area. The Autonomous machines can move freely in the Autonomous Area but cannot enter the Manual Area.

The Autonomous Area is H-shaped (overall size 9500mm X 8000mm) and surrounded by a wooden wall of 50 mm height and 30 mm in width. There is a grid of lines in the Autonomous Area and these lines are made of 30 mm wide White, non-shiny tape.

Manual machine Start zone

Manual machine Start zone is a square (1000 mm x 1000 mm) and is located in the Manual Area. There are two (2) Manual machine start zones. One, colored red, is for the Red team and the other, colored blue for the Blue team.

Central Bowl

Central Bowl is in the centre of the game field. The Bowl is fastened to the top of tower. The Butter cube with Yellow color is placed in this Bowl. The top surface of this cube is at a height of 1500 mm from the floor of the game field.

Bowls

There are Two (2) Side Bowls in the Autonomous Area. Bowls are fastened to the top of towers. Each of these Bowls carries one White Butter cube. The top surface of these cubes is at a height of 750 mm from the floor of the game field.

Butter

Each butter will be made up of a 200mm cube of low density polystyrene. The butter cube painted Yellow will be placed in Central Bowl and the butter cube painted White will be placed in each Side Bowls. The weight of each Butter cube is 130g (± 20 g).

Machines

Autonomous machines

The entire set of Autonomous machines of a team should fit within a cube of 1000 mm before the game begins and when the machines are in the Autonomous Start zone.

Each autonomous machine's size and form may undergo a change during the game, but each machine should fit into a cube of 1350mm thereafter. Each machine should fit into a 1350mm cube whose bottom is entirely touching the field and no portion of the machine should penetrate this imaginary cube during a match.

The number of Autonomous machines is limited to three (3) maximum and to be used throughout the contest

Power Supply for Machines

Each team shall prepare its own power supply for all its machines.

Voltage of the electric power supply for machines shall not exceed 24V DC.

A Power supply that is considered dangerous or unsuitable by the Contest Committee shall not be permitted.

Weight

All Manual and Autonomous machines including their power sources, cables, remote controller and other parts of each machine shall be weighed prior to the competition. The total allowable weight of all machines and above accessories for each team to be used throughout the contest must not exceed 50 Kg. The total weight of 50kg doesn’t include spare batteries with the same shape, same weight and voltage.

Drawings

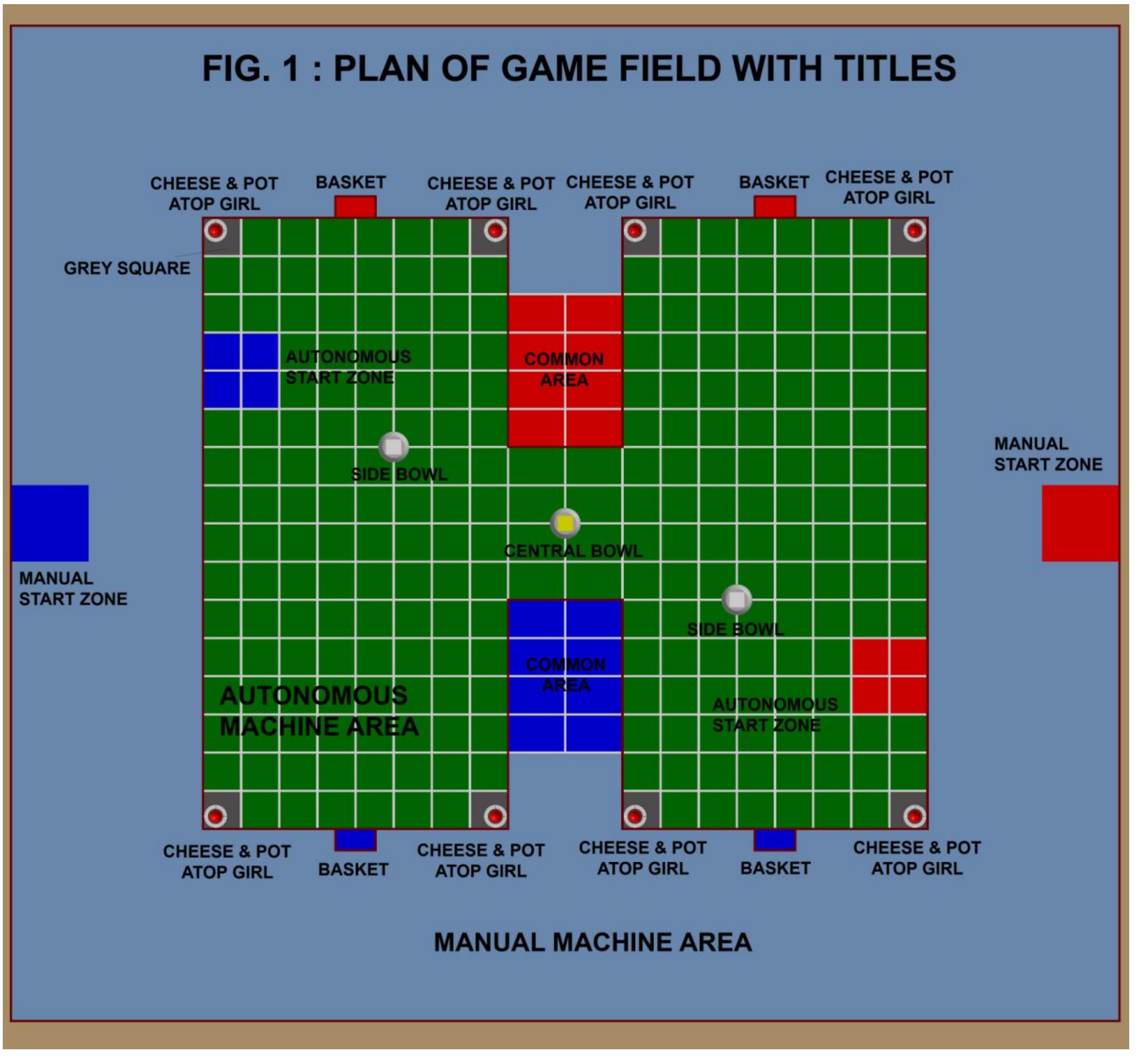
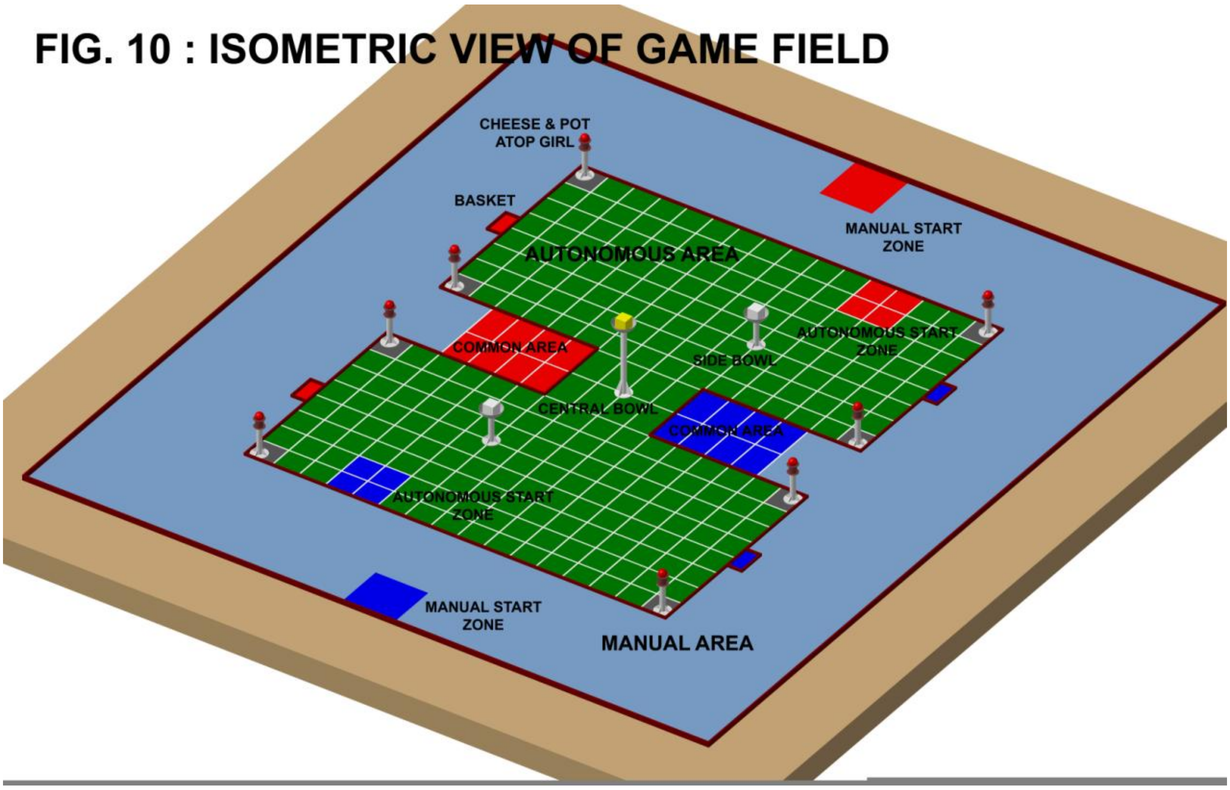
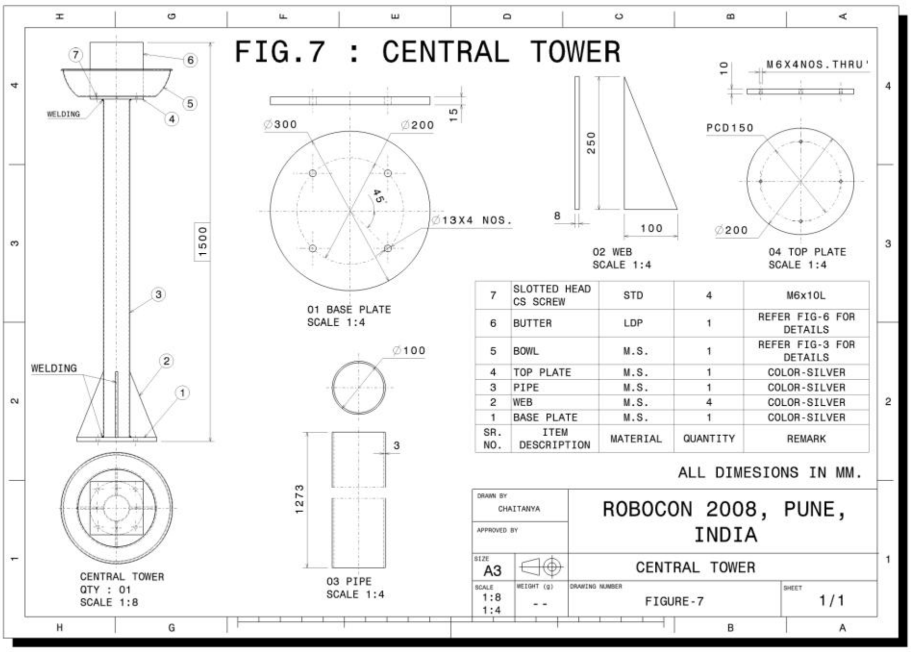
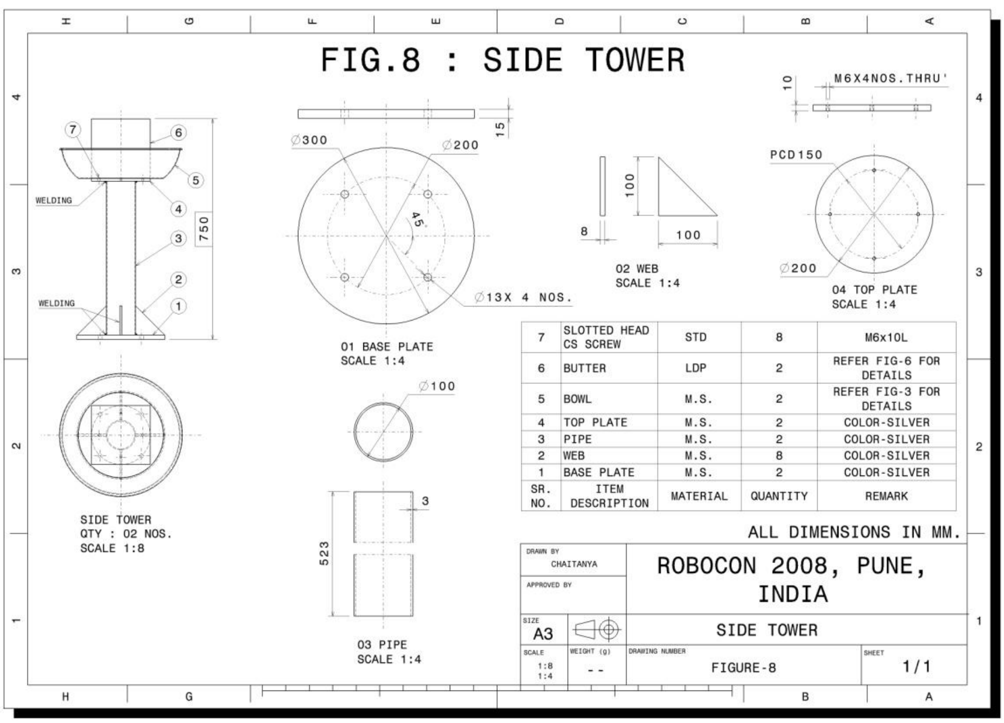


FIG. 1 : PLAN OF GAME FIELD WITH TITLES
CHEESE & POT
ATOP GIRL
BASKET
CHEESE & POT
ATOP GIRL
CHEESE & POT
ATOP GIRL
BASKET
CHEESE & POT
ATOP GIRL
GREY SQUARE
AUTONOMOUS
START ZONE
COMMON
AREA
MANUAL
START ZONE
SIDE BOWL
CENTRAL BOWL
MANUAL
START ZONE
SIDE BOWL
COMMON
AREA
AUTONOMOUS
MACHINE AREA
AUTONOMOUS
START ZONE
CHEESE & POT
ATOP GIRL
BASKET
CHEESE & POT
ATOP GIRL
CHEESE & POT
ATOP GIRL
BASKET
CHEESE & POT
ATOP GIRL
MANUAL MACHINE AREA

FIG. 10 : ISOMETRIC VIEW OF GAME FIELD







SR. NO.	ITEM DESCRIPTION	MATERIAL	QUANTITY	REMARK
7	SLOTTED HEAD CS SCREW	STD	8	M6x10L
6	BUTTER	LDP	2	REFER FIG-6 FOR DETAILS
5	BOWL	M.S.	2	REFER FIG-3 FOR DETAILS
4	TOP PLATE	M.S.	2	COLOR-SILVER
3	PIPE	M.S.	2	COLOR-SILVER
2	WEB	M.S.	8	COLOR-SILVER
1	BASE PLATE	M.S.	2	COLOR-SILVER

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