Minesweepers: Towards a Landmine-Free Egypt

First National Competition for Humanitarian Demining

http://www.landminefree.org

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Mobile Robot Locomotion and Positioning Systems

Dr. Alaa Khamis, SMIEEE

April 7, 2012

Webinars

ID	Topic	Date & Time	Speaker
1	Minesweepers Rules	March 10, 2012 at 18:00 (Cairo Time)	Minesweepers Organizers
2	Mobile Robot Locomotion and Positioning Systems	April 7, 2012 at 18:00 (Cairo Time)	Dr. Alaa Khamis
3	Buried Mine Detection	April 17, 2012, at 18:00 (Cairo Time)	Dr. Hisham El-Sherif
4	UXO Detection using Machine Vision	April 21, 2012, at 18:00 (Cairo Time)	Dr. Mohamed Salem
5	Autonomous Robot Navigation	April 28, 2012, at 18:00 (Cairo Time)	Prof. Dr. Howard Li
6	Wireless Communication	May 5, 2012, at 18:00 (Cairo Time)	Dr. Ahmed Madian

Objectives

When you have finished this webinar you should be able to:

- Understand different locomotion systems of mobile robots.
- Understand legged locomotion characteristics
- Recognize different mobility configurations of wheeled mobile robots (WMR).
- Understand different positioning techniques of mobile robots.
- Understand how to build robot body
- Learn how to select the right wheel
- Learn how to select the right battery
- Learn how to select the right motor
- Learn how to control the motor

Outline

- Mobile Robot Locomotion
- Legged Mobile Robots (Walking Machines)
- Wheeled Mobile Robots
- Mobile Robot Positioning
- Building the Body [For Reading]
- Choosing the Right Wheel [For Reading]
- Choosing the Power Supply [For Reading]
- Choosing the Right Motor [For Reading]
- Controlling the Motor [For Reading]
- Summary

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- **Mobile Robot Locomotion**
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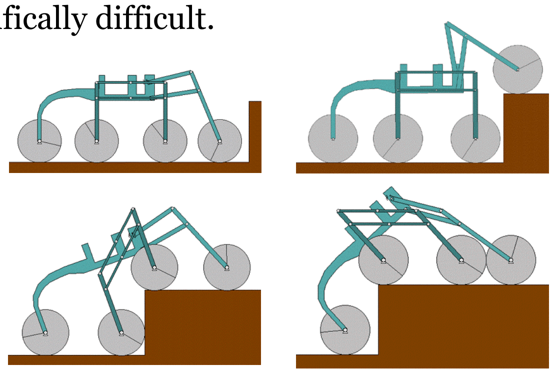
Mobile Robot Locomotion

- Robot locomotion is the study of how to design robot appendages and control mechanisms to allow robots to **move fluidly and efficiently**.
- What might seem a simple matter like negotiating stairs in practice has proved terrifically difficult.

Boston Dynamics BigDog Robot
The Army mule

Boston Dynamics
RHex



SHRIMP Robot, BlueBotics SA

Mobile Robot Locomotion

- In recent years, researchers have increasingly relied on motion capture studies of **insects and other organisms** to hone their designs.

Mobile Robot Locomotion

Unmanned Vehicles for Humanitarian Demining

Unmanned Ground Vehicles (UGVs)

- Legged Vehicles
- Wheeled Vehicles
- Hybrid Vehicles

Unmanned Aerial Vehicles (UAVs) or Drone

- Micro/Mini UAVs
- Tactical UAVs
- Strategic UAVs
- Special Task UAVs

Mobile Robot Locomotion

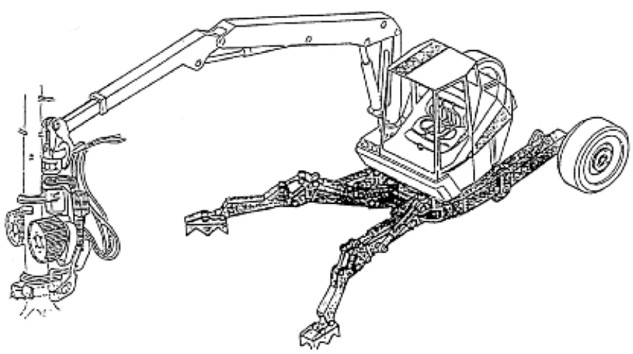
- **Unmanned Ground Vehicles: Walking or rolling?**
  - ◇ Mobile robots generally locomote either using:
    - – **Wheeled mechanisms**, a well-known human technology for vehicles,

    or

    - – using a small number of **articulated legs**, the simplest of the biological approaches to locomotion.

Mobile Robot Locomotion

- **Unmanned Ground Vehicles: Walking or rolling?**
  - ◇ Recently, for more natural outdoor environments, there has been some progress toward **hybrid** and legged industrial robots such as the forestry robot.



RoboTrac, a hybrid wheel-leg vehicle for rough terrain

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Legged Mobile Robots (Walking Machines)

Legged locomotion is characterized by a series of point contacts between the robot and the ground.

Toyota's One-Legged Robot
(Uniped)

Honda Asimo
(Biped)

WowWee Robotics
(Tripod or three-leeged robot)

Pentapod Robot
(5-Legged Robot)

Sony Aibo
(Quadruped)

Hexapod
(6-Legged Robot)

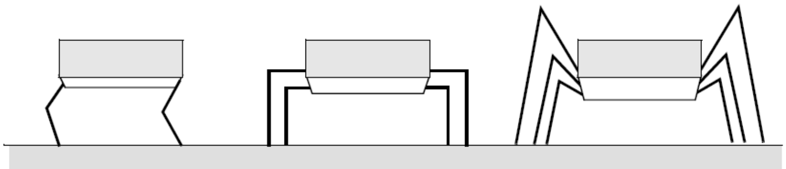
Legged Mobile Robots (Walking Machines)

- **Advantages of legged locomotion:**
  - **Adaptability and maneuverability in rough terrain:** because only a set of point contacts is required, the quality of the ground between those points does not matter so long as the robot can maintain adequate ground clearance. In addition, a walking robot is capable of crossing a hole or chasm so long as its reach exceeds the width of the hole.
  - **Potential to manipulate objects in the environment with great skill:** an excellent insect example, the dung beetle, is capable of rolling a ball while locomoting by way of its dexterous front legs.

Legged Mobile Robots (Walking Machines)

- **Disadvantages of legged locomotion:**
  - **Power:** the leg, which may include **several degrees of freedom**, must be capable of sustaining part of the robot's total weight, and in many robots must be capable of **lifting and lowering** the robot.
  - **Mechanical Complexity:** high maneuverability will only be achieved if the legs have a sufficient number of degrees of freedom to impart forces in a number of different directions.

Legged Mobile Robots (Walking Machines)



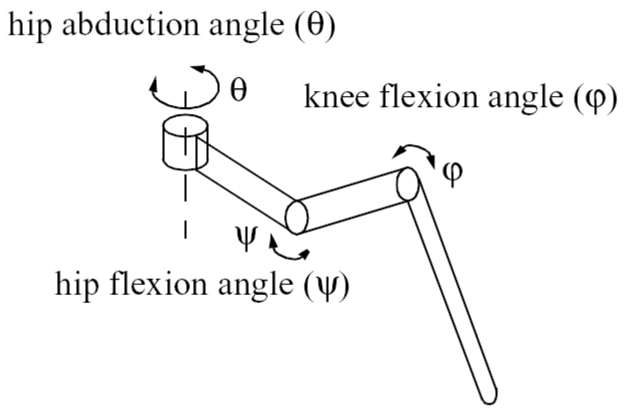
- The fewer legs the more complicated becomes locomotion
  - stability, at least three legs are required for **static stability**
- During walking some legs are lifted
  - thus loosing stability?
- For **static walking** at least 6 legs are required.
  - babies require months to stand and walk, and even longer to learn to jump, run, and stand on one leg.

Legged Mobile Robots (Walking Machines)

- **Degrees of Freedom (DOF)**
  - ◇ A minimum of **two DOF** is required to move a leg forward
    - – Lifting the leg
    - – Swinging it forward.
  - ◇ Three DOF for each leg in most cases for more complex maneuvers.

Legged Mobile Robots (Walking Machines)

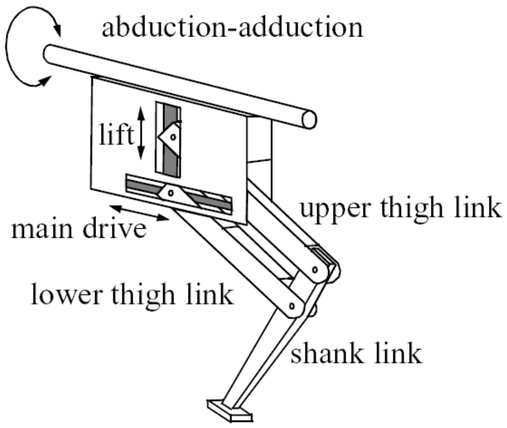
- **Degrees of Freedom (DOF)**



Example of a leg with three degrees of freedom.

Legged Mobile Robots (Walking Machines)

- **Degrees of Freedom (DOF)**



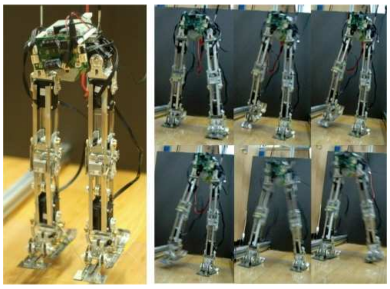
Example of a leg with three degrees of freedom.

Legged Mobile Robots (Walking Machines)

- **Degrees of Freedom (DOF)**
  - ◇ In general, **adding degrees of freedom** to a robot leg **increases the maneuverability** of the robot, both augmenting the range of terrains on which it can travel and the ability of the robot to travel with **a variety of gaits**.
  - ◇ The primary **disadvantages** of additional joints and actuators are, of course, **energy, control, and mass**.
  - ◇ Additional actuators require energy and control, and they also add to leg mass, further increasing power and load requirements on existing actuators.

Legged Mobile Robots (Walking Machines)

- **Number of Possible Gaits**
  - ◇ The gait is characterized as the sequence of lift and release events of the individual legs.



  – it depends on the number of legs.

  – the number of possible events N for a walking machine with k legs is: $N = (2k-1)!$

Legged Mobile Robots (Walking Machines)

- **The number of possible gaits**
  - With two legs (biped) one can have four different states:
    1. Both legs down $\substack{\bullet\\\bullet}$
    2. Right leg down, left leg up $\substack{\circ\\\bullet}$
    3. Right leg up, left leg down $\substack{\bullet\\\circ}$
    4. Both leg up $\substack{\circ\\\circ}$
  - A distinct event sequence can be considered as a change from one state to another and back.

Legged Mobile Robots (Walking Machines)

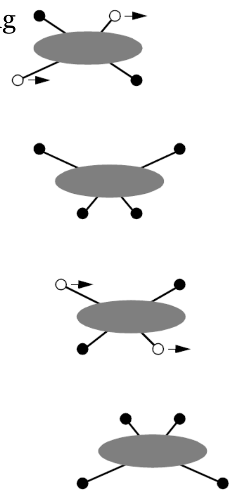
- **The number of possible gaits**
  - The number of possible events N is:

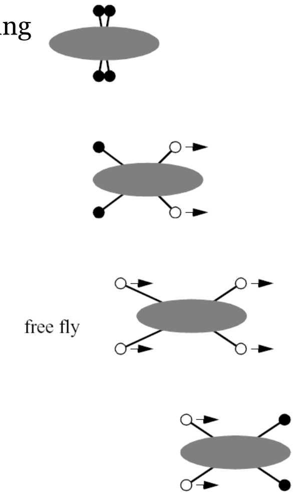
$$N = (2k-1)! = 3! = 3\cdot 2\cdot 1 = 6$$

1→2 →1	$\substack{\bullet\\\bullet}\ \substack{\circ\\\bullet}\ \substack{\bullet\\\bullet}$	→ turning on right leg
1→3 →1	$\substack{\bullet\\\bullet}\ \substack{\bullet\\\circ}\ \substack{\bullet\\\bullet}$	→ turning on left leg
1→4 →1	$\substack{\bullet\\\bullet}\ \substack{\circ\\\circ}\ \substack{\bullet\\\bullet}$	→ hopping with two legs
2→3 →2	$\substack{\circ\\\bullet}\ \substack{\bullet\\\circ}\ \substack{\circ\\\bullet}$	→ walking running
2→4 →2	$\substack{\circ\\\bullet}\ \substack{\circ\\\circ}\ \substack{\circ\\\bullet}$	→ hopping right leg
3→4 →3	$\substack{\bullet\\\circ}\ \substack{\circ\\\circ}\ \substack{\bullet\\\circ}$	→ hopping left leg

Legged Mobile Robots (Walking Machines)

- **The number of possible gaits**
  - ◇ For a robot with 4 legs (Quadruped): $N = 7! = 5040$
    - ▪ Changeover walking
    - ▪ Galloping

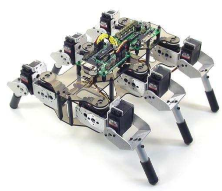




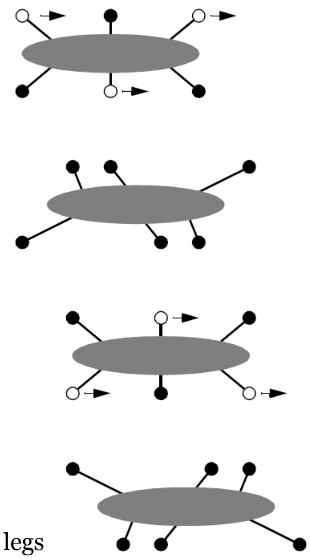
Legged Mobile Robots (Walking Machines)

- **The number of possible gaits**
  - ◇ For a robot with 6 legs (hexapod):

$$N = 11! = 39'916'800$$



Hexapod



Most obvious gaits with 6 legs

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- **Wheeled Mobile Robots**
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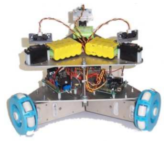
Wheeled Mobile Robots

- Wheels are the most appropriate solution for most applications
- **Three wheels** are sufficient and to guarantee stability.
- With more than three wheels a **flexible suspension** is required.
- Selection of wheels depends on the application.
- **Bigger wheels** allow overcoming **higher obstacles** but they require higher torque or reductions in the gear box.
- Combining **actuation and steering** on one wheel makes the design **complex** and adds additional errors for odometry.



Wheeled Mobile Robots

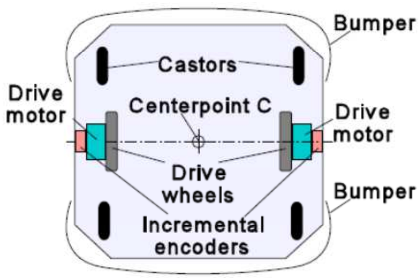
- **Mobility Configurations**

Typical Mobility Configurations
- Differential Drive
- Tricycle Drive
- Ackerman Steering
- Synchro Drive
- Omnidirectional Drive
- Tracked Vehicles
- Multi-Degree-of-Freedom Vehicles
- MDOF Vehicle with Compliant Linkage

Wheeled Mobile Robots

- **Differential Drive**

Differential steered vehicles have two drive wheels, which are responsible for driving and steering. The **steering action** is accomplished by having each wheel to rotate at **different speeds**. This type of configuration provides some additional advantages like forward and backward movements which can be performed at the same speed. In addition, the vehicle requires a smaller area to maneuver.



TRC LabMate platform

Magellan Pro

Cybor

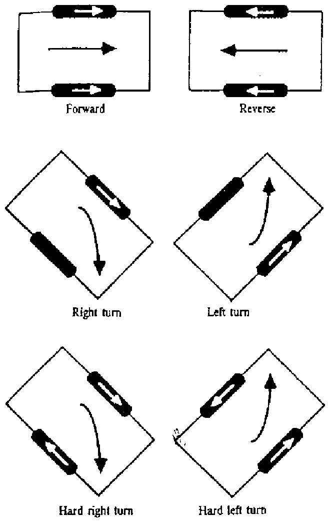
Wheeled Mobile Robots

- **Differential Drive**

V_R is the right motor voltage

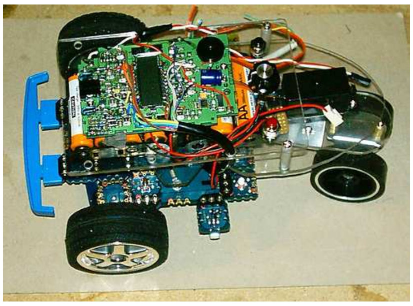
V_L is the left motor voltage.

Voltage	Polarity	Motion	Direction
$V_R=V_L$	+	Translational	Forward
$V_R>V_L$	+	Rotational	CCW
$V_R<V_L$	+	Rotational	CW
$V_R=V_L$	-	Translational	Backward
$V_R>V_L$	-	Rotational	CW
$V_R<V_L$	-	Rotational	CCW



Wheeled Mobile Robots

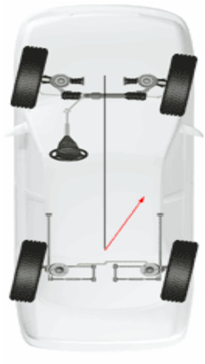
- **Tricycle Drive**
  - ◇ Tricycle-drive configurations employing **a single driven front wheel** and **two passive rear wheels** (or vice versa) are fairly common in AGV applications because of their inherent simplicity.
  - ◇ One problem associated with the tricycle-drive configuration is that the **vehicle's center of gravity** tends to move away from the front wheel when **traversing up an incline**, causing a **loss of traction**.



bulldog2

Wheeled Mobile Robots

• **Ackerman Steering (Car Drive)**



◇ Used almost exclusively in the automotive industry, Ackerman steering is designed to ensure that the inside front wheel is rotated to a slightly sharper angle than the outside wheel when turning, thereby eliminating geometrically induced tire slippage.

◇ Ackerman steering provides a **fairly accurate odometry** solution while supporting the traction and ground clearance needs of all-terrain operation. Ackerman steering is thus the method of choice for **outdoor autonomous vehicles**.

Wheeled Mobile Robots

• **Ackerman Steering (Car Drive)**

◇ Associated drive implementations typically employ a gasoline or diesel engine coupled to a manual or automatic transmission, with **power applied to four wheels** through a transfer case, a differential, and a series of universal joints.

USMC Tele-Operated Vehicle (TOV)

STV (Surrogate Teleoperated Vehicle)

Wheeled Mobile Robots

• **Ackerman Steering (Car Drive)**

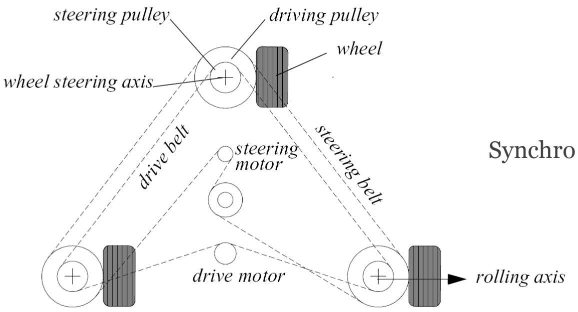
◇ From a **military** perspective, the use of **existing-inventory equipment** of this type simplifies some of the logistics problems associated with vehicle maintenance.

◇ In addition, **reliability** of the drive components is high due to the **inherited stability** of a proven power train. (Significant **interface problems** can be encountered, however, in retrofitting **off-the-shelf vehicles** intended for human drivers to accommodate remote or computer control.)

Wheeled Mobile Robots

• **Synchro Drive**

This configuration known as synchro drive or **all-wheel steering** features three or more wheels **mechanically coupled** in such a way that all rotate in the same direction at the same speed, and similarly pivot in unison about their respective steering axes when executing a turn.



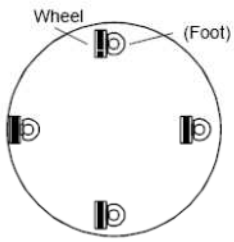
Synchro drive

Wheeled Mobile Robots

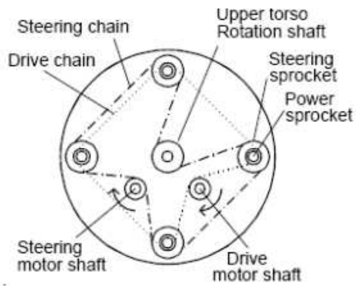
- **Synchro Drive**

This drive and steering "**synchronization**" results in **improved odometry** accuracy through reduced slippage, since all wheels generate equal and parallel force vectors at all times.

This configuration allows the vehicle to move transversally and a diagonal movement is also possible.



B21 Robot Top view



B21 Robot Bottom view

Wheeled Mobile Robots

- **Synchro Drive**

The required mechanical synchronization can be accomplished in a number of ways, the most common being a chain, belt (like in B21), or gear drive.

Carnegie Mellon University has implemented an electronically synchronized version on one of their Rover series robots, with dedicated drive motors for each of the three wheels.

Chain- and belt-drive configurations experience some degradation in steering accuracy and alignment due to uneven distribution of slack, which varies as a function of loading and direction of rotation. In addition, whenever chains (or timing belts) are tightened to reduce such slack, the individual wheels must be realigned. These problems are eliminated with a completely enclosed gear-drive approach.

iRobot B21

Denning Blacky

Wheeled Mobile Robots

- **Synchro Drive**

In a synchronous drive robot, each wheel is capable of being driven and steered.

Typical configurations

◇ Three steered wheels arranged as vertices of an equilateral

◇ Triangle often surmounted by a cylindrical platform

◇ All the wheels turn and drive in unison

This leads to a **holonomic behavior**.

Wheeled Mobile Robots

- **Synchro Drive**

In robotics **holonomicity** refers to the relationship between the controllable and total degrees of freedom of a given robot (or part thereof). If the **controllable degrees of freedom** are **equal** to the **total degrees of freedom** then the robot is said to be **holonomic**.

If the controllable degrees of freedom is less than the total degrees of freedom it is non-holonomic.

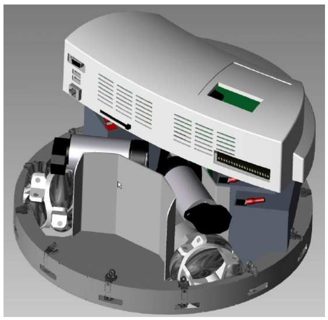
Holonomic Robot

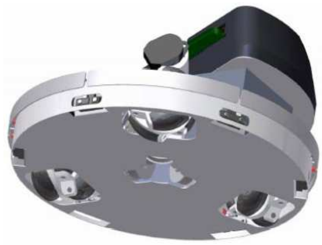
Non-holonomic Robot

Robot can move in some directions (forwards and backwards), but not others (side to side).

Wheeled Mobile Robots

- **Omnidirectional Drive**
  - ◇ This configuration is a multi-degree of freedom configuration.
  - ◇ Movement in the plane has 3 DOF thus only three wheels can be independently controlled.
  - ◇ It might be better to arrange three Swedish wheels in a triangle.



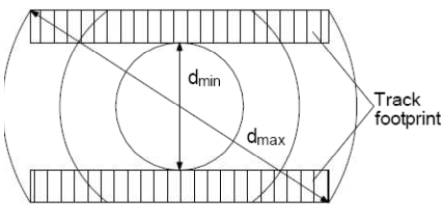


Uranus, CMU: Omnidirectional Drive with 4 Wheels

Festo Robotino

Wheeled Mobile Robots

- **Tracked Vehicles**
  - ◇ This very special implementation of a **differential drive** is known as **skid steering** and is routinely implemented in track form on bulldozers and armored vehicles.
  - ◇ Such **skid-steer** configurations intentionally rely on **track or wheel slippage** for normal operation, and as a consequence provide rather poor dead-reckoning information.



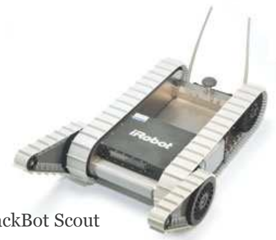
The effective point of contact for a skid-steer vehicle is roughly constrained on either side by a rectangular zone of ambiguity corresponding to the track footprint. As is implied by the concentric circles, considerable slippage must occur in order for the vehicle to turn.

More information: Tracked Vehicle Steering, http://www.gizmology.net/tracked.htm

Wheeled Mobile Robots

- **Tracked Vehicles**
  - ◇ **Skid steering** is generally employed only in **tele-operated** as opposed to **autonomous** robotic applications, where the ability to surmount significant floor discontinuities is more desirable than accurate odometry information.
  - ◇ An example is seen in the track drives popular with remote-controlled robots intended for explosive ordnance disposal.

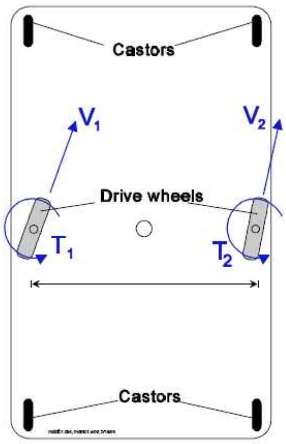
Remotec Andros V tracked vehicle



PackBot Scout

Wheeled Mobile Robots

- **Multi-Degree-of-Freedom Vehicles**
  - ◇ Multi-degree-of-freedom (MDOF) vehicles have multiple drive and steer motors.
  - ◇ MDOF configurations display exceptional maneuverability in tight quarters in comparison to conventional 2-DOF mobility systems, but have been found to be difficult to control due to their overconstrained nature. Resulting problems include increased wheel slippage and thus reduced odometry accuracy.



A 4-degree-of-freedom vehicle platform can travel in all directions, including sideways and diagonally. The difficulty lies in coordinating all four motors so as to avoid slippage.

Wheeled Mobile Robots

• **Multi-Degree-of-Freedom Vehicles**

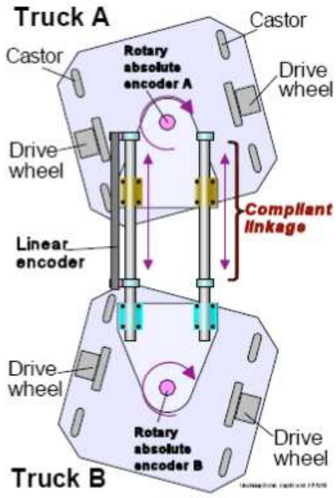
◇ Unique Mobility, Inc. built an **8-DOF vehicle** for the U.S. Navy under an SBIR grant. Unique Mobility engineers faces some difficulties in controlling and coordinating all eight motors.

An 8-DOF platform with four wheels individually driven and steered.

Wheeled Mobile Robots

• **MDOF Vehicle with Compliant Linkage**

To overcome the problems of control and the resulting excessive wheel slippage described above, researchers at the University of Michigan designed a Multi-Degree-of-Freedom (MDOF) vehicle with compliant linkage.

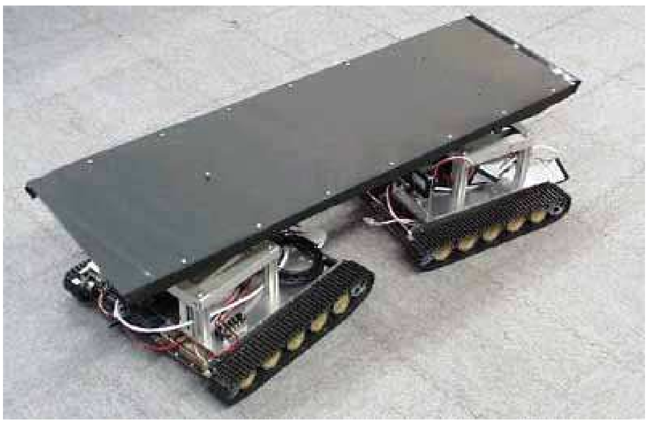


Wheeled Mobile Robots

- **MDOF Vehicle with Compliant Linkage**
  - ◇ This vehicle comprises **two differential-drive** LabMate robots. The two LabMates, here referred to as "**trucks**," are connected by a **compliant linkage and two rotary joints**, for a total of three internal degrees of freedom.
  - ◇ The purpose of the compliant linkage is to accommodate momentary controller errors without transferring any mutual force reactions between the trucks, thereby eliminating the excessive wheel slippage reported for other MDOF vehicles.

Wheeled Mobile Robots

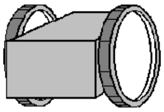
- **MDOF Vehicle with Compliant Linkage**



Kosuge and Hirata Lab, Japan

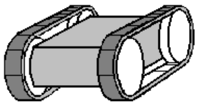
Wheeled Mobile Robots

- **Other classification**



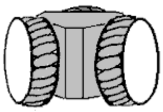
Bi-wheel type robot

- Smooth motion
- Risk of slipping
- Some times use roller-ball to make balance



Caterpillar type robot

- Exact straight motion
- Robust to slipping
- Inexact modeling of turning



Omnidirectional robot

- Free motion
- Complex structure
- Weakness of the frame

Source: Prof. Jizhong Xiao, "Mobile Robot Locomotion," Department of Electrical Engineering City College of New York.

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- Summary

Mobile Robot Positioning

- **Relative Position Measurements: Odometry**

This method uses encoders to measure wheel rotation and/or steering orientation.

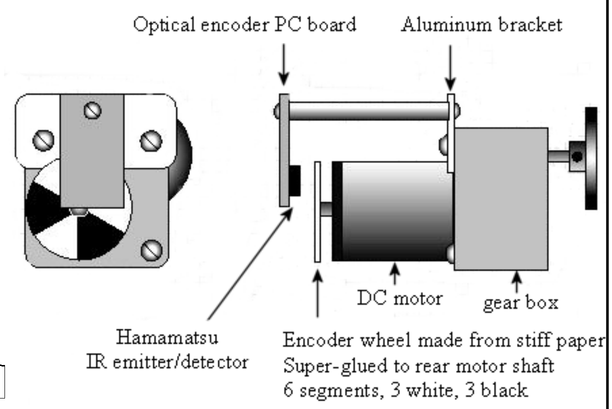
Odometry

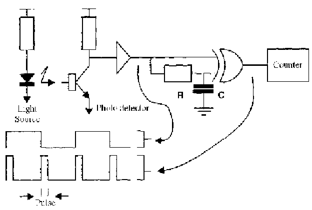
- **Optical Encoders**
  - Absolute Optical Encoders
  - Incremental Optical Encoders
- **Hall-Effect Sensors**
- **Doppler Sensors**
- **…**

Mobile Robot Positioning

- **Relative Position Measurements: Odometry**
  - ◇ **Encoder**

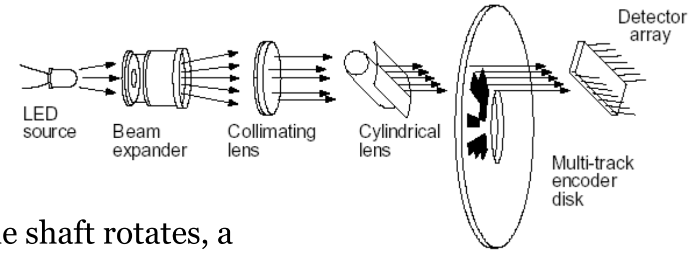
    A rotary encoder is a sensor for converting rotary motion or position to a series of electronic pulses.



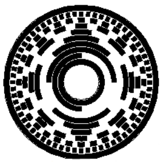


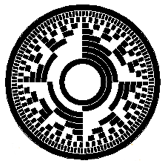
Mobile Robot Positioning

- **Relative Position Measurements: Odometry**
  - ◊ **Absolute Optical Encoder**



As the shaft rotates, a pulse train is generated. Counting the number pulses gives the angle of rotation.

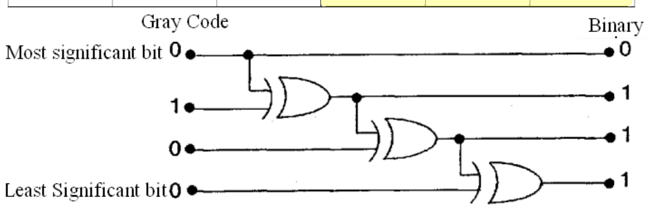

Gray Code


Binary Code

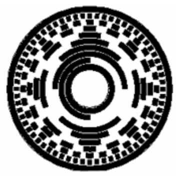
Mobile Robot Positioning

- **Relative Position Measurements: Odometry**
  - ◊ **Absolute Optical Encoder**

Decimal Number	Binary Code	Gray Code	Decimal Number	Binary Code	Gray Code
0	0000	0000	8	1000	1100
1	0001	0001	9	1001	1101
2	0010	0011	10	1010	1111
3	0011	0010	11	1011	1110
4	0100	0110	12	1101	1010
5	0101	0111	13	1101	1011
6	0110	0101	14	1110	1001
7	0111	0100	15	1111	1000



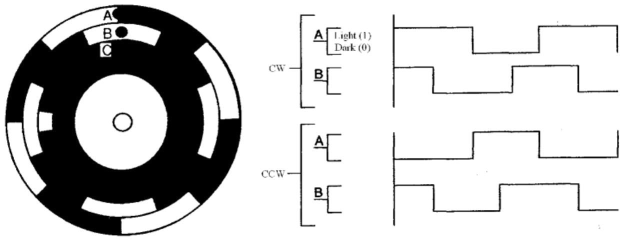

Binary Code


Gray Code

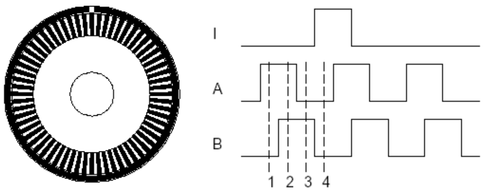
Mobile Robot Positioning

• **Relative Position Measurements: Odometry**

◇ **Incremental Optical Encoder**



The observed phase relationship between Channel A and B pulse trains can be used to determine the **direction of rotation** with a phase-quadrature encoder, while unique output states S1 - S4 allow for up to a four-fold increase in resolution. The single slot in the outer track generates one index pulse per disk rotation.

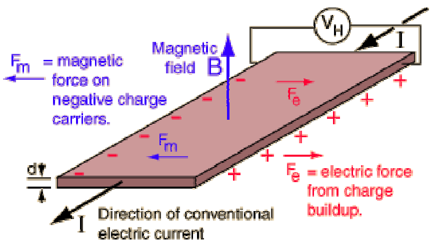


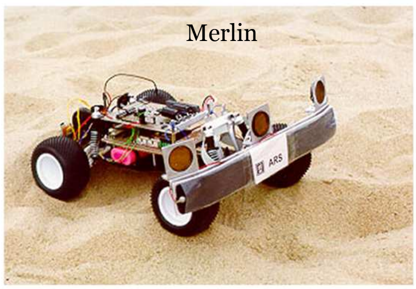
State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Mobile Robot Positioning

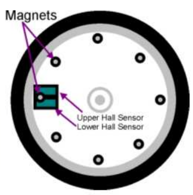
• **Relative Position Measurements: Odometry**

◇ **Hall-Effect Sensor**





$$V_H = \frac{I.B}{n.e.d}$$



n=density of charge carriers

e=electron charge

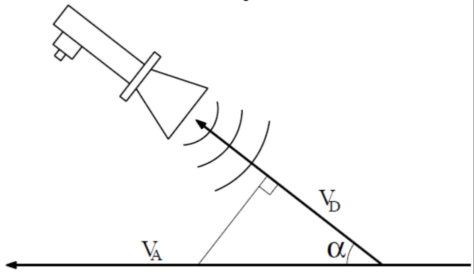
Mobile Robot Positioning

- **Relative Position Measurements: Odometry**

◇ **Doppler Sensor**

The microwave **radar (radio detection and ranging)** sensor is aimed downward at a prescribed angle (typically 45°) to sense **ground movement**.

Actual ground speed V_A is derived from the measured velocity V_D according to the following equation.



$$V_A = \frac{V_D}{\cos\alpha} = \frac{cF_D}{2F_0\cos\alpha}$$

V_A = actual ground velocity along path
V_D = measured Doppler velocity
α= angle of declination
c = speed of light
F_D = observed Doppler shift frequency
F_o = transmitted frequency.

Mobile Robot Positioning

- **Relative Position Measurements: Odometry**

◇ **Potentiometers**

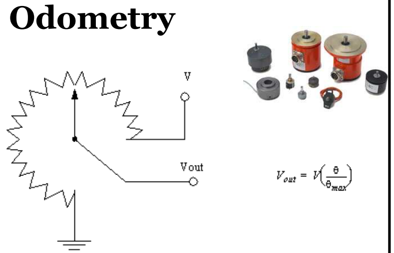
Potentiometer is an instrument used for measuring an unknown voltage by comparison to a standard voltage.

$$V_{unknown} = \frac{R_2}{R_1 + R_2} * V_{known}$$

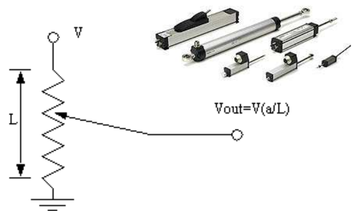
V = F<u>n</u>(R)

R=F<u>n</u>(slider position)

Slider position can be obtained by measuring V



Rotary Position Sensor

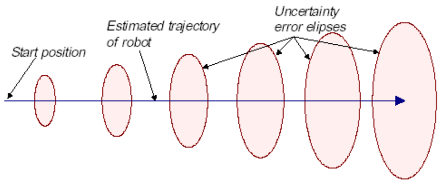


Linear Position Sensor

Mobile Robot Positioning

• **Relative Position Measurements: Odometry**

Advantages	Disadvantages
Odometry is totally self-contained, and it is always capable of providing the vehicle with an estimate of its position.	The position error grows without bound unless an independent reference is used periodically to reduce the error.



Accumulated odometry errors

Mobile Robot Positioning

• **Relative Position Measurements: Inertial Navigation**

Heading Sensors
- Mechanical Gyroscopes
  - Space-Stable Gyroscopes
  - Gyrocompasses
- Piezoelectric Gyroscopes
- Optical Gyroscopes
  - Active Ring Laser Gyros
  - Resonant Fiber Optic Gyros
- Geomagnetic Sensors
- Hall-Effect Compasses
- Magnetoresistive Compasses
- Digital Compasses

Mobile Robot Positioning

- **Relative Position Measurements: Inertial Navigation**

This method uses gyroscopes and sometimes accelerometers to measure rate of rotation and acceleration.

◊ **Advantages**

– Measurements are **integrated once (or twice)** to yield position.

– Inertial navigation systems also have the advantage that they are **self-contained**.

Mobile Robot Positioning

- **Relative Position Measurements: Inertial Navigation**

◊ **Disadvantages**

– Inertial sensor **data drifts with time** because of the need to integrate rate data to yield position; **any small constant error increases without bound after integration**. Inertial sensors are thus **unsuitable** for accurate positioning over an **extended period of time**.

Mobile Robot Positioning

- **Relative Position Measurements: Inertial Navigation**
  - ◇ **Disadvantages**
    - – Another problem with inertial navigation is the **high equipment cost**. For example, highly accurate gyros, used in airplanes, are inhibitively expensive.

      Very recently **fiber-optic gyros** (also called **laser gyros**), which are said to be very accurate, have fallen dramatically in price and have become a very attractive solution for mobile robot navigation.

Mobile Robot Positioning

- **Absolute Position Measurements: Active Beacons**

This method computes the **absolute position** of the robot from measuring the direction of incidence of **three or more actively transmitted beacons**.

The transmitters, usually using light or radio frequencies, must be located at known sites in the environment.

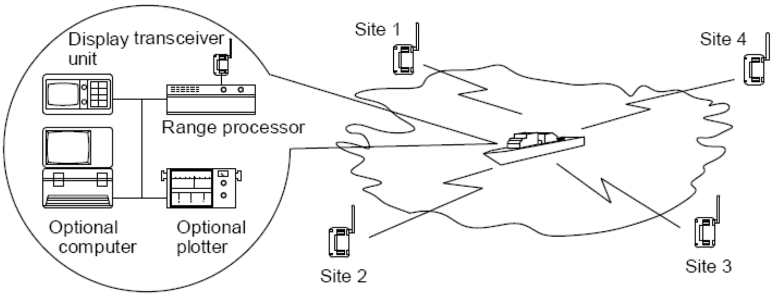
Active Beacons

Ground-Based RF Systems

Global Positioning Systems (GPSs)

Mobile Robot Positioning

- **Absolute Position Measurements**: **Active Beacons**
  - ◇ **Ground-Based RF Systems**



Motorola's Mini-Ranger Falcon 484 R position-location system provides 2 m accuracy over ranges of 100 m to 75 km.

The **actual distance** between the **interrogator** and a given **transponder/transciever** is found by:

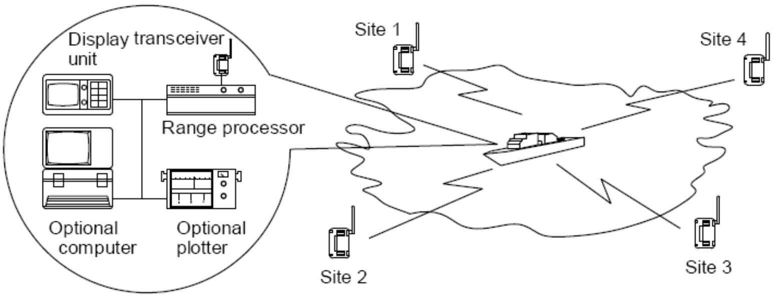
$$D = \frac{(T_e - T_d)c}{2}$$

where D = separation distance, T_e = total elapsed time

T_d = transponder turn-around delay, c = speed of light.

Mobile Robot Positioning

- **Absolute Position Measurements**: **Active Beacons**
  - ◇ **Ground-Based RF Systems**

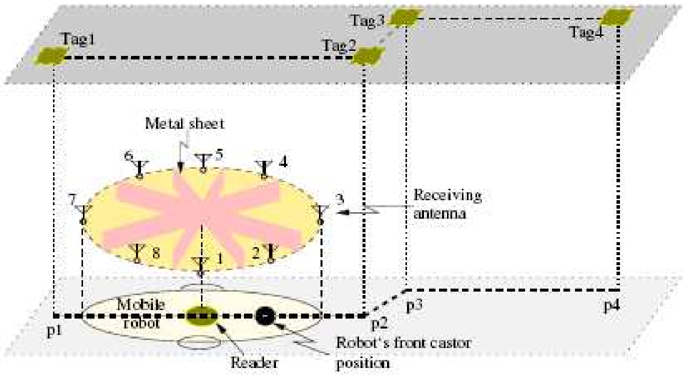


Motorola's Mini-Ranger Falcon 484 R position-location system provides 2 m accuracy over ranges of 100 m to 75 km.

An initial calibration is performed at a known location to determine the **turn-around delay (TAD)** for each transponder (i.e., the time required to transmit a response back to the interrogator after receipt of interrogation).

Mobile Robot Positioning

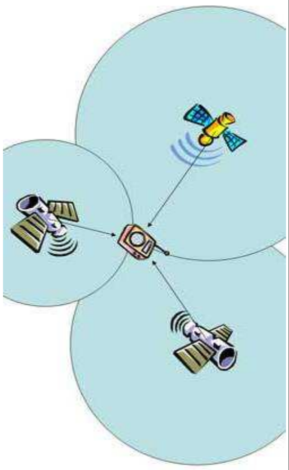
- **Absolute Position Measurements: Active Beacons**
  - ◇ **Indoor RFID-based Localization**



More info.: M. Suruz Miah and Wail Gueaieb, "Indoor Robot Navigation Through Intelligent Processing of RFID Signal Measurements", 2010 International Conference on Autonomous and Intelligent Systems (AIS-2010), June 21-23, 2010, Povoa de Varzim, Portugal.

Mobile Robot Positioning

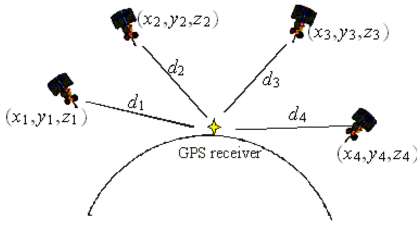
- **Absolute Position Measurements: Active Beacons**
  - ◇ **Global Positioning Systems (GPSs)**
    - GPS satellites **broadcast** the time and data about their locations.
    - a GPS receiver compares signals from **at least three or four GPS** satellites to determine it's own location.
    - A GPS receiver figures out **how far away** it is from each satellite based on **how much time** it takes a broadcast signal to travel from the satellite to the receiver.



Source: http://www.how-gps-works.com/

Mobile Robot Positioning

- **Absolute Position Measurements**: **Active Beacons**
  - ◇ **Global Positioning Systems (GPSs)**
    - – Since the location of each GPS satellite is known, the receiver's location can be determined by "**triangulating**" the distances from several satellites.



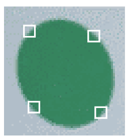
For perfectly synchronized satellites

$$(x-x_1)^2+(y-y_1)^2+(z-z_1)^2=d_1^2$$
$$(x-x_2)^2+(y-y_2)^2+(z-z_2)^2=d_2^2$$
$$(x-x_3)^2+(y-y_3)^2+(z-z_3)^2=d_3^2$$
$$(x-x_4)^2+(y-y_4)^2+(z-z_4)^2=d_4^2$$

Source: http://www.math.tamu.edu/~dallen/physics/gps/gps.htm

Mobile Robot Positioning

- **Absolute Position Measurements**: **Artificial Landmark Recognition**
  - ◇ In this method distinctive artificial landmarks are placed at known locations in the environment.



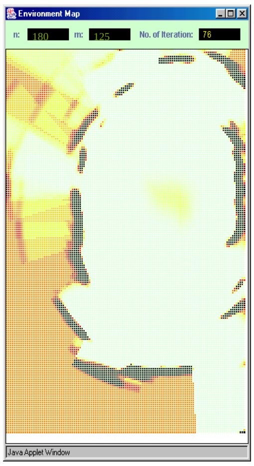
  - ◇ The advantage of artificial landmarks is that they can be designed for **optimal detectability** even under adverse environmental conditions.
  - ◇ As with active beacons, **three or more landmarks** must be "in view" to allow position estimation. Landmark positioning has the advantage that the **position errors are bounded**, but **detection of external landmarks** and real-time position fixing may **not always be possible**.

Mobile Robot Positioning

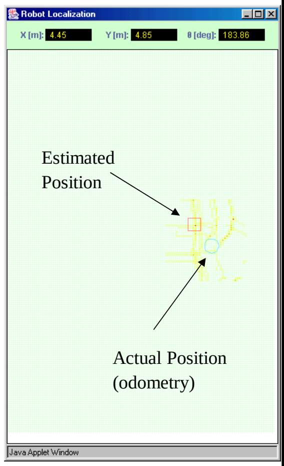
- **Absolute Position Measurements**: **Natural Landmark Recognition**
  - ◇ Here the landmarks are distinctive features in the environment.
  - ◇ There is **no need for preparation** of the environment, but the environment must be known in advance.
  - ◇ The **reliability** of this method is **not as high** as with artificial landmarks.

Mobile Robot Positioning

- **Absolute Position Measurements**: **Model Matching**
  - ◇ In this method information acquired from the robot's onboard sensors is **compared to** a map or world model of the environment.
  - ◇ If features from the sensor-based map and the world model map match, then the vehicle's absolute location can be estimated.



Sonar-based Environment Map

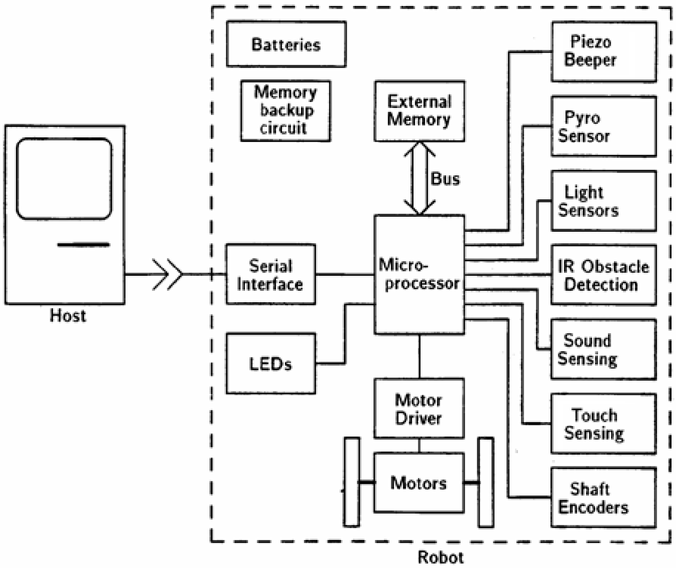


Self Localization

Outline

- Mobile Robot Locomotion
- Legged Mobile Robots (Walking Machines)
- Wheeled Mobile Robots
- Mobile Robot Positioning
- **Building the Body [For Reading]**
- Choosing the Right Wheel [For Reading]
- Choosing the Power Supply [For Reading]
- Choosing the Right Motor [For Reading]
- Controlling the Motor [For Reading]
- Summary

Building the body



Building the body

Building the body

Building from Scratch

- Body (Mechanical structure, locomotion system, motors, power supply, sensors, interfacing)
- Brain (microcontroller, motor control, reactive behaviors and deliberative behaviors)

Converting toys into working robots

- Meccano and Erector Set
- Fischertechnik kits
- Armatron
- Milton-Bradley Robotix kits
- RoboQuad, etc...

Starter kits

- Lego Mindstorms NXT
- The Vex Robotics Design System, Trekker Fire Fighter
- IntelliBrain™ 2 Robotics Controller
- NI LabVIEW Robotics Starter Kit
- K-Junior, KoreBot II, etc.

More info: Allaa R. Hilal, Khaled M.Wagdy, Alaa M. Khamis, "A Survey on Commercial Starter Kits for Building Real Robots", The 2nd International Conference on Electrical Engineering (CEE'07), Portugal, 2007.

Building the body

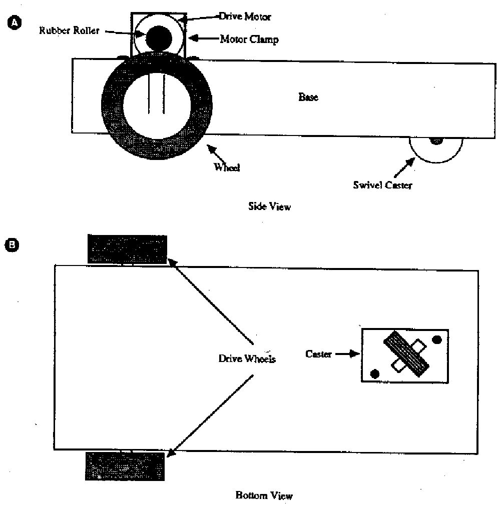
- **Hacking a toy**

  Erector Set: is the trade name of a toy construction set that was wildly popular in the United States during much of the 20th century. Like **Meccano**, it consists of collections of small metal beams with regular holes for nuts, bolts, screws, and mechanical parts such as pulleys, gears, and small electric motors. Erector beams have flanges, which make them more sturdy than those of Meccano.

Building the body

- **Hacking a toy**

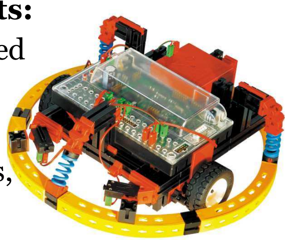
  Erector set: Constructing the motorized base for a robot out of Erector Set parts. A. attaching the motor and drive roller over the wheel; B. Drive wheel/caster arrangement

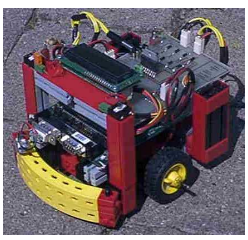


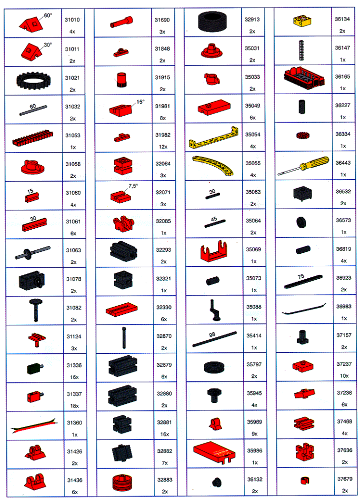
Building the body

- **Hacking a toy**

  Fischertechnik kits: are primarily designed for high school and collge industrial engineering students, and offer a snap-together approach to making working electromagnetic, hydraulic, pneumatic, static, and robotic mechanisms.





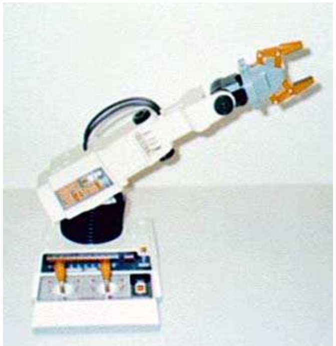


Building the body

- **Hacking a toy**

RadioShack

Armatron: is a toy from the 1980s distributed by Radio Shack. It consisted of a crane-like arm with two attached joysticks which could be manipulated to pick up small objects.



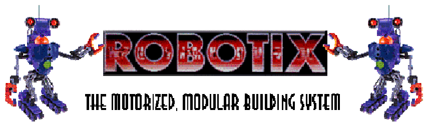
Building the body

- **Hacking a toy**

Milton-Bradley Robotix kits: are especially designed to make snap-together walking and rolling robots.

The complete kits come with two or more gear motor assemblies, and you can buy additional motors separately.

You control the motors using a central switch pas.



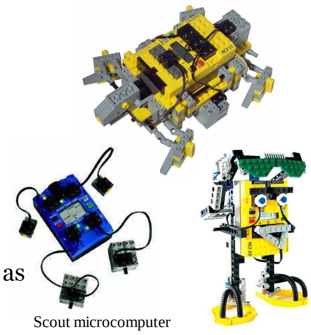
More info: http://www.roboticsandthings.com/robotix/rbxindex.html

Building the body

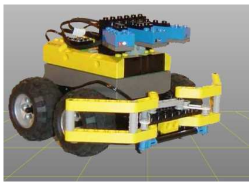
- **Starter Kits**

Lego Mindstorms: is a line of Lego Group robot kits combining programmable bricks with electric motors, sensors, Lego bricks, and Lego Technic pieces (such as gears, axles, beams, and pneumatic parts) to build robots and other automated or interactive systems.

Lego Mindstorms is marketed commercially as the Robotics Invention System (RIS). It is also sold and used as an educational tool, originally through a partnership between Lego and the MIT Media Laboratory. The educational version of the products is called Lego Mindstorms for Schools, and comes with the ROBOLAB GUI-based programming software, developed at Tufts University using the National Instruments LabVIEW as an engine.



Scout microcomputer



http://www.robocity.de/

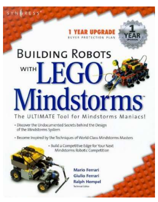
For Reading: Allaa R. Hilal, Khaled M.Wagdy, Alaa M. Khamis, "A Survey on Commercial Starter Kits for Building Real Robots", The 2nd International Conference on Electrical Engineering (CEE'07), 26-28 November 2007 Coimbra – Portugal.

Building the body

- **Starter Kits**

The latest product in the Mindstorms series is Mindstorms NXT, released in August 2006. The kit includes three servo motors, a touch sensor, a light sensor (now with the ability to differentiate between colors based on grayscale readings), a new sound sensor, an ultrasonic sensor and a new NXT 'Intelligent Brick'.

The kit is sold for $249 USD.



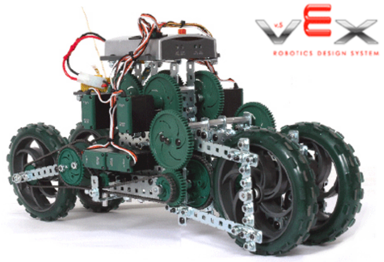
Mario Ferrari, Giulio Ferrari, Ralph Hempel, *Building Robots With Lego Mindstorms : The Ultimate Tool for Mindstorms Maniacs*. Syngress Publishing; 1 edition, 2001.

Building the body

- **Starter Kits**

The Vex Robotics Design System: is a build-it-yourself robot creation kit. Like an electric erector set, you need some batteries, some imagination, and a desire to build.

The results will be a functional robot you can control with a wireless radio transmitter (like a remote-controlled car).



More info: http://www.vexlabs.com/

For a review: http://www.andybrain.com/extras/vex-robotics-design-system-review.htm

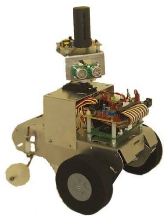
Building the body

- **Starter Kits**

Fire Fighters

http://www.superdroidrobots.com/

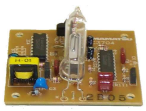
Trekker Fire Fighter
Item#: TP-026-000
Base Price/ea. $599.00



Trekker Fire Seeker
Item#: TP-025-000
Base Price/ea. $379.00

UVTRON Fire Detection Kit - with UV sensor
Item#: TS-021-000
Base Price/ea. $78.00

Trekker Thermal Array Sensor TPA81
Item#: TS-038-000
Price/ea. $109.00

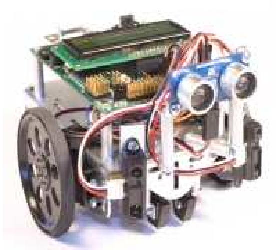


Hamamatsu UVTRON 2868 Flame Detector
Item#: TS-023-000
Price/ea. $49.00

Building the body

- **Starter Kits**

- Robotics class library
- RoboJDE™Java™-enabled robotics software development environment
- Integrating Java Robotics into Your Curriculum
- Beginning Robotics Course Outline
- Java Robotics in Education



IntelliBrain-Bot

IntelliBrain™ 2 Robotics Controller
The IntelliBrain 2 controller's design makes it easy to interface with many popular sensors and effectors including hobby servos, DC motors, infrared sensors, sonar sensors, wheel encoders, vision sensors, compasses, GPS devices, speech synthesizers and many more!

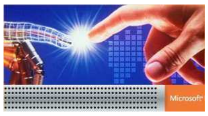
Building the body

- **Starter Kits**

The Microsoft Robotics Studio: is a Windows-based environment for robot control and simulation.

Features
- End-to-end robotics development platform
- 3-D Simulation
- Lightweight services-oriented runtime
- Scalable, extensible platform

More info: http://msdn.microsoft.com/robotics



Building the body

- **Starter Kits**

Featured Third Parties of Microsoft Robotics Studio



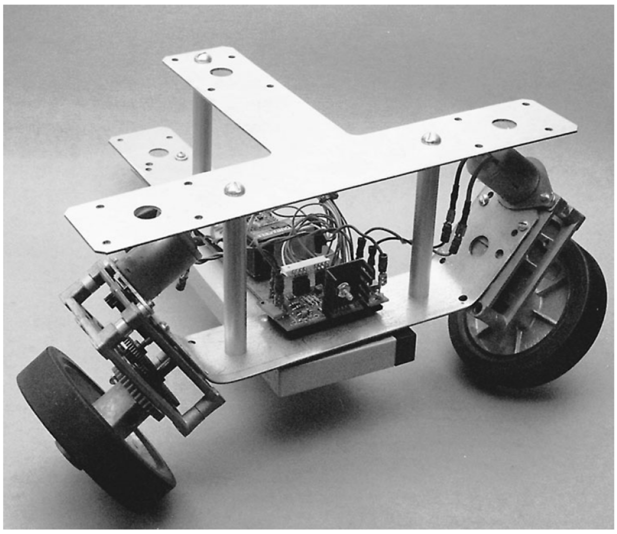



- Coroware, http://www.coroware.com/
- Kuka, http://www.kuka.com/en/
- Parallax, http://www.parallax.com
- Robosoft, http://www.robosoft.fr/eng/
- RoboticsConnection, http://www.roboticsconnection.com/
- Yujin Robot, http://www.yujinrobot.com/english/index.php

More info: http://msdn.microsoft.com/robotics

Building the body

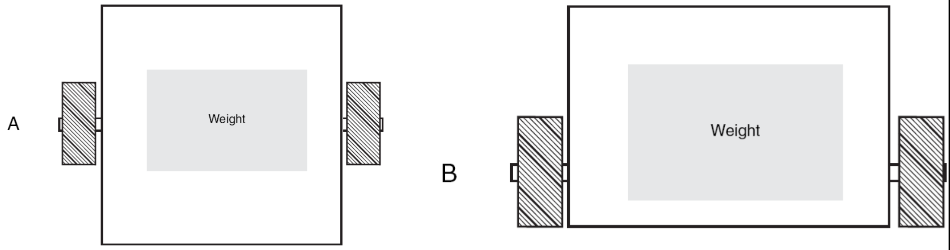
- **Building Metal Platform from Scratch**



Building the body

- **Building Metal Platform from Scratch**

  Horizontal Center of Balance : The distribution of weight on a robot affects its stability and traction.



Centering the weight down the middle in a robot with two balancing casters

Sliding the center of balance toward the drive wheel in a single-caster 'bot.

Building the body

- **Building Metal Platform from Scratch**

  Vertical Center of Balance : A robot with a small base but high vertical center of gravity risks toppling over.

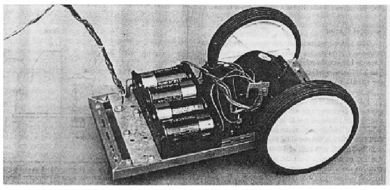
  You can correct such a design in either of two ways:

  - Reduce the height of the robot to better match the area of the base, or
  - Increase the area of the base to compensate for the height of the robot.

Building the body

- **Building Metal Platform from Scratch**

Build the frame of the robot from a single three foot length of channel aluminum or steel stock. The prototype used aluminum shelving standards; you can use steel standards or extruded aluminum channel.



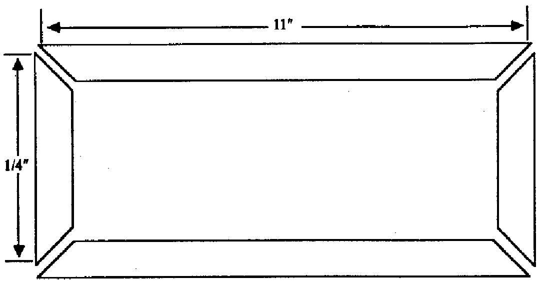
Metal Platform Parts List

Frame:	
2	11-inch length aluminum or steel shelving standards
2	5 3/4-inch length aluminum or steel shelving standards
4	1 1/2- by 3/8-inch flat corner irons
8	1/2-inch by 8/32 stove bolts, nuts, lockwashers
Motor and Mount:	
1	Surplus Big Trak motor (or two dc gear reduction motors)
1	5 3/4-inch length 1 1/4-inch wide galvanized nail mending plate
2	1-inch by 8/32 stove bolts, nuts, flat washers, tooth lockwashers
1	Four-cell "D" battery holder
Support Caster:	
1	5 3/4-inch length 1 1/4-inch wide galvanized nail mending plate
1	1 1/4-inch swivel caster
2	1/2" by 8/32 stove bolts, nuts, tooth lockwashers, flat washers (as spacers)

Building the body

- **Building Metal Platform from Scratch**

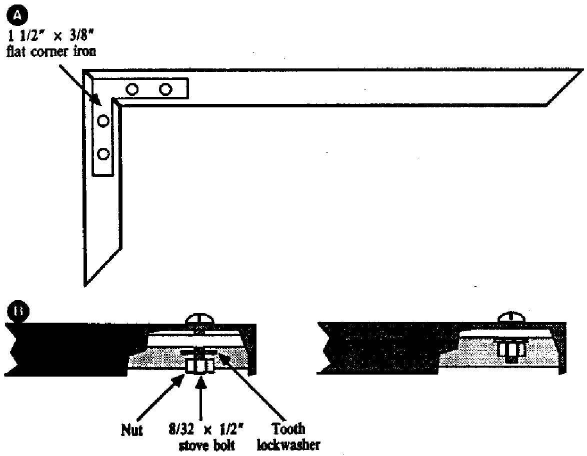
Cut the pieces, using a hacksaw and miter box, as shown below. Be sure to cut the precise 45 degree angles, and that the pieces are as close to the specified length as possible. A deviation of as little as 1/8-inch will cause the frame to be off-square, and the robot may not roll in a straight line.



Building the body

- **Building Metal Platform from Scratch**

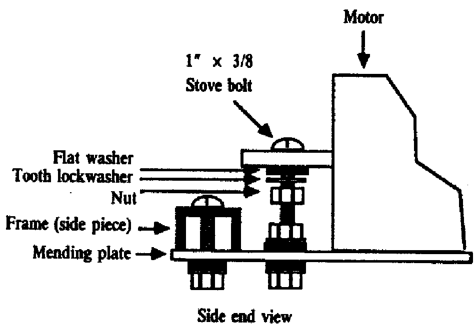
Using 1 ½-inch by 3/8-inch flat corner irons, as shown, attach the pieces in picture frame style.



Building the body

- **Building Metal Platform from Scratch**

The motor can be attached to the frame with a 1 ¼-inch by 5 ¾-inch mending plate. Secure the motor, at the center flanges of the unit, with two 8/32 by 1-inch stove bolts and 8/32 nuts. Use washers as needed. Secure the plate to the frame using 8/32 by ½-inch bolts and nuts.



Motor Mount

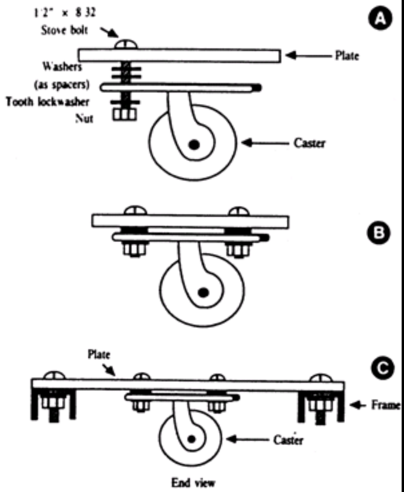
Attach 5-or 6-inch rubber wheels to the motor shaft. The shafts of the motors are notched, and can easily slot the hubs of the wheels match.

Building the body

- **Building Metal Platform from Scratch**

If the robot uses the two-wheel drive tripod arrangement. You need a caster on the other end of the frame to balance the robot and provide a steering swivel.

Attach the caster using another piece of 1 ¼-inch by 6-inch mending plate. Secure the plate to the frame with 8/32 by ½-inch bolts and 8/32 nuts. Secure the caster with 8/32 by ½-inch bolts and 8/32 nuts.

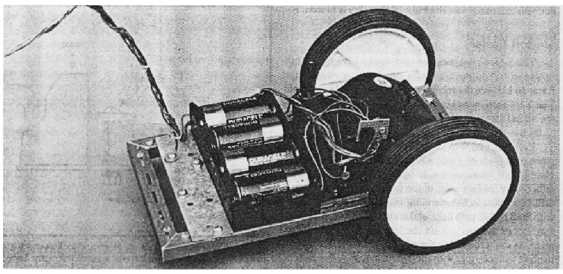


Support Caster

Building the body

- **Building Metal Platform from Scratch**

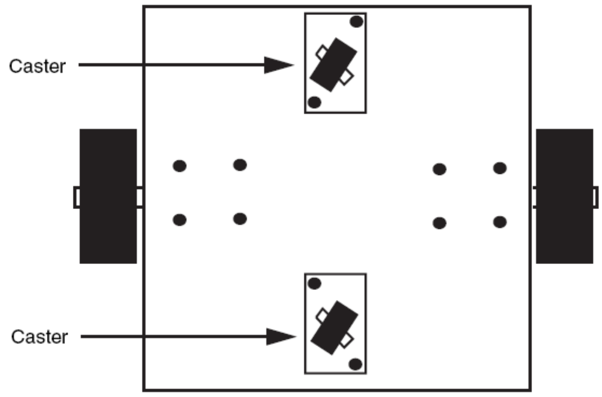
If the robot uses a 4-cell "D" batteries, holder is nearly 6-inch wide, and can fit nicely on the top of the frame. Drill holes in the corners of the holder and secure it to the base using 6/32 by ½-inch pan-head stove bolts and 5/32 nuts. Be sure the head of the bolts do not interfere with any of the batteries.



Battery Holder

Building the body

- **Building Metal Platform from Scratch**



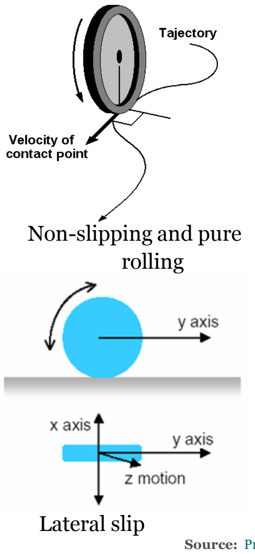
A robot with a centerline motor mount uses two casters (very occasionally one) for balance. When using one caster, you may need to shift the balance of weight toward the caster end to avoid having the robot tip over.

Outline

- Mobile Robot Locomotion
- Legged Mobile Robots (Walking Machines)
- Wheeled Mobile Robots
- Mobile Robot Positioning
- Building the Body [For Reading]
- **Choosing the Right Wheel [For Reading]**
- Choosing the Power Supply [For Reading]
- Choosing the Right Motor [For Reading]
- Controlling the Motor [For Reading]
- Summary

Choosing the Right Wheel

- **Wheels: Idealized Rolling Wheel**



Assumptions:

- No slip occurs in the orthogonal direction of rolling (non-slipping).
- No translation slip occurs between the wheel and the floor (pure rolling).
- At most one steering link per wheel with the steering axis perpendicular to the floor.

Wheel parameters:

- r = wheel radius
- v = wheel linear velocity
- ω = wheel angular velocity
- t = steering velocity

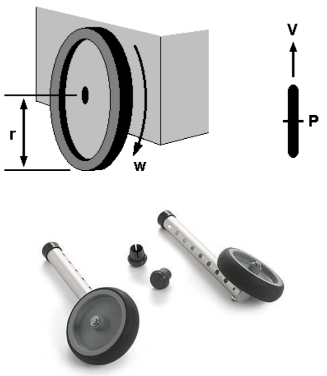
Source: Prof. Jizhong Xiao, "Mobile Robot Locomotion," Department of Electrical Engineering City College of New York.

Choosing the Right Wheel

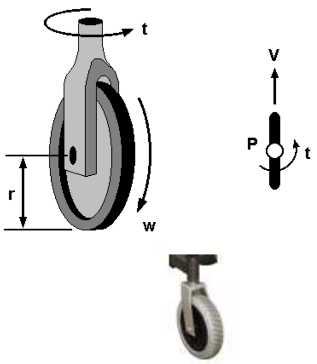
- **Wheels: Standard Wheel**

Two degrees of freedom; rotation around the (motorized) wheel axle and the contact point.

Fixed wheel



Centered orientable wheel

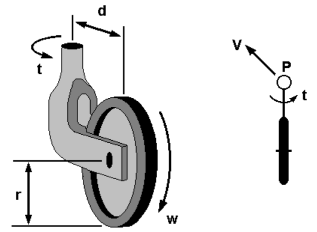


Choosing the Right Wheel

• **Wheels: Castor Wheel**

Three degrees of freedom; rotation around the wheel axle, the contact point and the castor axle.

Off-centered orientable wheel
(Castor wheel)

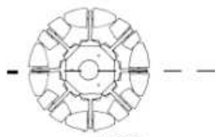


Swivel wheels

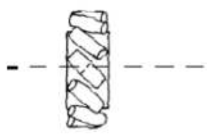
Choosing the Right Wheel

• **Wheels: Swedish Wheel**

Three degrees of freedom; rotation around the (motorized) wheel axle, around the rollers and around the contact point.

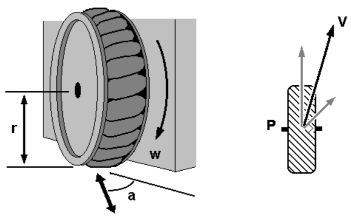


swedish 90°



swedish 45°

Swedish wheel: omnidirectional property



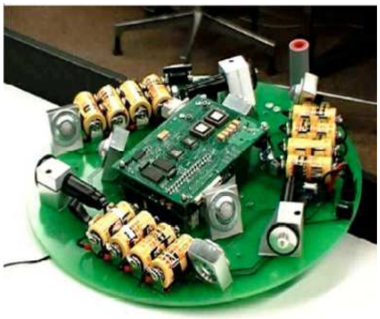
Choosing the Right Wheel

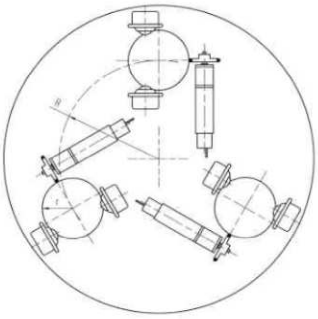
- **Wheels: Ball or Spherical Wheel**

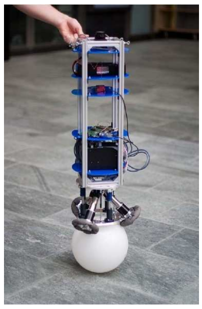
Suspension technically not solved.

Tribolo, Omnidirectional Drive with 3 Spheric Wheels

Omni Wheel



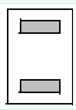
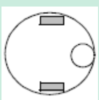
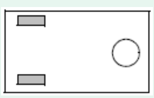




Source: R. Siegwart and I. Nourbakhsh. *Introduction to Autonomous Mobile Robots*. Chapter 2, MIT Press, 2004.

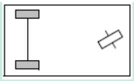
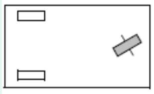
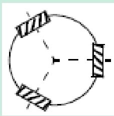
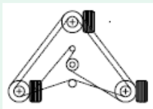
Choosing the Right Wheel

- **Wheels Arrangement**

# of wheels	Arrangement	Description	Typical examples
2		One steering wheel in the front, one traction wheel in the rear	Bicycle, motorcycle
2		Two-wheel differential drive with the center of mass (COM) below the axle	Cye personal robot 
3		Two-wheel centered differential drive with a third point of contact.	Nomad Scout, smartRob EPFL
3		Two independently driven wheels in the rear/front, 1 unpowered omnidirectional wheel in the front/rear	Many indoor robots, including the EPFL robots Pygmalion and Alice

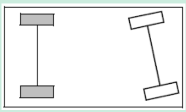
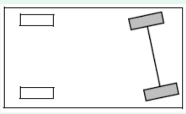
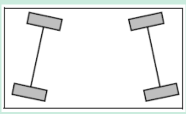
Choosing the Right Wheel

- **Wheels Arrangement**

# of wheels	Arrangement	Description	Typical examples
3		Two connected traction wheels (differential) in rear, 1 steered free wheel in front	Piaggio minitrucks
3		Two free wheels in rear, 1 steered traction wheel in front	Neptune (Carnegie Mellon University), Hero-1
3		Three motorized Swedish or spherical wheels arranged in a triangle; omnidirectional movement is possible	Stanford wheel Tribolo EPFL, Palm Pilot Robot Kit (CMU), **Robotino**
3		Three synchronously motorized and steered wheels; the orientation is not controllable	Three synchronously motorized and steered wheels; the orientation is not controllable

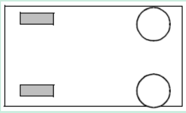
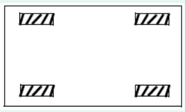
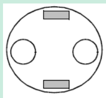
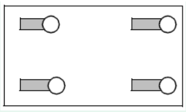
Choosing the Right Wheel

- **Wheels Arrangement**

# of wheels	Arrangement	Description	Typical examples
4		Two motorized wheels in the rear, 2 steered wheels in the front; steering has to be different for the 2 wheels to avoid slipping/skidding.	Car with rear-wheel drive
4		Two motorized and steered wheels in the front, 2 free wheels in the rear; steering has to be different for the 2 wheels to avoid slipping/skidding.	Car with front-wheel drive
4		Four steered and motorized wheels	Four-wheel drive, fourwheel steering Hyperion (CMU)

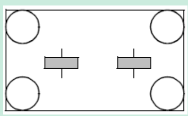
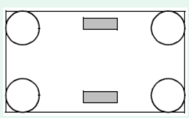
Choosing the Right Wheel

- **Wheels Arrangement**

# of wheels	Arrangement	Description	Typical examples
4		Two traction wheels (differential) in rear/front, 2 omnidirectional wheels in the front/rear.	Charlie (DMT-EPFL)
4		Four omnidirectional wheels	Carnegie Mellon Uranus
4		Two-wheel differential drive with 2 additional points of contact	EPFL Khepera, Hyperbot Chip
4		Four motorized and steered castor wheels	Nomad XR4000

Choosing the Right Wheel

- **Wheels Arrangement**

# of wheels	Arrangement	Description	Typical examples
6		Two motorized and steered wheels aligned in center, 1 omnidirectional wheel at each Corner.	First
6		Two traction wheels (differential) in center, 1 omnidirectional wheel at each corner	Terregator (Carnegie Mellon University)

Choosing the Right Wheel

- **Wheels Arrangement**

Icons for the each wheel type are as follows:	
	unpowered omnidirectional wheel (spherical, castor, Swedish);
	motorized Swedish wheel (Stanford wheel);
	unpowered standard wheel;
	motorized standard wheel;
	motorized and steered castor wheel;
	steered standard wheel;
	connected wheels.

Outline

- Mobile Robot Locomotion
- Legged Mobile Robots (Walking Machines)
- Wheeled Mobile Robots
- Mobile Robot Positioning
- Building the Body [For Reading]
- Choosing the Right Wheel [For Reading]
- **Choosing the Power Supply [For Reading]**
- Choosing the Right Motor [For Reading]
- Controlling the Motor [For Reading]
- Summary

Choosing the Power Supply

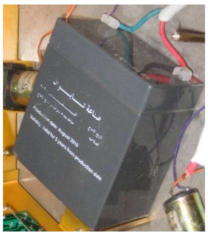
The battery is one of most challenging problems of mobile robots which limits their autonomy

Choosing the Power Supply

Mobile robots are typically powered by **12, 24 or 48 V DC** industrial batteries.

Robots may be powered by a variety of methods. Some large robots use internal combustion engines to generate electricity or power hydraulic or pneumatic actuators.

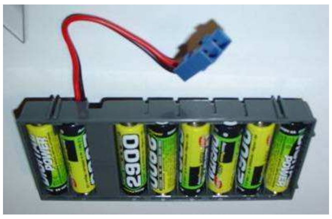
Amp-hour requirements vary according to the mobile robot characteristics and the application.



Battery (12v-4Ah)

Choosing the Power Supply

For a **small robot**, however, battery power offers a number of advantages over any other method. **Batteries are cheap, relatively safe, small, and easy to use**. Also, motors convert electrical power into mechanical power with relative efficiency. There are many different types of batteries, each with its own tradeoffs.



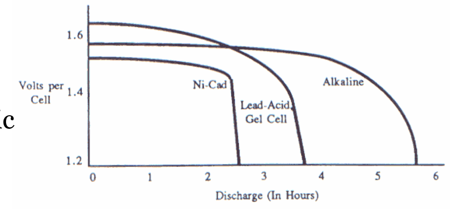
Choosing the Power Supply

- **Cell Characteristics**

Cell type	Voltage	Power Density	Internal Resistance	Rechargeable	Cost
Carbon-Zinc	1.5 volts	Low	High	No	Low
Alkaline	1.5 volts	High	High	No	Moderate
Lithium	1.5 volts	Very high	Low	No	High
Nickel-Cadmium	1.2 volts	Moderate	Low	Yes	Moderate
Lead-Acid	2.0 volts	Moderate	Low	Yes	Moderate
Nickel-Hydride	1.2 volts	High	Low	yes	Very high

Choosing the Power Supply

- **Cell Characteristics**
  - ◊ **Discharge Curve:** When a cell discharges, its voltage lessens over the course of the cell life. The characteristic discharge curve varies considerably over different types of cell.



For example, **alkaline cells have a fairly linear drop** from full cell voltage to zero volts. This makes it easy to tell when the cell is weakening. **Nickel cadmium cells have a linear voltage drop region that then drops o sharply at some point**. For this reason, when consumer products use nickel cadmium cells, the device will suddenly "die" with no warning from the cells. One minute, they are fine, the next, they are dead. For a ni-cad cell, this is normal, but it can be annoying.

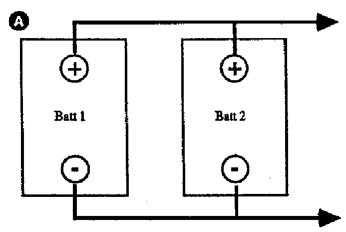
Choosing the Power Supply

- **Battery Packs**

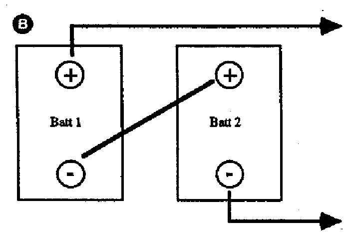
There are two ways that cells may be combined to make batteries: series connections and parallel connections.

When cells are connected in series, their voltages add but their amp-hour capacity does not. Series batteries should be composed of cells of equal capacities.

When cells are connected in parallel, their voltages remain the same, but their capacities add.



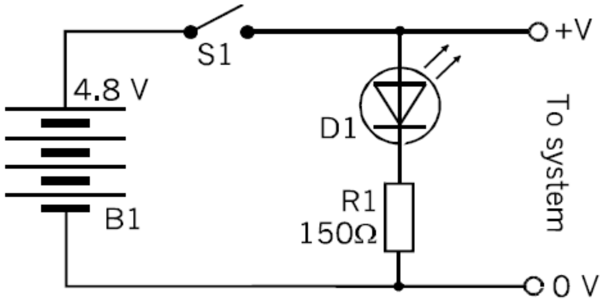
Parallel Connection -- 2X Current



Series Connection—2X Voltage

Choosing the Power Supply

• **Single-voltage System**

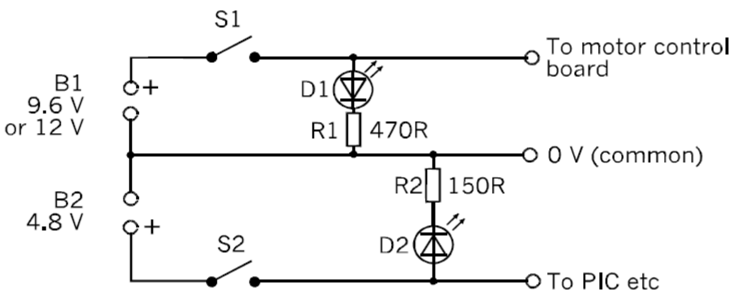


Circuit for the supply of a single-voltage system

- ◇ The source is a battery of four NiMH cells.
- ◇ S1 is a panel-mounting toggle switch.
- ◇ D1 is a standard brightness LED.
- ◇ The resistor limits the current through the LED to about 20 mA.

Choosing the Power Supply

• **Dual-voltage System**

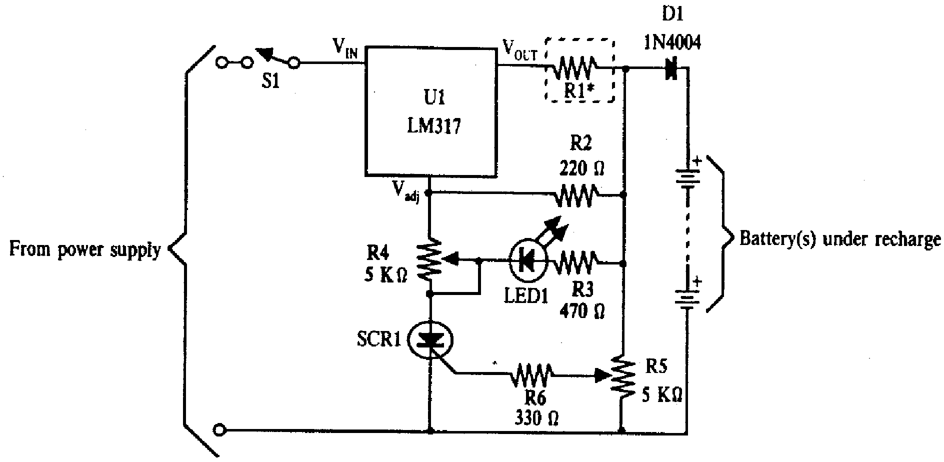


Circuit for the supply of a dual-voltage system

- ◇ There is a switch for each supply, but the 0 V rail is common to both supplies.
- ◇ Note the differing resistances of R1 and R2.

Choosing the Power Supply

- **Battery Recharger**



Universal Battery Recharger

Source: G. McComb. *The Robot Builder's Bonanza*. TAB books, Division of McGraw-Hill, ISBN: 0-8306-0800-1, 1987

Choosing the Power Supply

- **Battery Recharger**

U1	LM317 Adjustable Voltage Regulator
R1	See Text; Table 11-2
R2	220 Ω resistor
R3	470 Ω resistor
R4,R5	5K 10-turn precision potentiometers
R6	330 Ω resistor
D1	1N4004 diode
SCR1	200 volt silicon controlled rectifier (1 amp or up)
LED1	Light Emitting Diode
S1	SPST toggle switch
Misc.	Heat sink for voltage regulator, binding posts or contacts for battery under charge, dc source

Resistor R1 determines the current flow to the battery. Its value can be found by using this formula:

$$R1=1.25/Icc$$

Where Icc is the desired charging current in mA. The table lists common currents for recharging and the calculated value of R1.

Icc in mA	R1 in ohms
50	25.00
100	12.50
200	6.25
400	3.13
500	2.50
700	1.79
800	1.56
1 amp	1.25

Source: G. McComb. *The Robot Builder's Bonanza*. TAB books, Division of McGraw-Hill, ISBN: 0-8306-0800-1, 1987

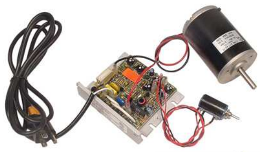
Outline

Choosing the Right Motor

Motors are the muscles of robots. Attach a motor to a set of wheels and your robot can scoot around the floor. Attach a motor to a level, and the shoulder joint for your robot can move up and down. Attach a motor to a roller and the head of your robot can turn back and forth, scanning its environment.

- **AC or DC?**

  Direct current dominates mobile robotics. Few robots use motors designed to operate from ac.



- **Continuous or Stepping**

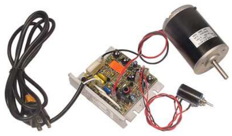
DC motors → Continuous → Permanent magnet / Brushless / Variable reluctance

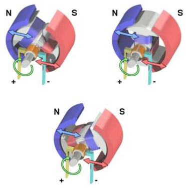
DC motors → Stepping

Choosing the Right Motor

- **Continuous Motor**

With a continuous motor, application of power causes the shaft to **rotate continuously**. The shaft stops only when the power is removed, or if the motor is stalled because it can no longer drive the load attached to it.





Common Sources of DC Motors

Car Window Motor

Rated Voltage: 12V, Rated Torque: 3N. M
No Load Current: ≤2. 8, No Load Speed: 90rpm(80-100)
Rated Current: ≤9. 0A, Rated Speed: 65rpm(55-75)
Stall Current: ≤28A, Stall Torque: ≥9. 0

Car Windscreen Wipers

Car Sunroof

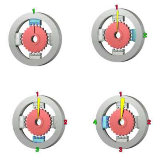
Dc 12V
No Load Speed:180 rpm
Lock Torque: Min.4.0 Nm

Old toy or Coffee Grinder

Choosing the Right Motor

- **Stepping Motor**

With a stepping motor, application of power causes the shaft to **rotate a few degrees**, then stops. Continuous rotation of the shaft requires that the power be pulsed to the motor.



User Interface —High Level Instructions→ Indexer —Step Pulses→ Driver —Motor Currents→ Motor

Common Sources of Stepper Motors

Burned printers

Canon Printer Carriage Motor, Used in many Canon and other inkjet printers. Canon part number: QH4-4240, Mitsumi part number: M42SP-4NP. $8.50 Each

CD drives

Camera Shutter Blades

Choosing the Right Motor

- **Servo**

A Servo is a small device that has an output shaft. This shaft can be positioned to **specific angular positions** by sending the servo a coded signal. As long as the coded signal exists on the input line, the servo will maintain the angular position of the shaft. As the coded signal changes, the angular position of the shaft changes. In practice, servos are used in radio controlled airplanes to position control surfaces like the elevators and rudders. They are also used in **radio controlled cars, puppets**, and of course, robots.

S3306 Hi-Torque Futaba Servo
Torque: 25.0 kg/cm
Speed: 0.16 sec/60°
Dimensions: 66 x 30 x 57.1mm
Weight: 128g

HiTEC Servo
Torque 18 oz/in
Speed/60 0.14 sec
Size 0.9x .46x .95 in
Weight 8.0g (0.28oz)

Choosing the Right Motor

Motor Type	Pros	Cons
Continuous DC	-Wide selection available, both new and used. Easy to control via computer with relays or electronic switches. -With gearbox, larger DC motors can power a 200 pound robot.	-Requires gear reduction to provide torques needed for most robotic applications. -Poor standards in sizing and mounting arrangements.
Stepper	-Does not require gear reduction to power at low speeds. -Low cost when purchased on the surplus market. -Dynamic braking effect achieved by leaving coils of stepper motor energized (motor will not turn, but will lock in place).	-Poor performance under varying loads. Not great for robot locomotion over uneven surfaces. -Consumes high current. -Needs special driving circuit to provide stepping rotation.
Servo	-Least expensive non-surplus source for gear motors. -Can be used for precise angular control, or for continuous rotation (the latter requires modification). -Available in several standard sizes, with standard mounting holes.	-Requires modification for continuous rotation. -Requires special driving circuit. -Though more powerful servos are available, practical weight limit for powering a robot is about 10 pounds.

Choosing the Right Motor

- **Motor Specifications**

The primary specifications of motors are voltage, current draw, speed, and torque.

◇ **Voltage**

All motors are related by their operating voltage.

With small **dc hobby motors**, the rating is a range, usually **1.5 to 6 volts**.

Some high-quality dc motors are designed for a specific voltage, such as **12 or 24 volts**.

The kind of motors of most interest to **robot builders** are the low-voltage variety-those that operate at **1.5 to 12 volts**.

Choosing the Right Motor

- **Motor Specifications (cont'd)**

◇ **Current Draw**

Current draw is the amount of current, in milliamps or amps, that the motor requires from the power supply. Current draw is more important when specification considers loading.

$$T = KI_a\Phi$$

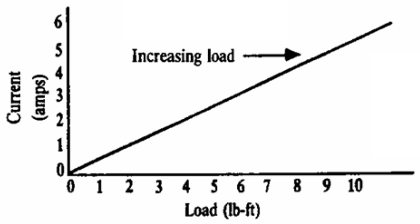
where

T = torque or load, in newton-meters

K = a constant, depending on physical dimensions of motor

Ia = armature current, in amperes

Φ = flux entering armature, in webers



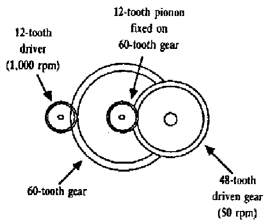
Some motors, but not many, are rated (by manufacturer) by the amount of current it draws when stalled. This is considered the **worst case condition**: the motor will never draw more than this current, unless it is shorted out, so if the system is designed to handle the **stall current**, it can handle anything.

Choosing the Right Motor

- **Motor Specifications (cont'd)**
  - ◇ **Speed**

The rotational speed of a motor is given in revolutions per minutes (rpm). Most continuous dc motors have a normal operating speed of **4,000 to 7,000 rpm**, although some special purpose motors, such as those used in tape recorders and computer disk drives, operate as slow as **2,000 to 3,000 rpm.**

For just about robotic applications, these speeds must be reduced to no more than **150 rpm** (even less for motors driving arms and grippers) with the use of a gear train.



Choosing the Right Motor

- **Motor Specifications (cont'd)**
  - ◇ **Speed**

The speed of stepping motors is not rated in rpm, but **pulses (or steps) per second**. The speed of a stepper motor is a function of the number of steps required to make one full revolution.

As a comparison, steppers motors for robotic application must operate at the equivalent of a minimum of **100 to 140rpm**.

For DC motors: $S = \dfrac{V_a - I_a R_a}{K\Phi}$

Where

S = speed, in rpm

Va = armature voltage

IaRa = armature voltage drop

K = a constant, depending on physical dimensions of motor

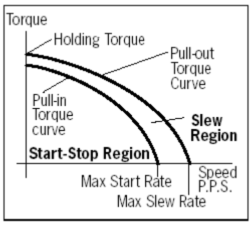
Φ = flux entering armature, in webers

Choosing the Right Motor

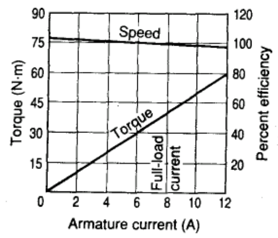
- **Motor Specifications (cont'd)**
  - **Torque**

    Torque is the force the motor exerts upon its load. The higher the torque, the larger the load can be. Most motors are rated by their **running torque**, or the force they exert as long as the shaft continuous rotate. Another torque specification, **stall torque**, is sometime provided. In most cases, the stall torque will not deviate more than 10 or 20 % from the running torque.

Stepper Motor



DC Shunt Motor



$$T = KI_a\Phi$$

$$S = \frac{V_a - I_a R_a}{K\Phi}$$

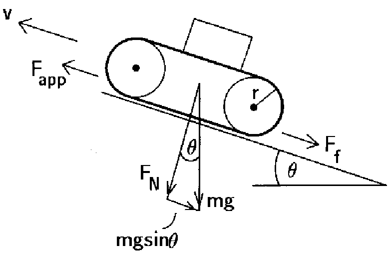
Choosing the Right Motor

- **Motor Specifications (cont'd)**

$$F_{app} = F_w + F_f$$

$$F_f = \mu F_N = \mu\, mg \cos\theta$$

$$F_w = mg \sin\theta$$



Necessary power to make the robot move at velocity v is:

$$P_m = F_{app} v$$

Taking into account that the locomotion system has two motors:

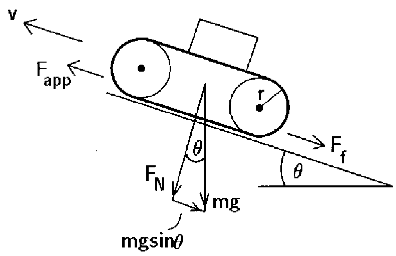
$$P_m / 2 = T\omega \quad \text{and} \quad \omega = v/r$$

The traveled distance D if the robot moves with speed v during time t is

$$D = v/t$$

Choosing the Right Motor

- **Motor Specifications (cont'd)**



If

m=2000 g

v=0.75 cm/s

θ=30°

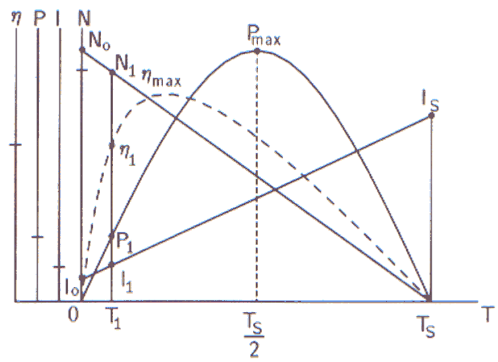
μ=0.3

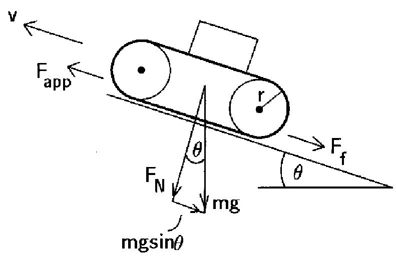
Then

$$P_m = F_{app} v = mg(\mu \cos\theta + \sin\theta)v$$
$$= (2\text{kg} * 9.81\,\text{m/s}^2)(0.3\cos 30^0 + \sin 30^0)(0.75\,\text{m/s}) = 15\,\text{watt}$$

Choosing the Right Motor

- **Motor Specifications (cont'd)**





We should choose a motor with rated power higher than (3 times) the calculated value (15 w). From load-efficiency curve of the DC motor

P_m=45 W or $P_m/2$=22.5 W

Choosing the Right Motor

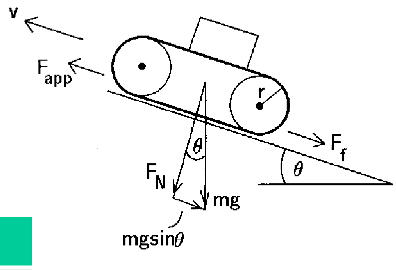
- **Motor Specifications (cont'd)**

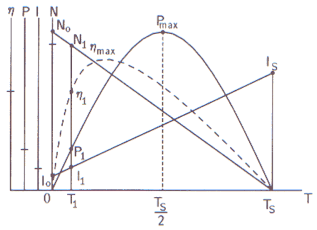
If r=0.5 cm

Then

$\omega = 140$ rpm and $T = 22.5/140$ N.m $= 0.1$

Characteristic	Value
Motor type	DC
Rated voltage	12 V
Max. power	22.5 w
Start current	564 mA
RPM	140
Torque	0.16 N.m





Choosing the Right Motor

- **Another Approach: Actuator Sizing Algorithm**

1. Define the geometric relationship between the actuator and load. In other words, select the type of motion transmission mechanism between the motor and load (N=reduction ratio).
2. Define the inertia and torque/force characteristics of the load and transmission mechanisms, i.e. define the inertia of the tool as well as the inertia of the gear reducer mechanisms (J_l, T_l).
3. Define the desired cyclic motion profile in the load speed versus time ($\theta'_l(t)$).
4. Using the reflection equations developed above, calculate the reflected load inertia and torque/force (J_{eff}, T_{eff}) that will effectively act on the actuator shaft as well as the desired motion at the actuator shaft ($\theta'_m(t)$).

Choosing the Right Motor

- **Another Approach: Actuator Sizing Algorithm**

5. Guess a actuator/motor inertia from an available list (catalog) (or make the first calculation with zero motor inertia assumption), and calculate the torque history, $T_m(t)$, for the desired motion cycle. Then calculate the peak torque and RMS torque from $T_m(t)$.
6. Check if the actuator size meets the required performance in terms of peak and RMS torque, and maximum speed capacity (T_p, T_{rms}, θ'_{max}). If the above selected actuator/motor from the available list does not meet the requirements (i.e. too small or too large), repeat the previous step by selecting a different motor. It should be noted that if a stepper motor is used, the torque capacity of the stepper motor is rated only in terms of the continuous rating, not peak. Therefore, the required peak and RMS torque must be smaller than the continuous torque capacity of the step motor.

Choosing the Right Motor

- **Another Approach: Actuator Sizing Algorithm**

7. Most servo motor continuous torque capacity rating is given for 25°C ambient temperature is different than 25°C, the continuous (RMS) torque capacity of the motor should be derated using the following equation for a temperature,

$$T_{rms} = T_{rms}(25^o C)\sqrt{\frac{(155 - Temp^o C)}{130}}$$

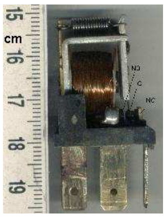
Outline

- Mobile Robot Locomotion
- Legged Mobile Robots (Walking Machines)
- Wheeled Mobile Robots
- Mobile Robot Positioning
- Building the Body [For Reading]
- Choosing the Right Wheel [For Reading]
- Choosing the Power Supply [For Reading]
- Choosing the Right Motor [For Reading]
- **Controlling the Motor [For Reading]**
- Summary

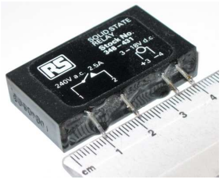
Controlling the Motor

- **Relay Control**

A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used.



A solid state relay (SSR) is a solid state electronic component that provides a similar function to an electromechanical relay but does not have any moving components, increasing long-term reliability



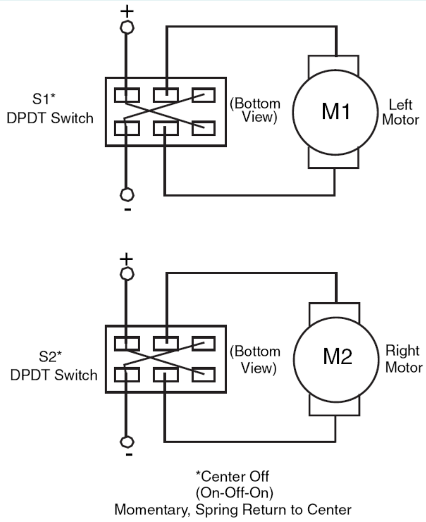
Controlling the Motor

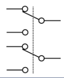
- **Relay Control: ON/OFF**

You can accomplish basic **on/off motor control** with a **single-pole relay**.

Rig up the relay so that current is broken when the relay is not activated.

Turn on the relay, and the switch closes, thus completing the electrical circuit. The motor turns.





DDPDT Double pole, double throw

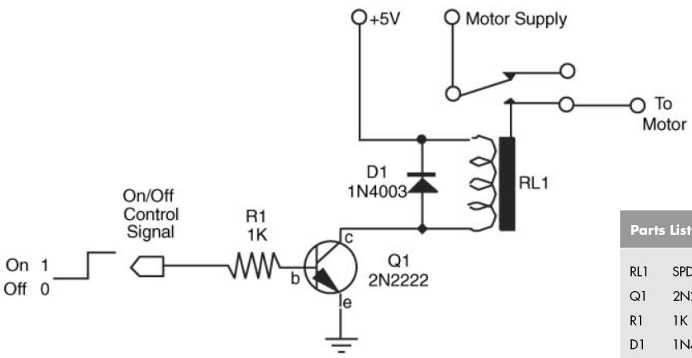
Controlling the Motor

- **Relay Control: ON/OFF**

How can you activate the relay?

◇ You could control it with a push-button switch, i.e. manually or

◇ Relays can easily be driven by digital signals.

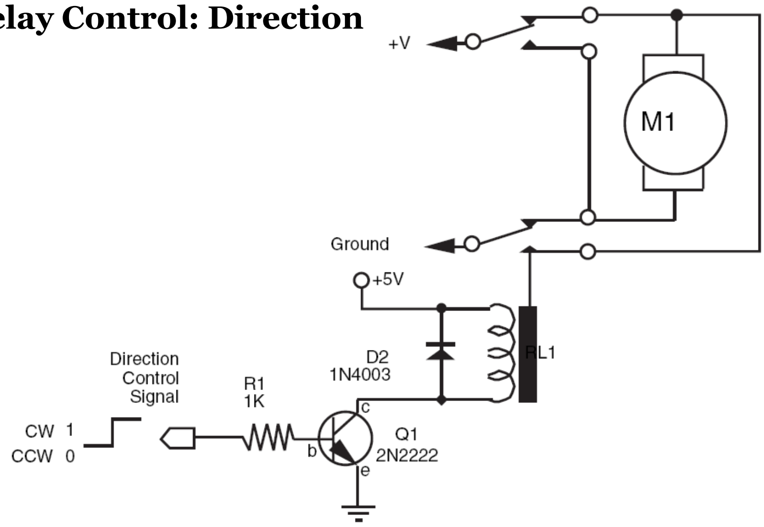


Parts List for On/Off Relay Control

RL1	SPDT relay, 5 V coil, contacts rated 2 A or more
Q1	2N2222 NPN transistor
R1	1K resistor
D1	1N4003 diode

Controlling the Motor

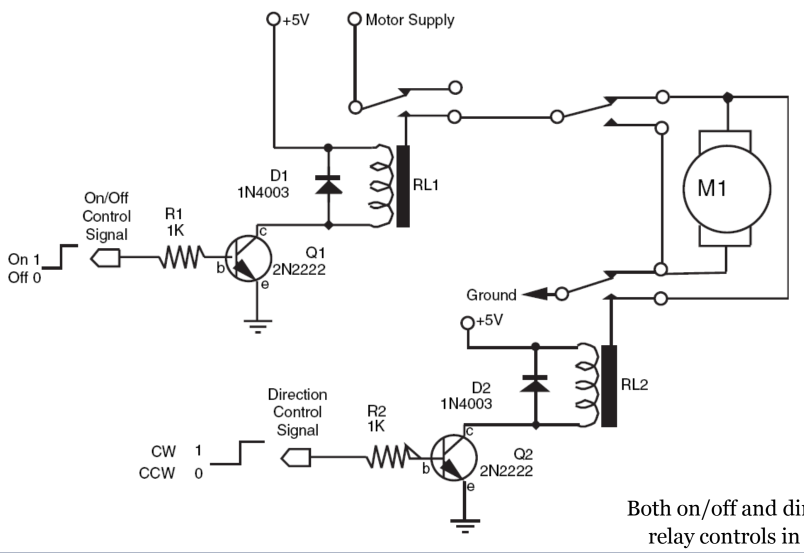
- **Relay Control: Direction**



Using a relay to control the direction of a motor. The input signal is TTL/microprocessor compatible.

Controlling the Motor

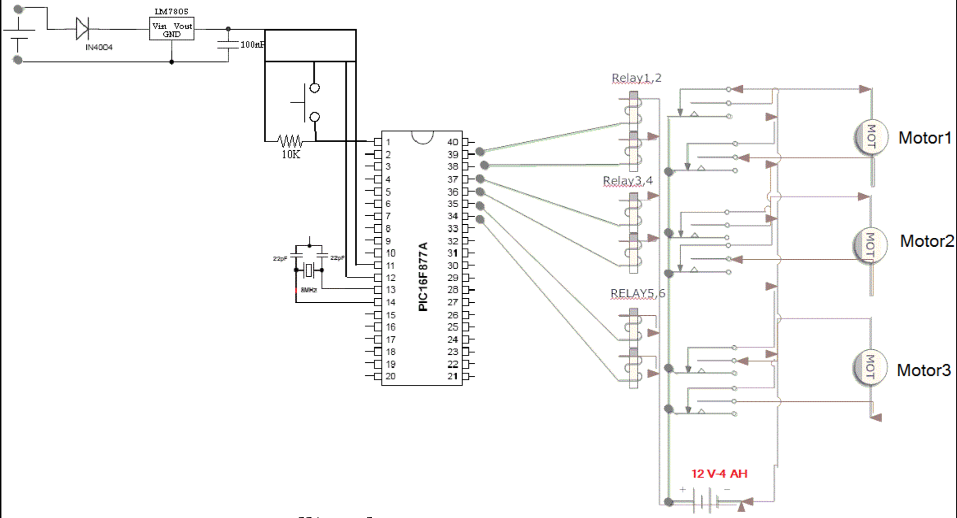
- **Relay Control: Both On/Off and Direction Control**



Both on/off and direction relay controls in one.

Controlling the Motor

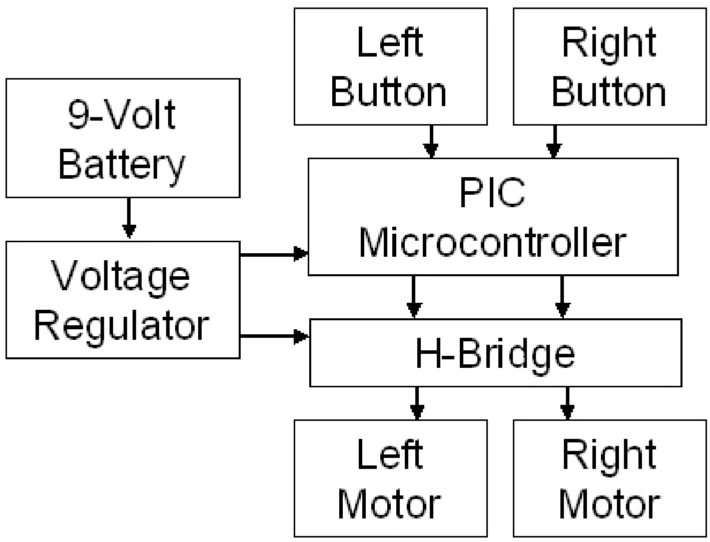
- **Relay Control: Both On/Off and Direction Control**



Controlling three motors

Controlling the Motor

- **H-Bridge Control**

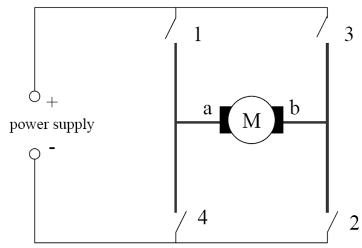


Controlling the Motor

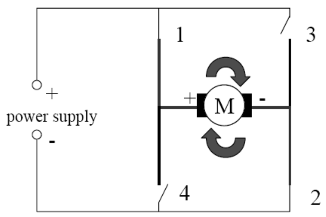
- **H-Bridge Control**
  - ◇ An H-Bridge is a circuit that is constructed from transistors that allows you to change the direction of rotation of motors or stop the motors.
  - ◇ An H-bridge is what is needed to enable a motor to run forward/backward.

Controlling the Motor

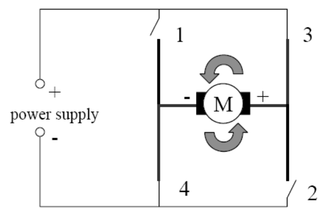
- **H-Bridge Control**



Drive forward:



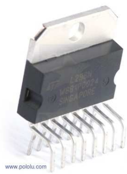
Drive backward:



Controlling the Motor

- **H-Bridge Control**
  - ◇ The H-Bridge chip provided is a 754410 chip from Acroname that is great for controlling small motors at roughly 1A peak current. The 754410 is a single chip with 2 H-Bridges in it that can handle up to 1A per channel.

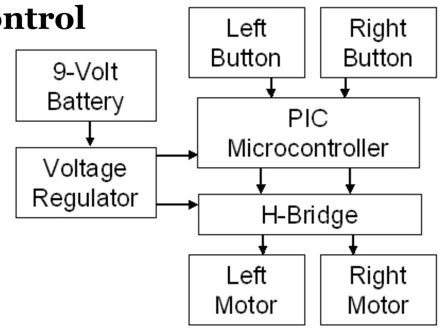
  - ◇ Another chip is L298N

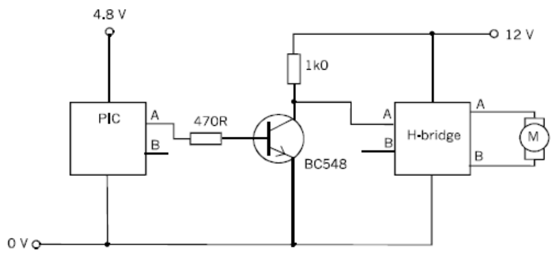


  - ◇ More recent one is TB6612FNG dual motor driver carrier

Controlling the Motor

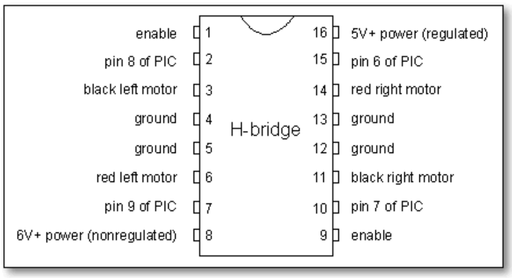
- **H-Bridge Control**

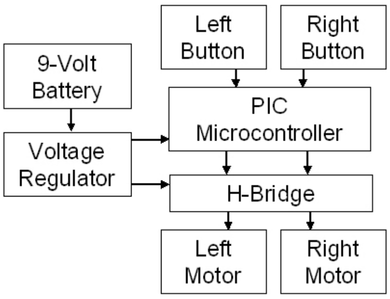


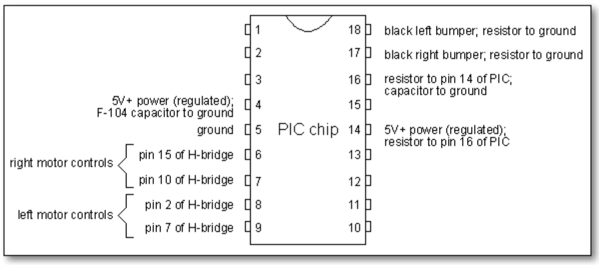


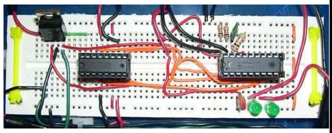
Controlling the Motor

- **H-Bridge Control**



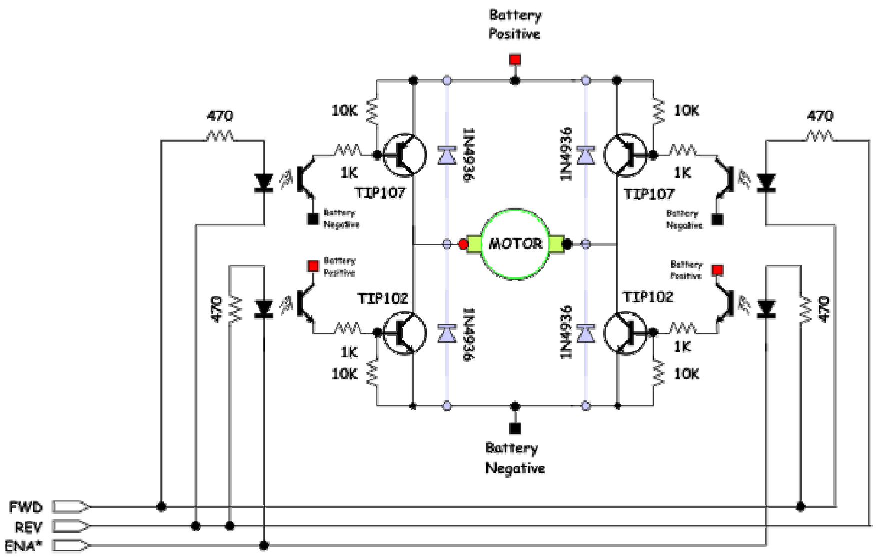






Controlling the Motor

- **H-Bridge Control: Building H-Bridge**



Controlling the Motor

- **H-Bridge Control: Building H-Bridge**

Parts List for the Simple H-Bridge

Qty	Mouser Part #	Description	Each	Total
2	511-TIP107	TIP107, PNP Power Darlington Transistor (TO-220AB)	$0.70	$1.40
2	511-TIP102	TIP102, NPN Power Darlington Transistor (TO-220AB)	$0.70	$1.40
1	652-4608X-102-10K	10K Ohm, SIP Resistor network (independent resistors)	$0.23	$0.23
1	652-4608X-102-560	560 Ohm, SIP Resistor network (independent resistors)	$0.23	$0.23
1	652-4608X-102-1K	1K Ohm, SIP Resistor network (independent resistors)	$0.23	$0.23
1	551-PS2501-4	Quad Opto-coupler (16 pin DIP)	$1.31	$1.31
4	625-1N4933	1A Fast Recovery Rectifier (Optional)	$0.05	$0.20
		Total For Components		$5.00

Controlling the Motor

- **H-Bridge Control: Building H-Bridge**

Processor Interface

FWD	REV	ENA*	Description
1	0	0	Turn on upper left source and lower right sink. (go forward)
1	0	1	Disable lower right sink. When fed a PWM signal the bridge modulates the “forward” current through the motor.
1	1	0	Turn on both lower left sink and lower right sink, shorting the motor. This causes a rotating motor to stop rotating so this mode is called “Braking.”
1	1	1	Disable both lower sinks. When fed a PWM signal the bridge modulates the “braking” of the motor.
0	1	0	Turn on the upper right source and lower left sink. (go backward)
0	1	1	Disable lower left sink. When fed a PWM signal the bridge modulates the “reverse” current through the motor.
0	0	0	Turn off all sources and sinks. “Coast” motor is not engaged at all.
0	0	1	Turn off all sources and sinks in a different way, same effect though.

More info: http://www.mcmanis.com/chuck/robotics/tutorial/h-bridge/bjt-circuit.html

Controlling the Motor

- **Controlling the speed of the motor: Not Good Way**
  - **Using Potentiometer:**

For DC motors: $S = \frac{V_a - I_a R_a}{K\Phi}$

Where

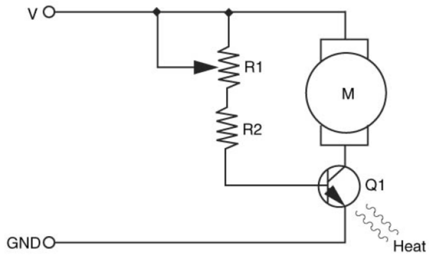
S = speed, in rpm

Va = armature voltage

IaRa = armature voltage drop

K = a constant, depending on physical dimensions of motor

Φ = flux entering armature, in webers



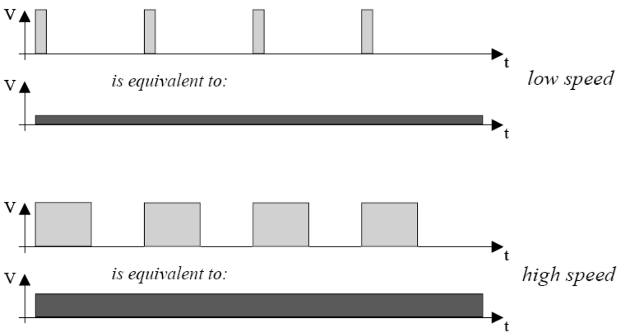
How not to vary the speed of a motor. This approach is very inefficient as the voltage drop through the transistor along with the current through the motor and transistor will cause a lot of power (heat) to be dissipated.

While this scheme certainly works, it wastes a lot of energy.

Controlling the Motor

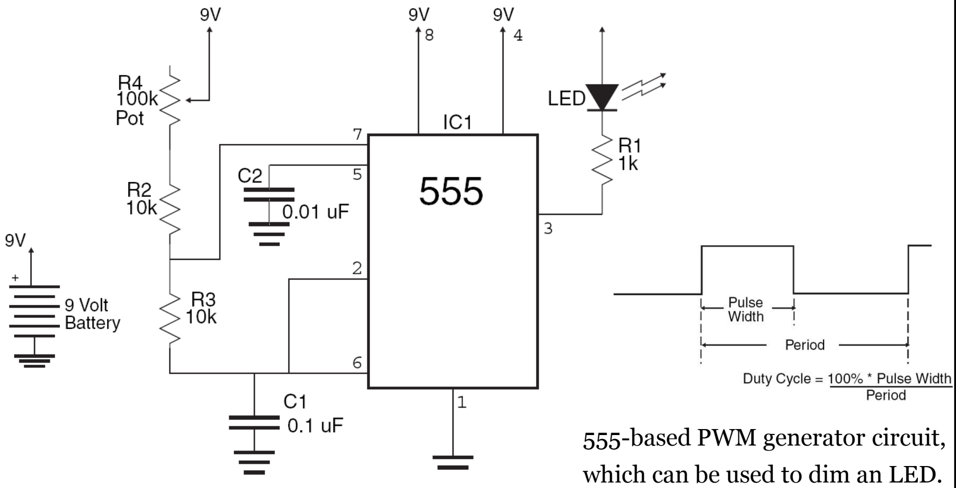
- **Controlling the speed of the motor: Not Good Way**
  - **Using Pulse Width Modulation (PWM):**

By varying the pulse width in software, we also change the equivalent or effective analog motor signal and therefore control the motor speed.



Controlling the Motor

- **Controlling the speed of the motor: Not Good Way**
  - **Using Pulse Width Modulation (PWM):**

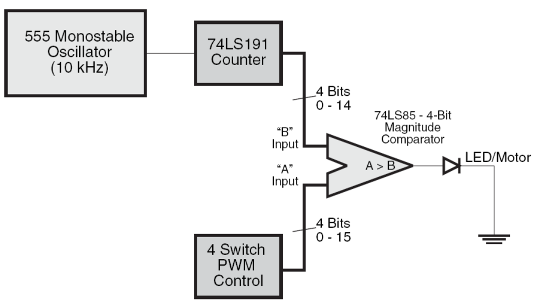


555-based PWM generator circuit, which can be used to dim an LED.

Controlling the Motor

- **Controlling the speed of the motor: Not Good Way**
  - **Counter-based PWM Speed Control :**

    Ideally the pulse width would be controlled by a digital value rather than an analog potentiometer or other components, which are difficult to interface digital signals and should not require constant monitoring by the robot's controller.

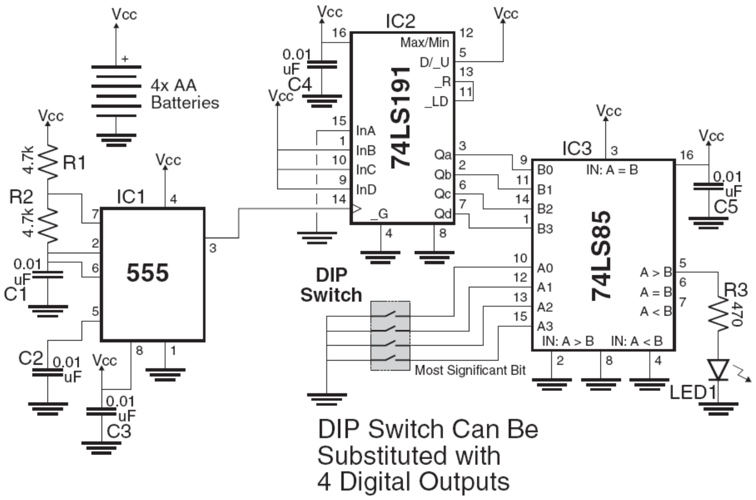


Block diagram of a basic four-bit PWM controller.

Controlling the Motor

• **Controlling the speed of the motor: Not Good Way**

◇ **Counter-based PWM Speed Control :**



Four-bit PWM motor control circuit.

Controlling the Motor

• **Controlling the speed of the motor: Not Good Way**

◇ **Counter-based PWM Speed Control :**

Parts List for Four BIT PWM Motor Control Circuit	
IC1	555 timer chip
IC2	74LS191 four-bit binary counter chip
IC3	74LS85 four-bit magnitude comparator chip
LED1	Visible light LED
R1–R2	4.7k resistors
R3	470 ω resistor
C1–C5	0.01 μF capacitor
DIP Switch	Breadboard mountable four-bit DIP switch
Misc.	Breadboard, breadboard wiring, 4x AA battery clip, 4x AA batteries

More info: GORDON McCOMB and MYKE PREDKO. ROBOT BUILDER'S BONANZA. 3rd Ed., McGraw-Hill, 2006.

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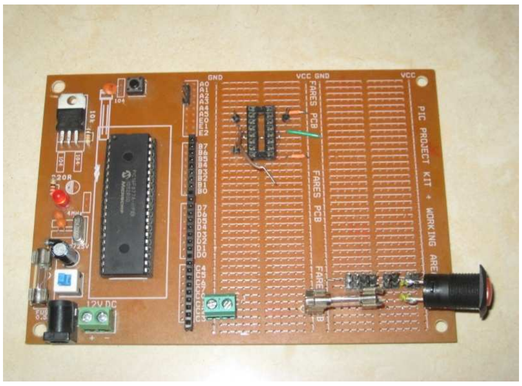

Outline

- Mobile Robot Locomotion
- Legged Mobile Robots (Walking Machines)
- Wheeled Mobile Robots
- Mobile Robot Positioning
- Building the Body [For Reading]
- Choosing the Right Wheel [For Reading]
- Choosing the Power Supply [For Reading]
- Choosing the Right Motor [For Reading]
- Controlling the Motor [For Reading]
- **Summary**

Summary

- Locomotion addresses how the robot moves through its environment.
- A mobile robot needs locomotion mechanisms that enable it to move unbounded throughout its environment. But there are a large variety of possible ways to move, and so the selection of a robot's approach to locomotion is an important aspect of mobile robot design.
- In the laboratory, there are research robots that can walk, jump, run, slide, skate, swim, fly, and, of course, roll. Most of these locomotion mechanisms have been inspired by their biological counterparts.
- Nature favors legged locomotion, since locomotion systems in nature must operate on rough and unstructured terrain. Most of mobile robots generally locomote using wheeled mechanisms.
- Odometry is the most widely used navigation method for mobile robot positioning.

Summary

- It is well known that odometry provides good short-term accuracy, is inexpensive, and allows very high sampling rates.
- However, the fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the accumulation of errors.
- In some cases, odometry is the only navigation information available; for example: when no external reference is available, when circumstances preclude the placing or selection of landmarks in the environment, or when another sensor subsystem fails to provide usable data.

Questions?