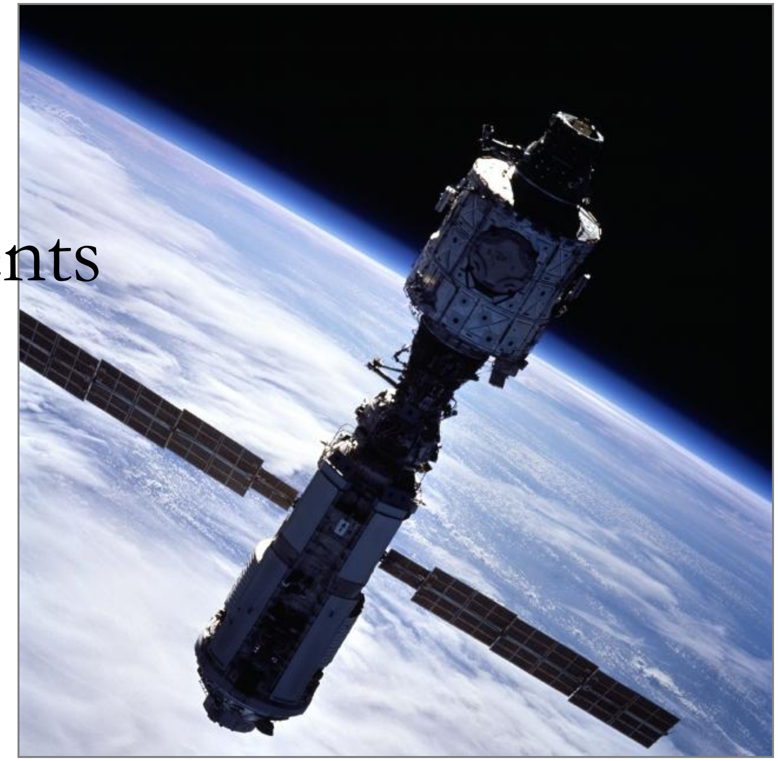
Walking Machine Technology:



- Medical Field – Disabled Patients
- Planetary Exploration
- Undersea Dredging/Salvage
- Radioactive Environments (power plants, etc.)
- Military Support

Robots from Colorado State University

Year	Finishes	Machine
1986-87	3rd Place	
1987-88	1st Place	Lurch
1988-89	1st Place	Lurch-Next Generation
1989-90	3rd Place	Lurch II
1990-91	1st Place	Lurch III
1991-92	1st Place	Airachnid
1992-93	1st Place	Airratic
1993-94	2nd Place	Airratic II
1994-95	1st Place	X-plorer
1995-96	1st Place	X-plorer 2
1996-97	1st Place	K8
1997-98	7th Place	Hydrox
1998-99	4th Place	Team Triad
2000-01	7th Place	Polyphemus

Mobile robots are popular class subjects. Competitions.

Design of a Rough Terrain Vehicle (RTV)

LEGO Parts Kits

- 5201 Connectors
- 5228/5235 Frame Members
- 5267 Shafts, Rigid Couplings
- 5269 Bell Cranks, Misc. Links
- 5287 Straight Links
- 5289 End Connectors, Bushings, Etc

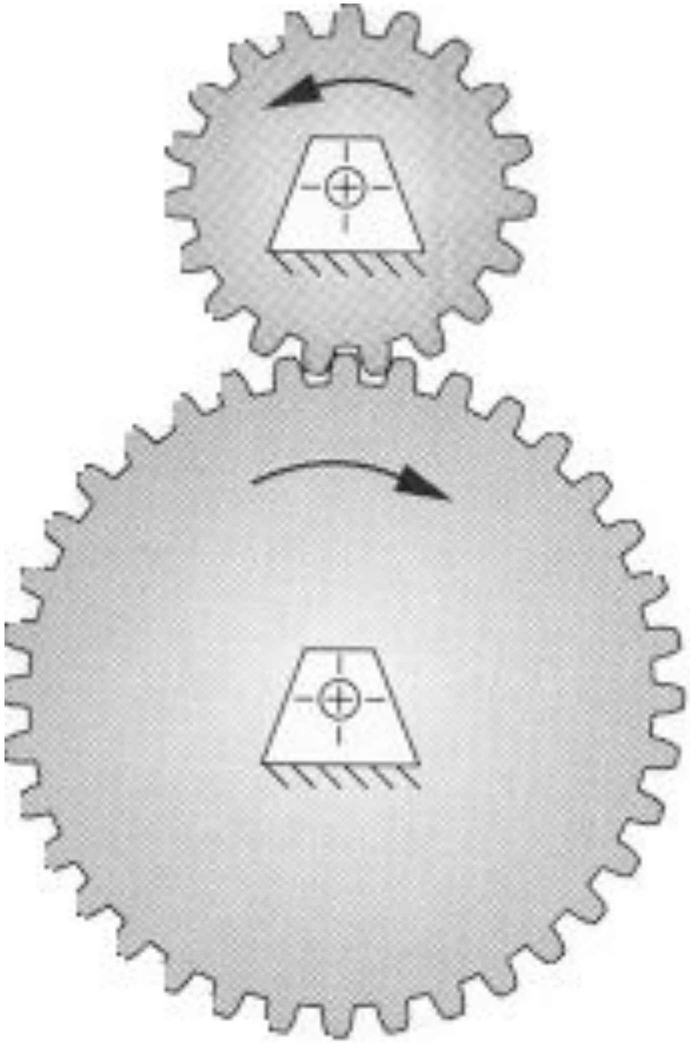
Lego is great for gear mechanisms prototyping

LEGO Parts Kits

- 9854 Rack & Pinion Gears
- 9965 Two sizes, small spur gears
- 9966 Two sizes, larger gears
- 9966/67 Appear to have same Pitch
- 9967 Bevel & Planetary Gears

Gear/Motor Fundamentals

- Spur gears have straight teeth
- Used to transmit torque and rotation between parallel shafts
- Electric motors have high speed and low torque and often must be geared down to slower speed
- Motor shaft speed is 350 rpm



Spur Gear and Pinion

Gear Fundamentals

- Torque times angular velocity is constant between two meshed gears
- Angular velocity ratio between two gears is inverse to the size (number of teeth) of each gear
- Gears must have same size teeth (pitch) to mesh correctly
- Ten to one is the maximum ratio to use between a pair of gears

Simple Gear Trains

- A Simple Gear Train has one gear per shaft- each shaft rotates in opposite direction
- Speed ratio of train is product of teeth on driver gears/product on driven gears
- Simple gear train speed ratio depends on size of first and last gear only

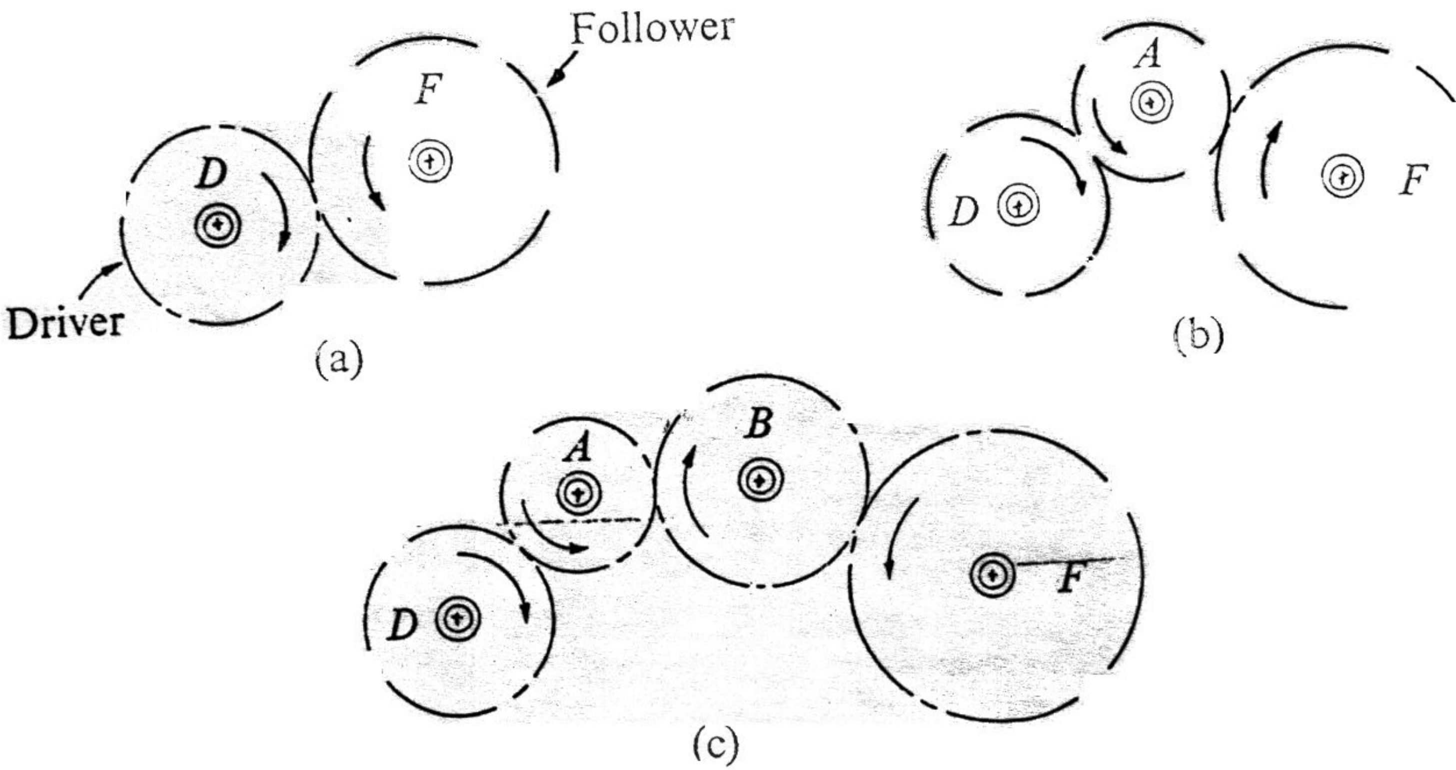
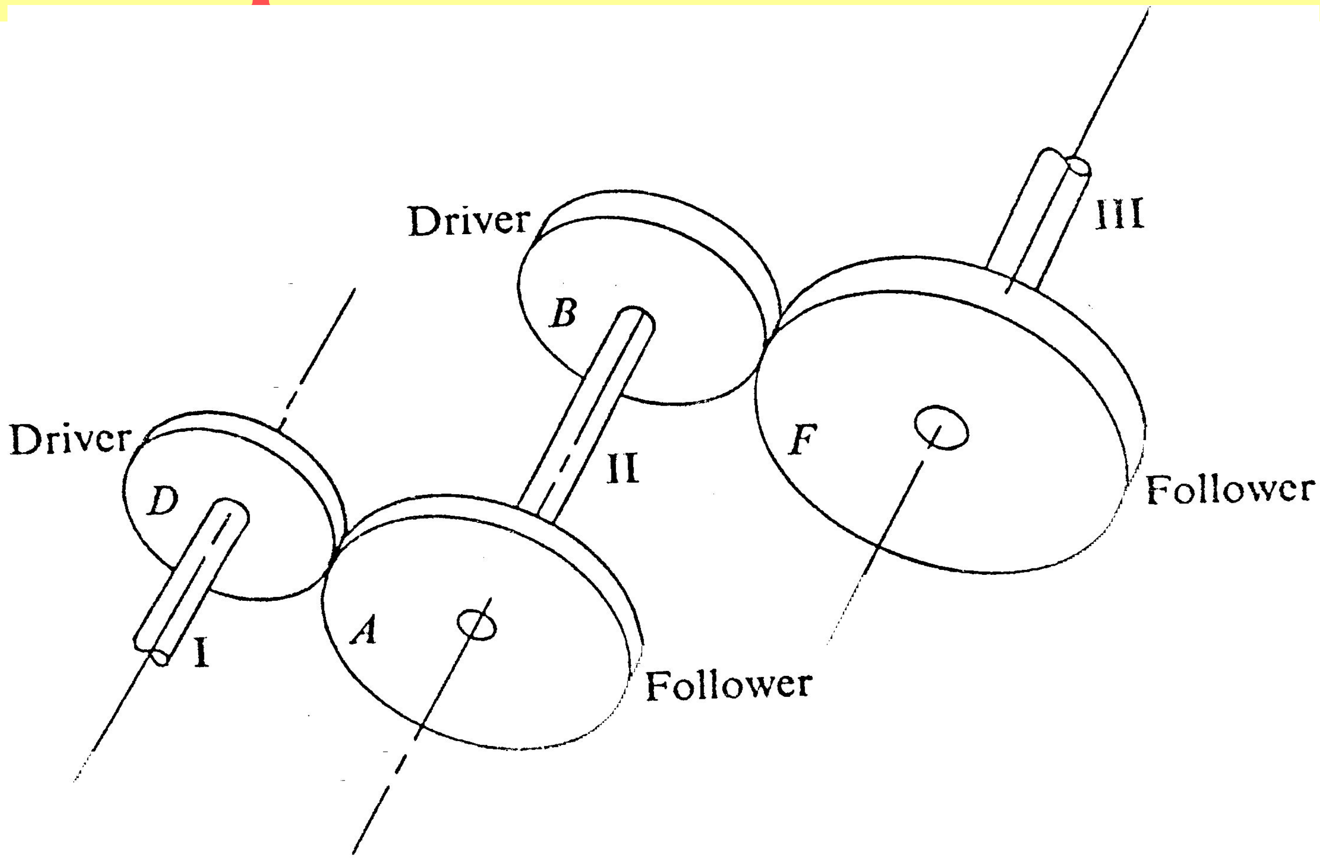


Fig. Simple gear trains.

Compound Gear Trains



- A Compound Gear Train has more than one gear on at least one shaft
- Gears on the same shaft have the same speed
- Speed ratio of train is product of teeth on driver gears/product on driven gears

Worm Gear & Worm

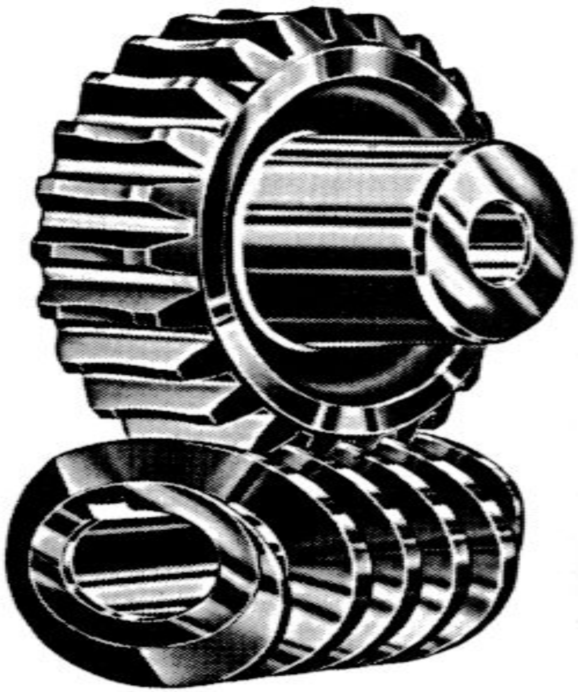
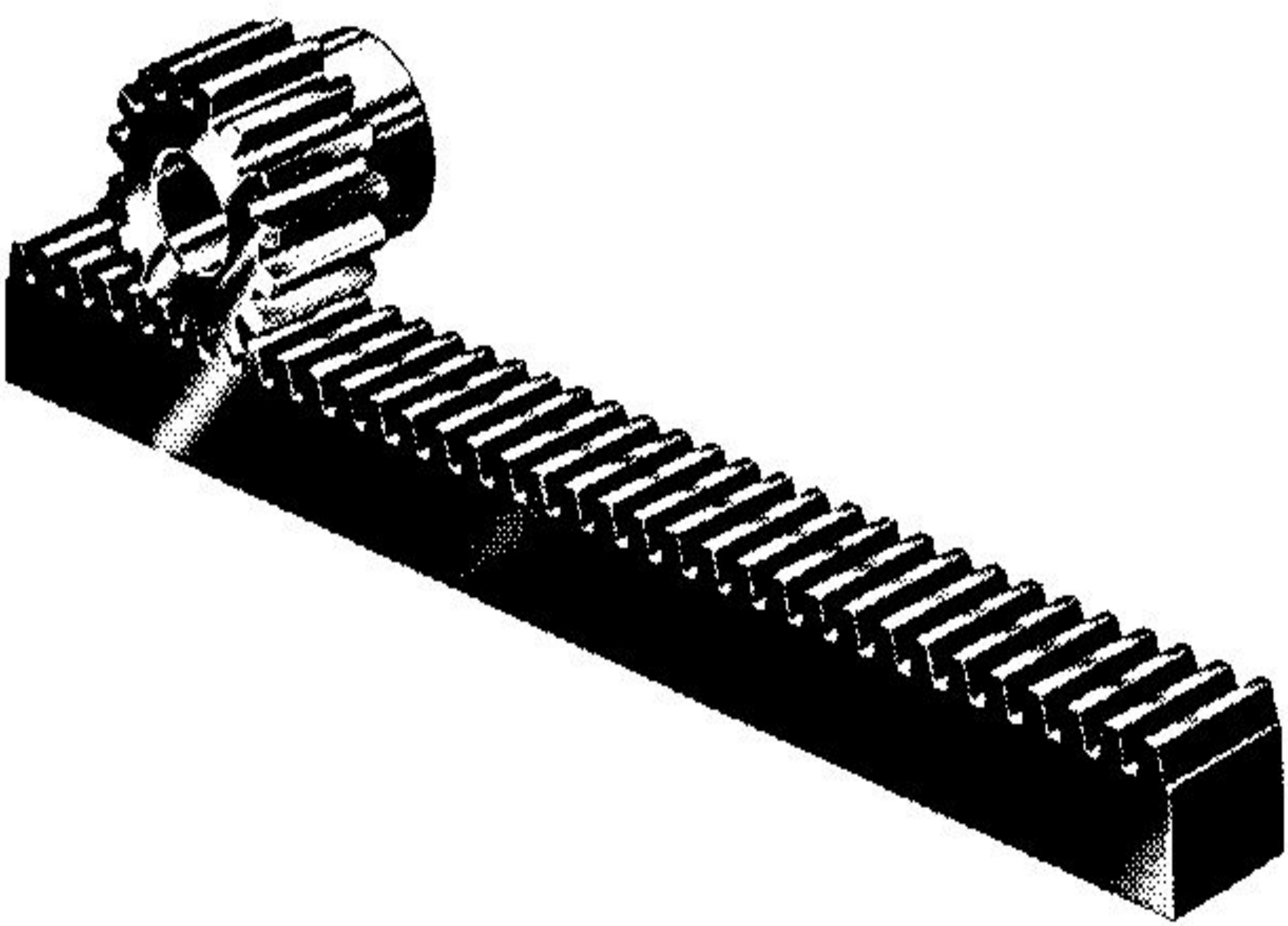


FIGURE 9-18

A worm and worm gear (or worm wheel)
Courtesy of Martin Sprocket and Gear Co., Arlington, TX

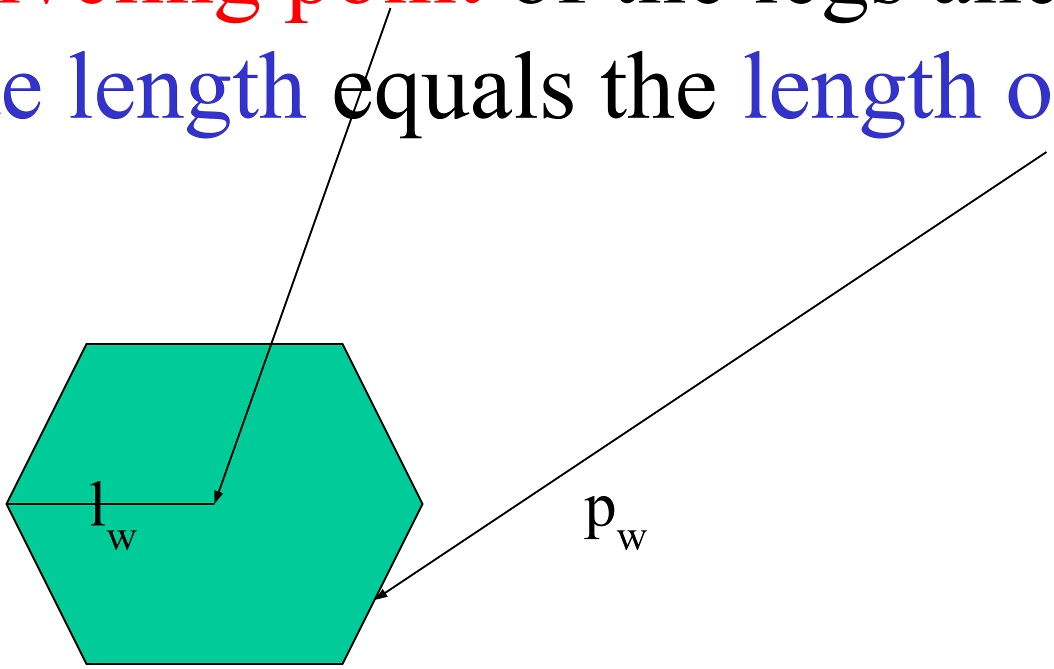
Rack & Pinion



Straight Bevel Gears

Measuring Legged Locomotion

- Walking is similar to rolling a polygon which has the center located at the swiveling point of the legs and whose side length equals the length of a step.



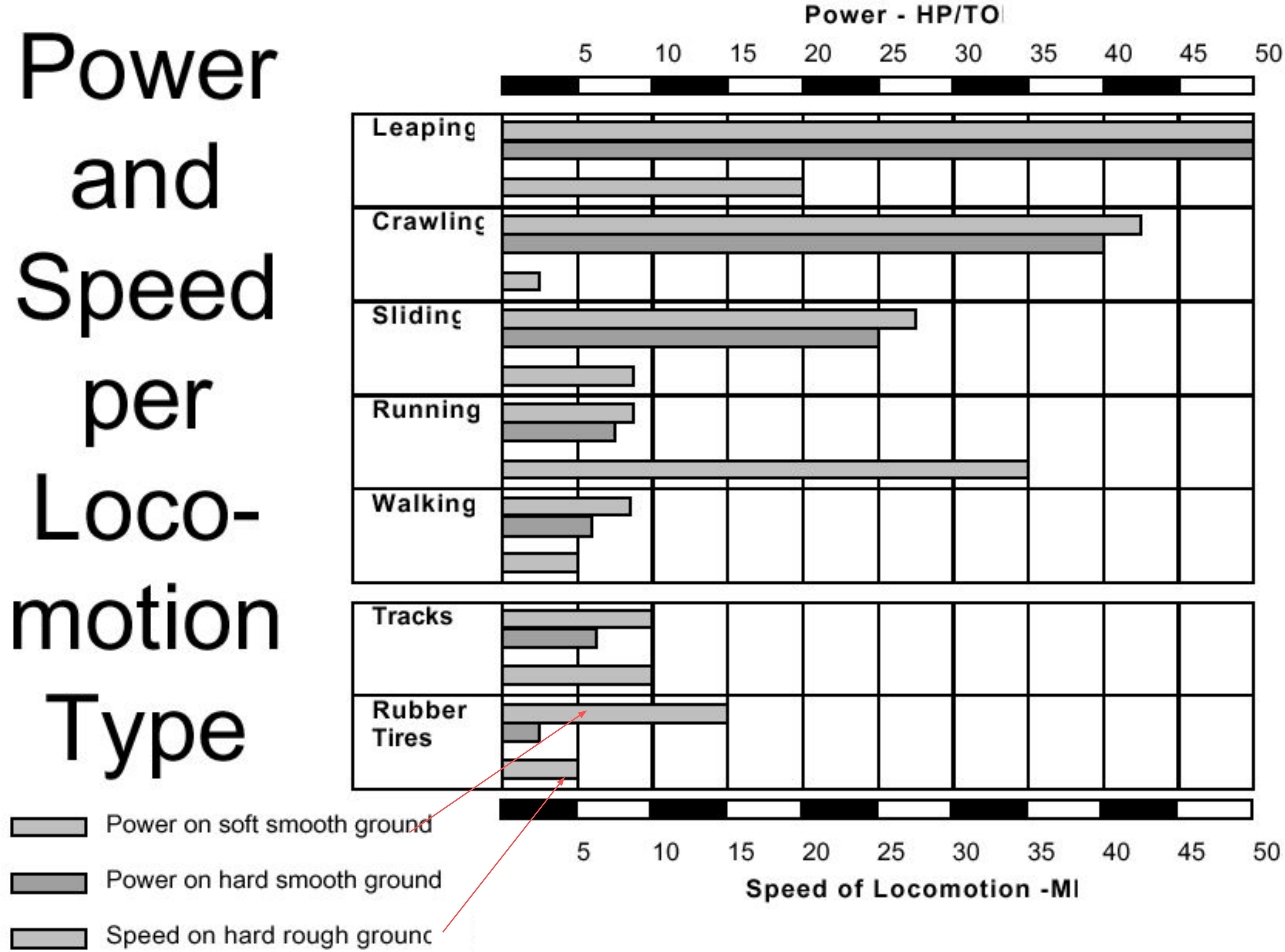
Power Required to Walk

- Work required to walk is wasted in the consecutive lifting and falling of the center of gravity of the animal body.
- The unit power is given in the equation

$$(P)_{walk} = 3.63v \frac{l_w}{p_w} \left[1 - \sqrt{1 - 0.25 \left(\frac{p_w}{l_w} \right)^2} \right]$$

l_w - leg length
p_w - step length

Power and Speed per Loco-motion Type

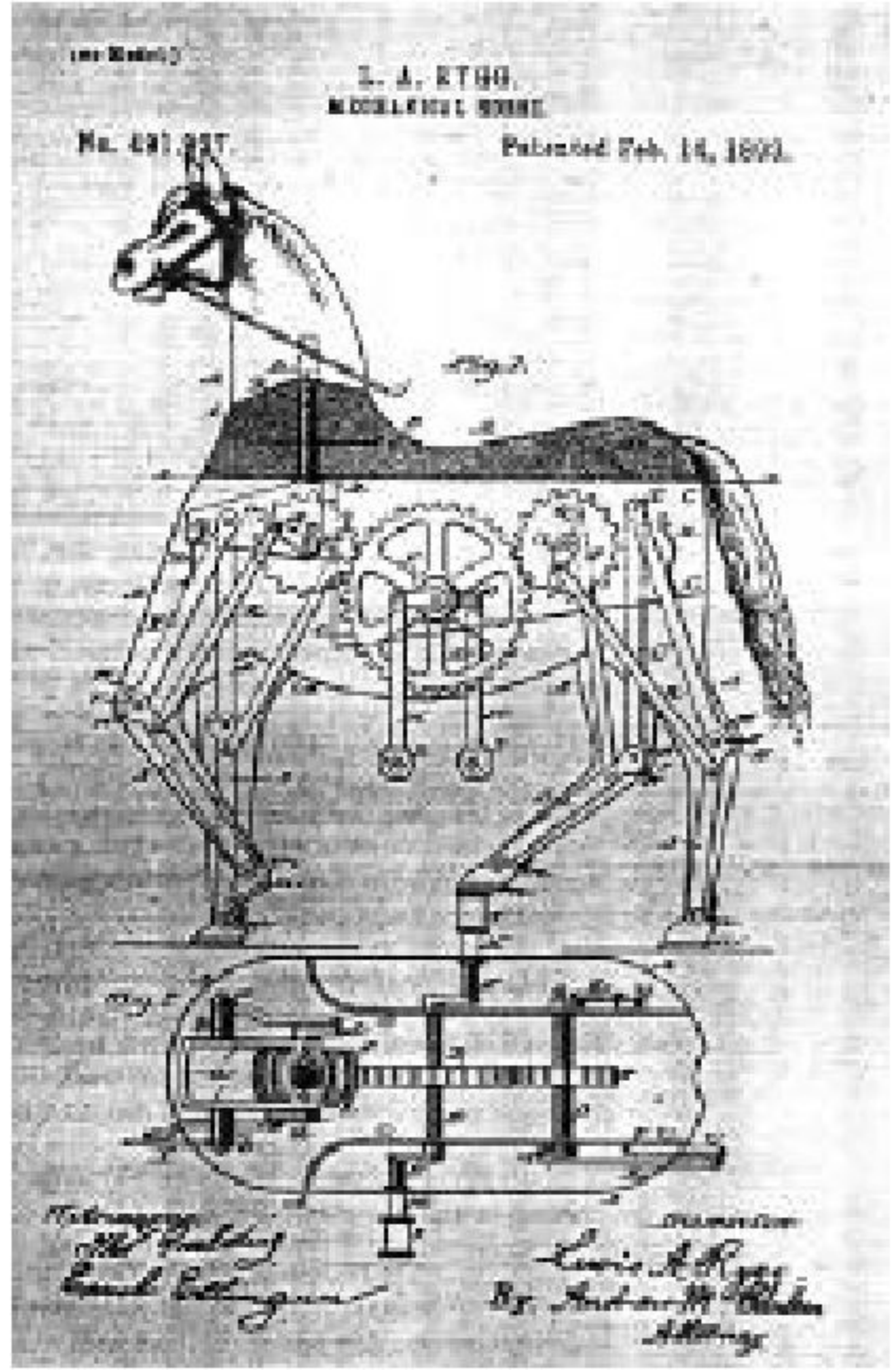


Great History Moments in Legged Locomotion

- **1837 Weber and Weber** Measure corpses and show that natural frequency of leg when swinging as compound pendulum is similar to cadence in live walking.
- **1872 Muybridge** develops stop-motion photography to document running animals. Initially to settle a bet concerning if a horses legs ever all leave the ground during running.
- **1893 Rygg** patents human-powered mechanical horse.
- **1968 Mosher** develops quadruped truck at GE. Able to climb railway ties under control of a human driver.
- **1977 Gurfinkel** develops hybrid computer controlled hexapod walker in USSR.
- **1980 Hirose and Umetani** demonstrate quadruped machine climbing over obstacles using simple sensors and reflex-like control. The leg mechanism has simplified control.

The Mechanical Horse

- Device patented by Lewis Rygg in 1893
- The stirrups double as pedals so the rider can power the stepping motions
- The reins move the head and forelegs from side to side for steering
- Never built.



Linkage Fundamentals

- Linkages are levers of various shapes joined together by joints which form the basic building blocks of machines or mechanisms
- The joints normally are:
  - **pins,**
  - **hinges,**
  - **bearings,**
  - **bushings,**
  - **sliders**, etc

  which allow the levers or links to move with respect to the frame or each other

Linkage Fundamentals

- Linkages are normally driven by a short lever
- This level is also called a crank
- Crank is connected to the motor or gear train shaft
- A hole in a gear body that is connected to the shaft can define the length of the **crank**
- Linkages are interesting and challenging to work with
- They are used in many devices used every day

What is a pivot?

- A short rod or shaft about which a related part rotates or swings

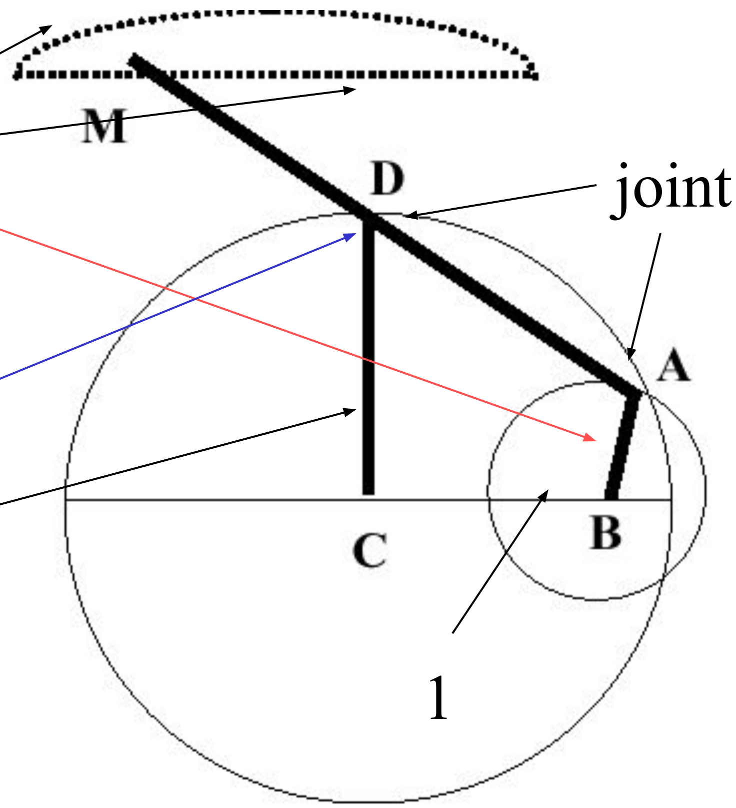
What is a crank?

A device for transmitting rotary motion, consisting of a handle attached at right angles to a shaft.

For examples look to the next slide

Generating Walking

- When input crank AB rotates,
  - 1/2 straight path and 1/2 arched path.
- Linkages like this consisting of pivots and rigid members are a simple means of generating patterned motion.



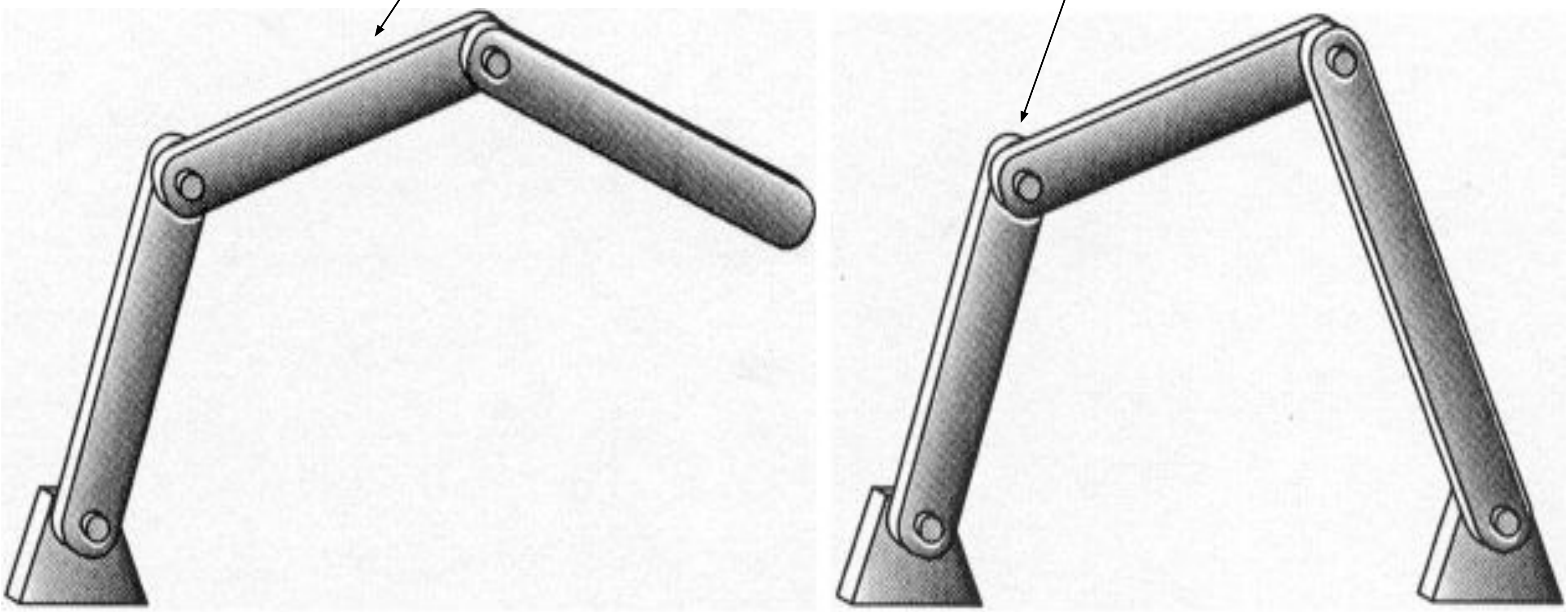
$$CD = AD = DM = \frac{3+\sqrt{7}}{2}$$

$$BC = \frac{4+\sqrt{7}}{3}$$

What are the types of mechanism chains?

Linkages are levers of various shapes

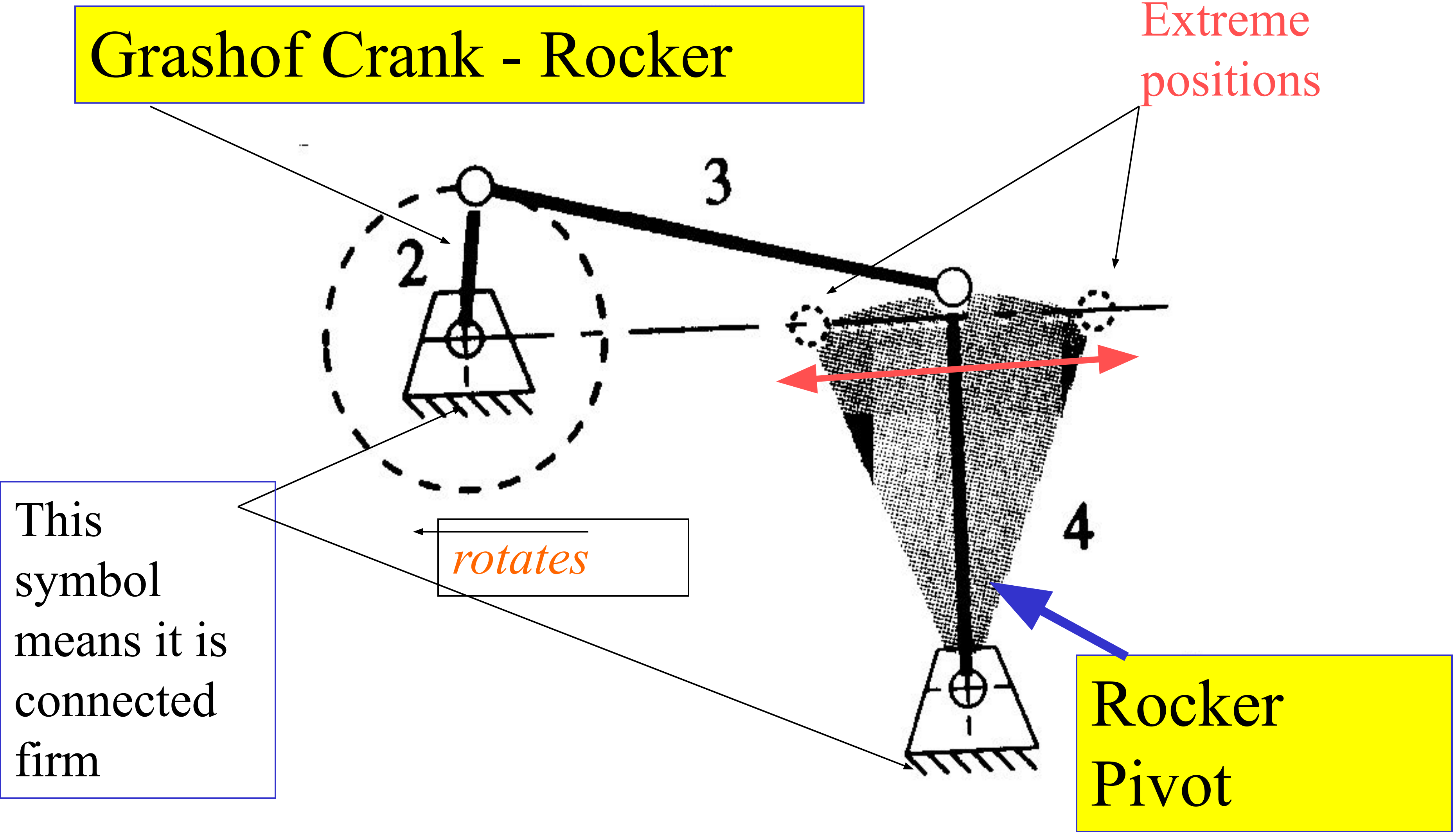
joined together by joints



(a) Open mechanism chain

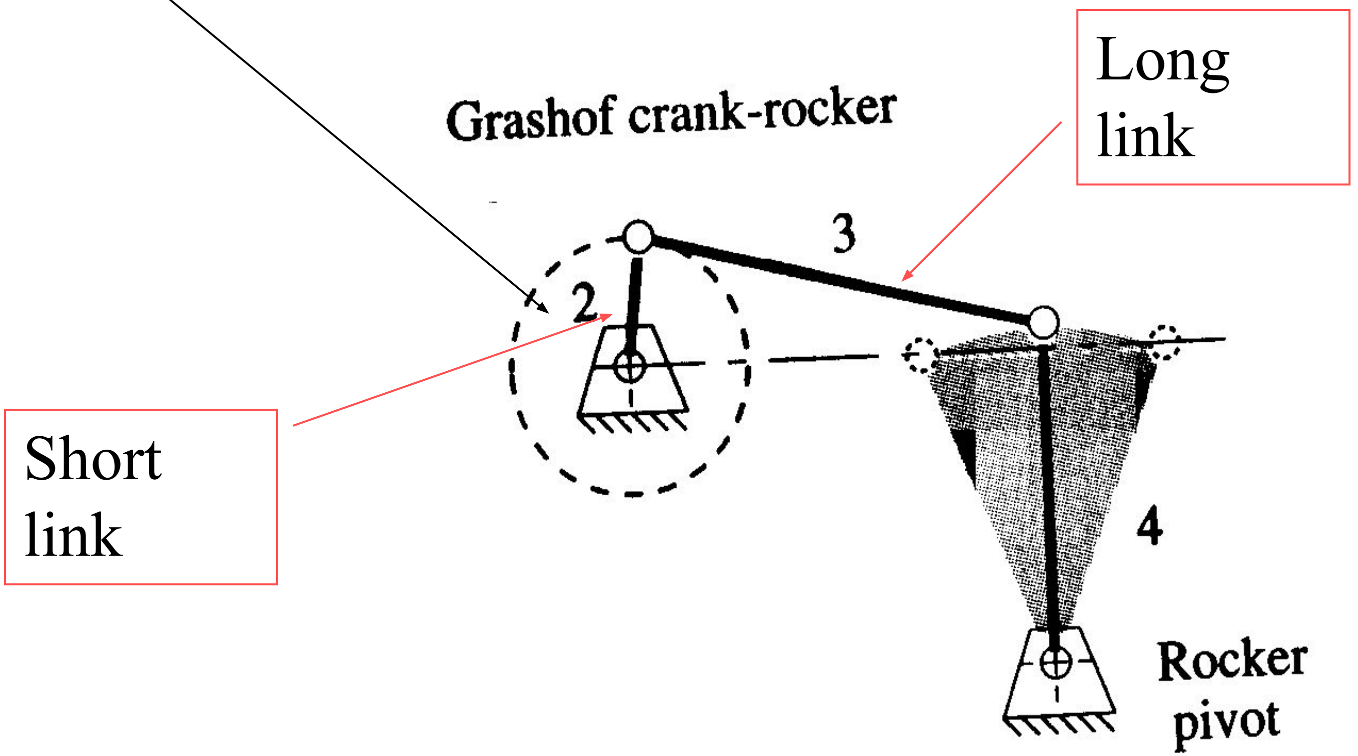
(b) Closed mechanism chain

Crank & Rocker



Rules For Link Lengths

- Long +Short Links <Sum of other Two Links
- **Crank & Rocker** When Short Link is Crank
- **Double Crank** When Short Link is Frame
- **Double Rocker** When Short Link is Floating Link

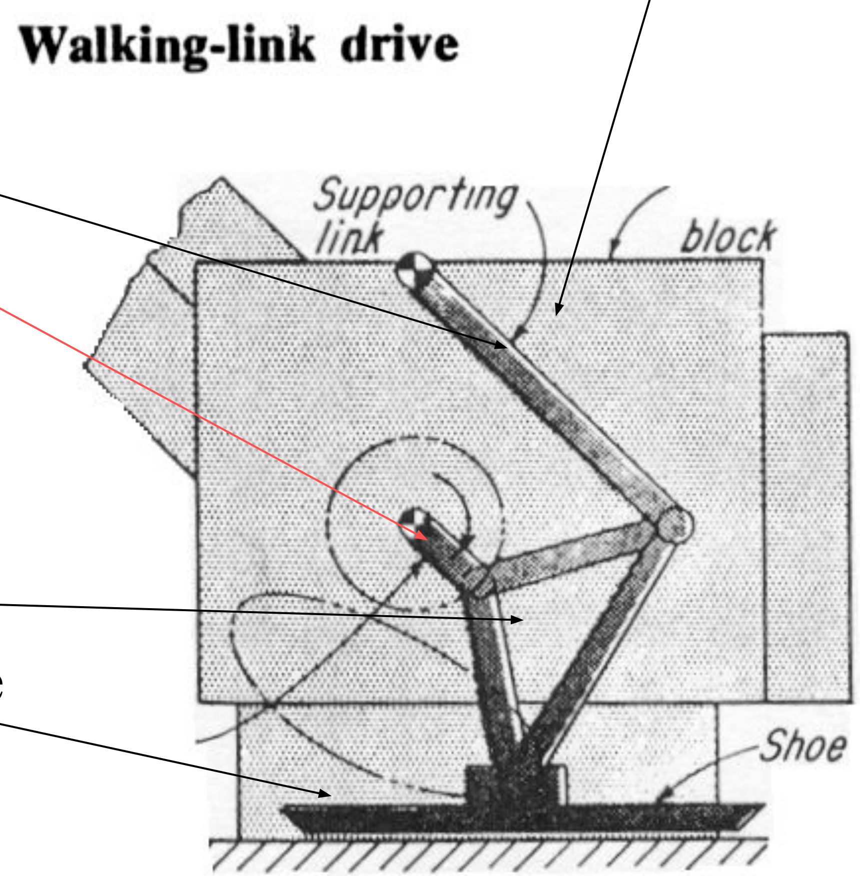


Walking-Link Crank & Rocker

A four-bar linkage

The drive motor can be inside the block

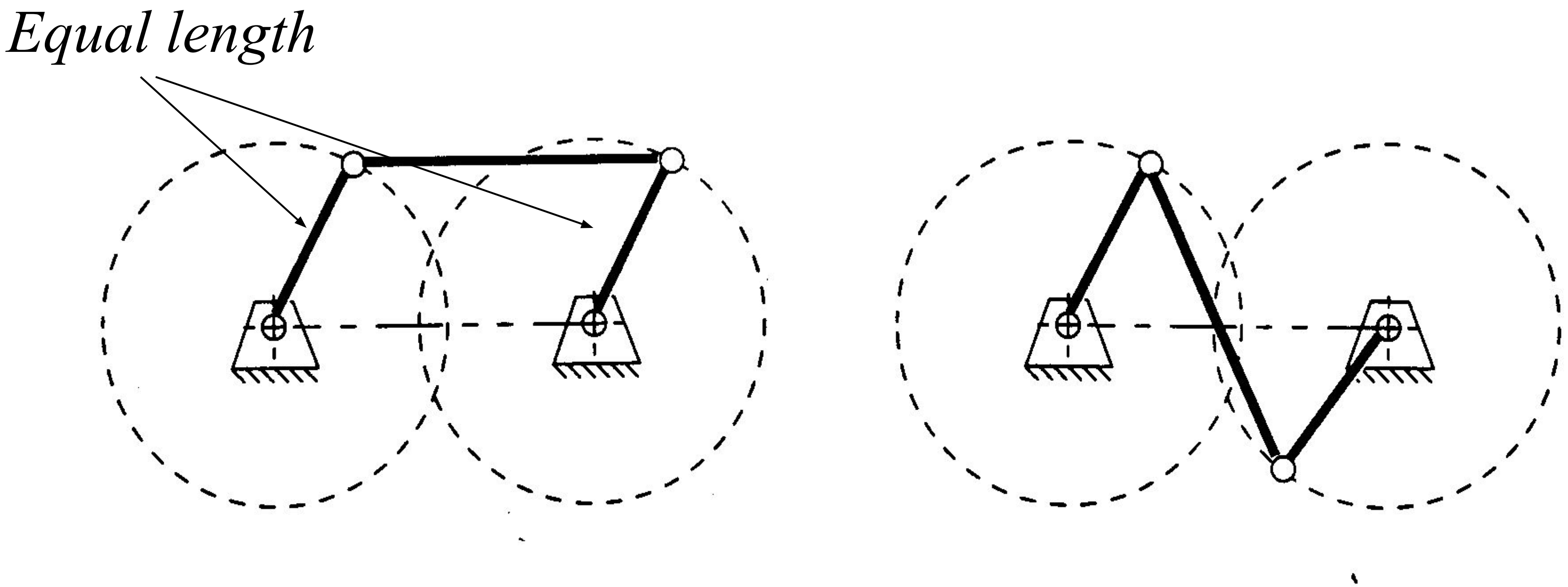
The crank and supporting link are connected to a block which is moved forward by the linkage



Triangular extension which supports a shoe which can pivot

Used in earth-moving equipment

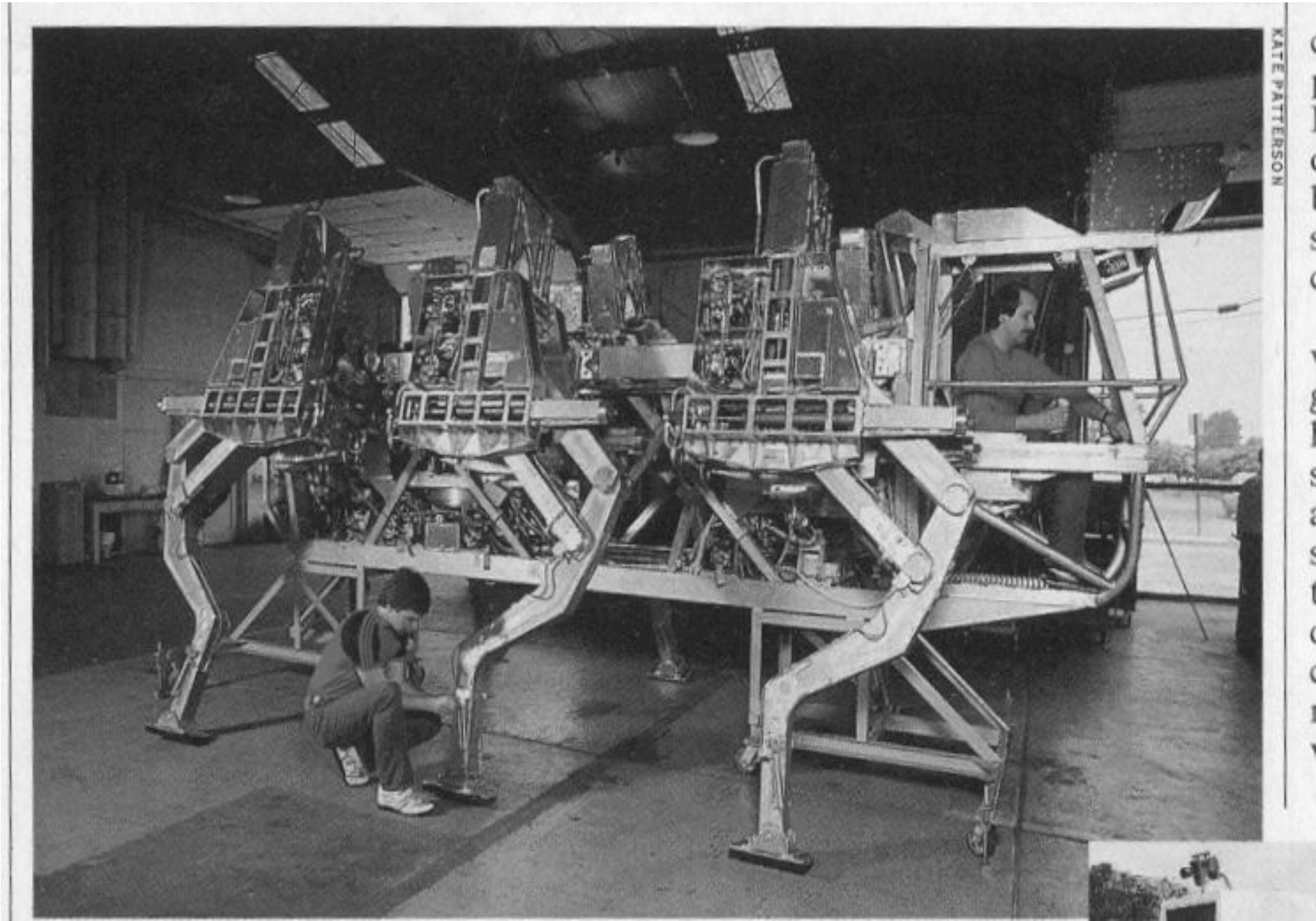
Equal Link Lengths On Opposite Sides



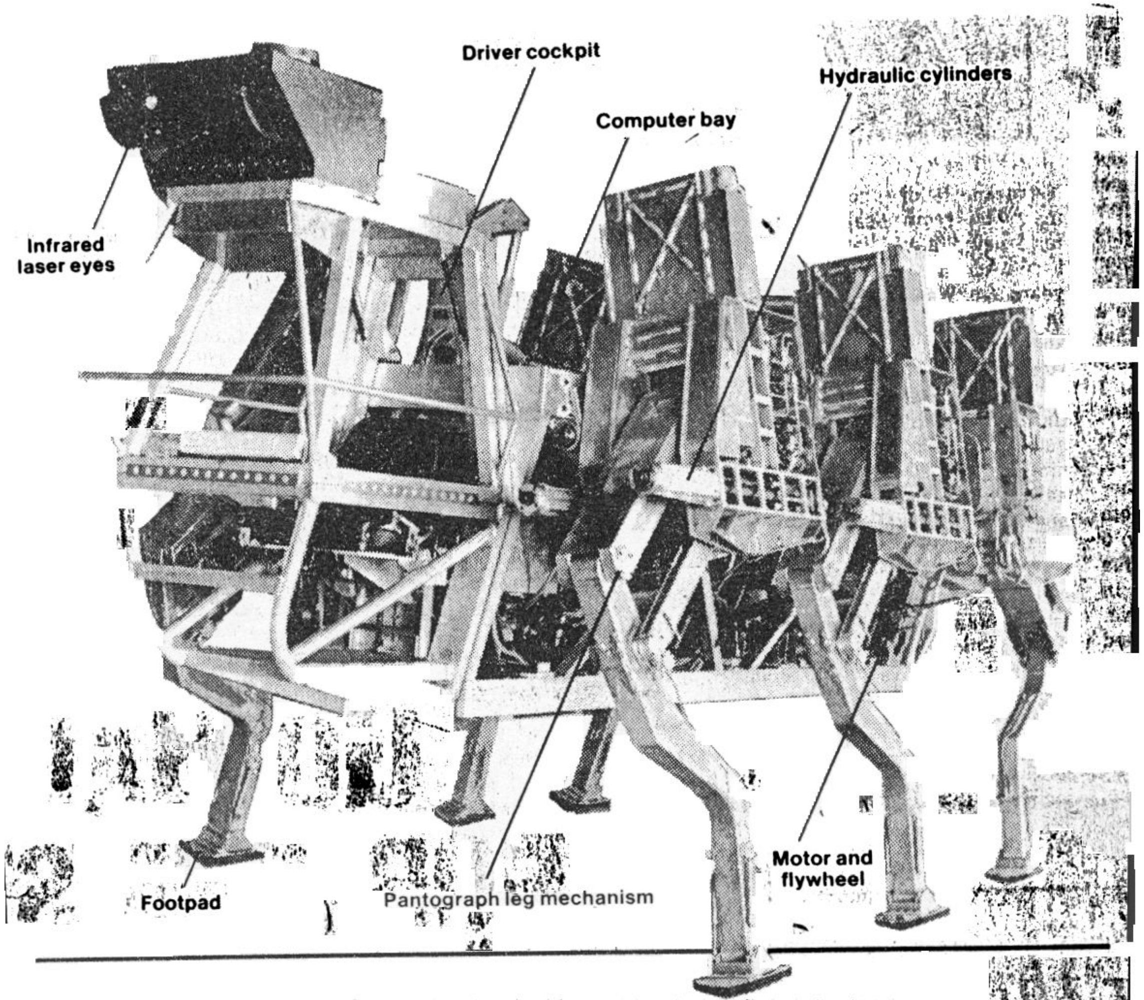
(*a*) Parallelogram form

(*b*) Antiparallelogram form

Hexapod Six-Legged Robot



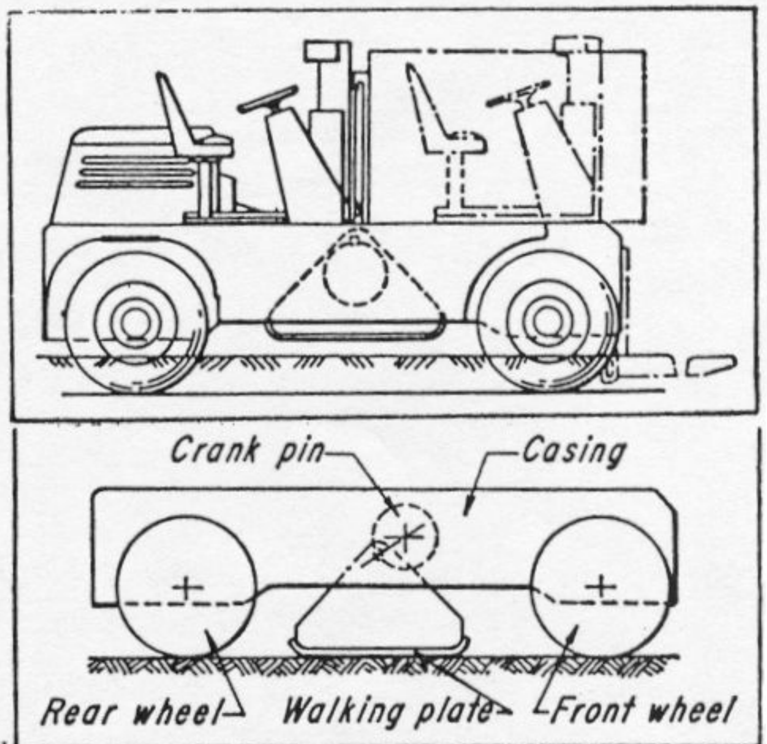
Another Hexapod



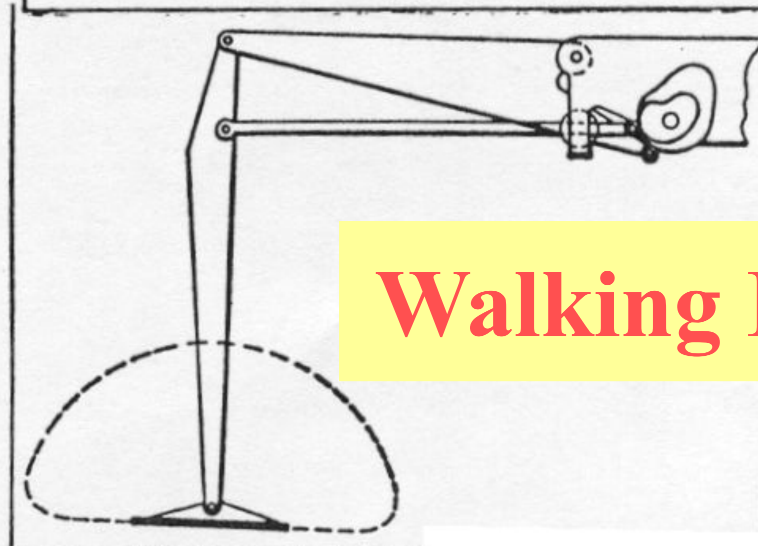
Robot with laser eyes takes lumbering first step.

If you want to design a fork truck or tractor that won't bog down in soft earth, or new vehicle to explore the moon, take a look at an old idea: walking plates.

In England, Lansing Bagnall, Ltd has just designed and patented what it claims is the first application of this type of mechanism to a moving vehicle. In this case, the vehicle is a fork lift truck. The mechanism (see diagrams) consists of a pair of plates mounted between the front and rear wheels of a truck. The plates, attached to a crankpin, are mounted so that normally they do not interfere with operation of the wheels. But, when they are brought into play, they can be pushed down so the wheels are lifted from the ground and a walking motion is created. They can also be used to assist the wheels when needed, since power can be applied to either system, or to both.



In the US, one of the latest systems for lunar locomotion, proposed by J. D. McKenney of Space-General Corp at the last ARS meeting, is a remarkably similar arrangment, the plates in this case being attached to jointed legs (see sketch).



Walking Plates

More Great History Moments

- **1983 Odetics** demonstrates a self-contained hexapod which lifts and moves back end of pickup truck.
- **1983 Raibert** demonstrates one-legged machine which hops in place, travels at a specified rate, keeps its balance when disturbed and jumps over small obstacles.
- **1987 Waldron and McGhee** demonstrate 3 ton self-contained hexapod carrying human driver which moves at 5 mph over irregular terrain and pulls a load.
- **1988 Hodgins and Koechling** demonstrate biped which climbs short stairways, jumps over obstacles and sets speed record of 13.1 mph.
- **1997 Honda** announces its bipedal walking project which has resulted in an autonomous humanoid.

Two Legged Vehicle--The P2

- Honda Motor Co.
- Obstacle Avoidance by stepping over and around.
- can walk stairs, forward or backward, and keep its balance if pushed
- Can perform simple tasks autonomously
- 15 minute battery capacity

Hexapods from Lynxmotion

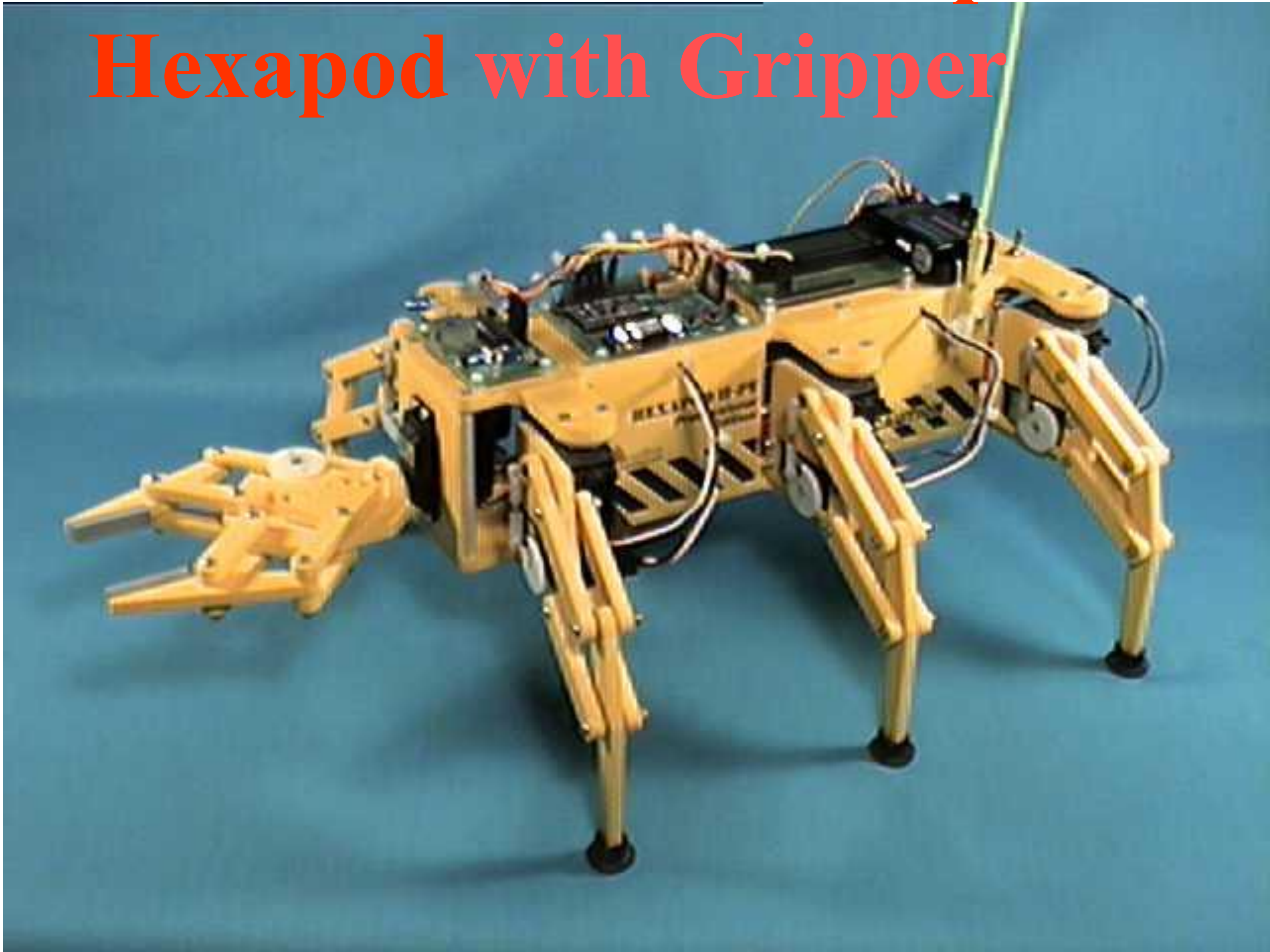
Lynxmotion Kits

- Hexapods
- Cars
- Arms
- Quadrupeds

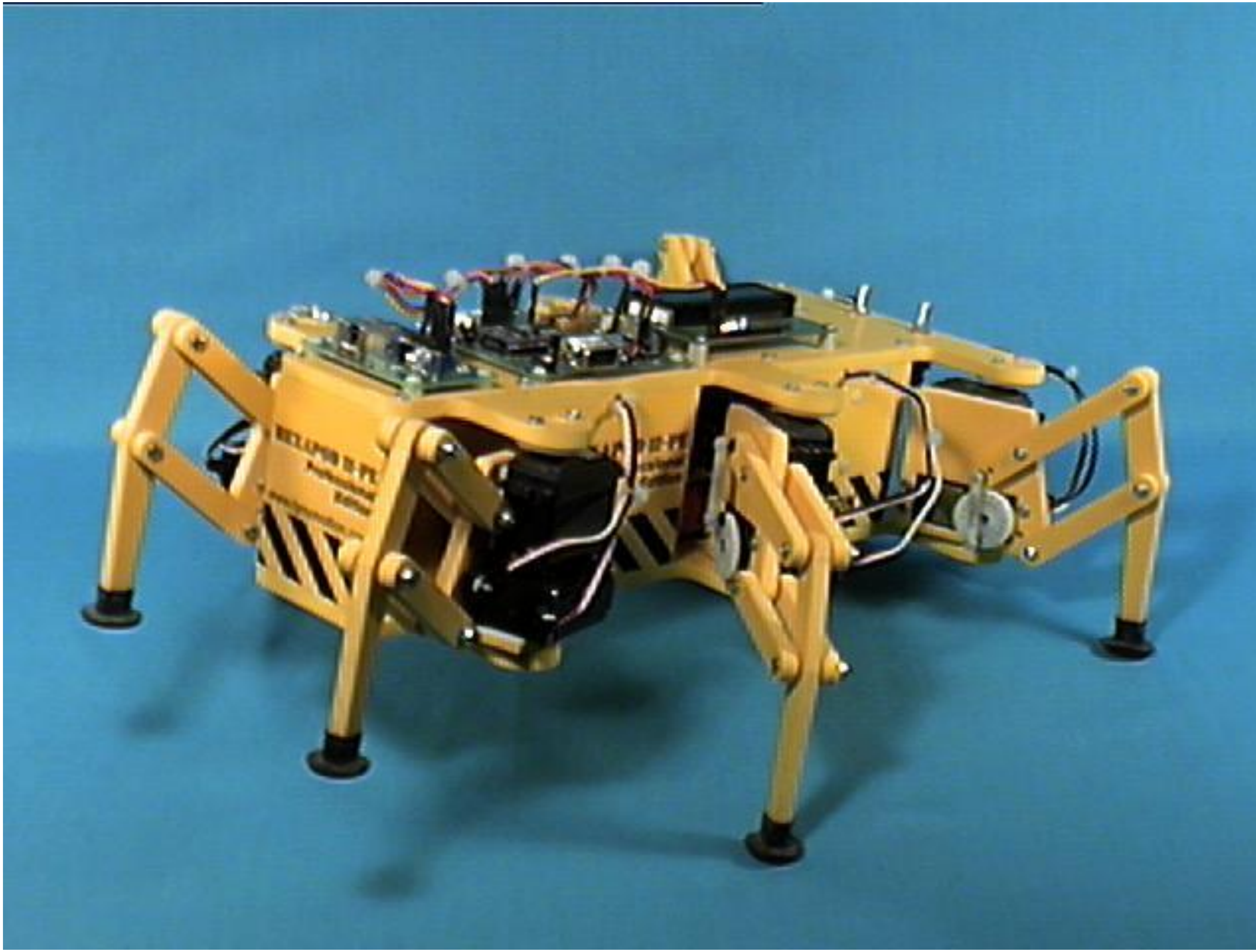
Lynxmotion Hexapods

Basic Radio-Controlled Spider

Hexapod with Gripper



Spider with a camera

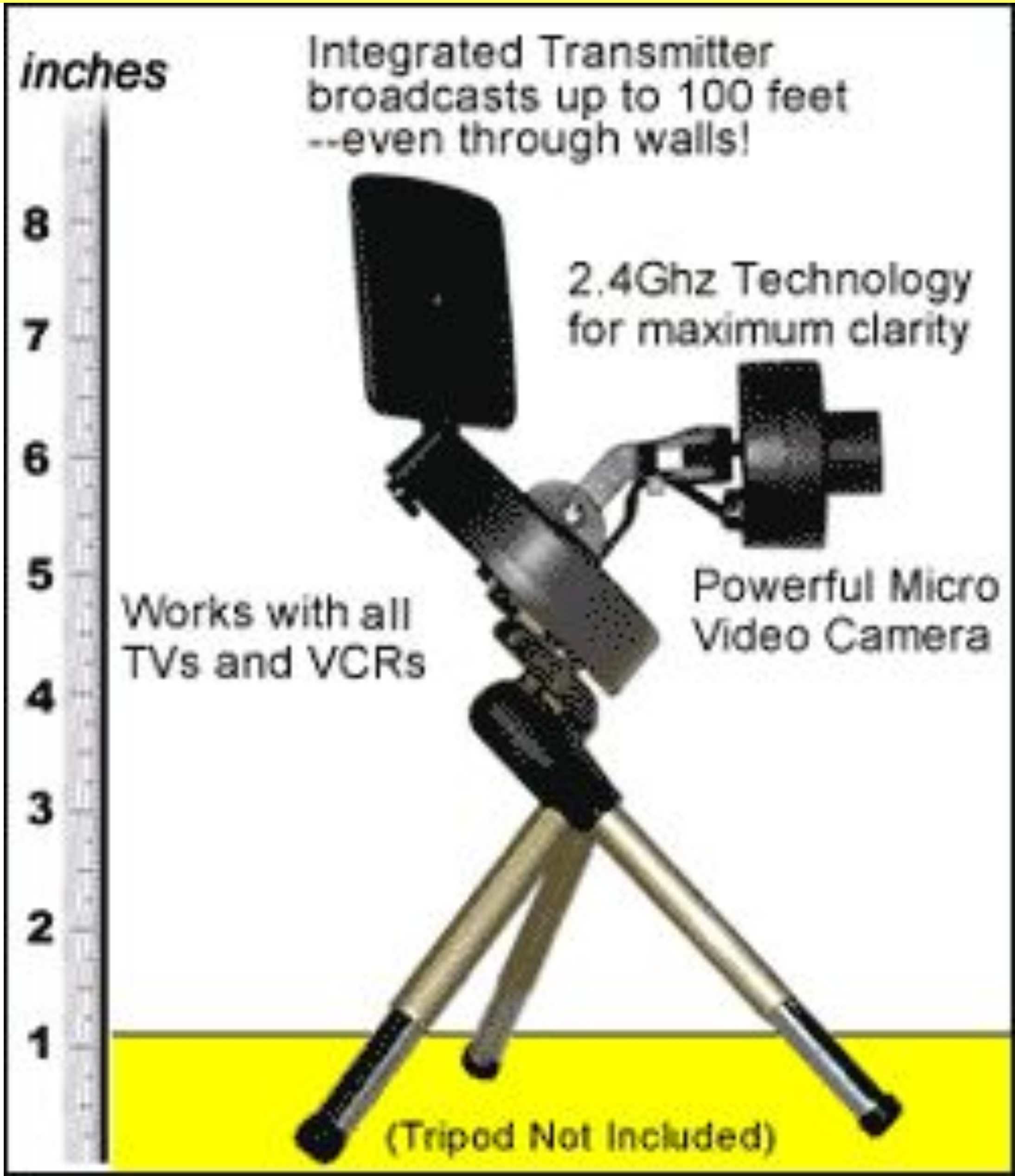


The Hexapod Kit

- Hexapod II Kit (body and 12 servos)
- A next step micro controller with basic stamp 2-sx module
- 2 MiniSSCII serial servo controllers
- An infrared Proximity detector
- Serial LCD Display Module
- Wire connector kit
- (2) 7.2 volt Battery Packs & charger
- Basic Stamp Programming Pack

Added Wireless Video Camera

- Called the XCAM2
- Purchased from X10.com
- It costs $99.99 with a battery pack
- $79.99 otherwise



Basic Stamp2-SX controller

- Microcontroller: Scenix SX28AC
  - Program execution speed: 10,000 instructions per second
  - Processor Speed: 50 Mhz
- Memory:
  - Program Memory size:
    - 8 programs x 2k Bytes each (16k Bytes)
  - Ram Size:
    - 32 Bytes (6 for I/Os and 26 for variables)
  - Scratch Pad RAM:
    - 64 Bytes (1 for program ID and 63 for user)

Controller continued…

- Inputs/Outputs: 16 + 2 dedicated serial I/O
  - Current @ 5v: 60mA Run / 200 micro Amps sleep
  - Source / Sink Current per I/O: 30 mA / 30 mA
- Connector Socket: 24 pin dip
- Programming:
  - PC Software Text Editor: STAMP@SX.exe
  - PC Programming interface: Serial Port (9600 Baud)
  - PBASIC Commands: 39

Next Step Carrier Board

- Basic stamp 2-sx module plugs into the Next Step Microcontroller
- Supplies:
  - Serial port interface
  - Pin connectors for easy connection to other items
  - Buttons and LEDS
  - Power connections

Component Interconnections

- The Next Step has the Basic Stamp 2 module on it
- Other components are interfaced to the next step
  - Serial LCD display
  - Infrared proximity detector
  - 2 MiniSSCII serial servo controllers
  - Batteries & switches

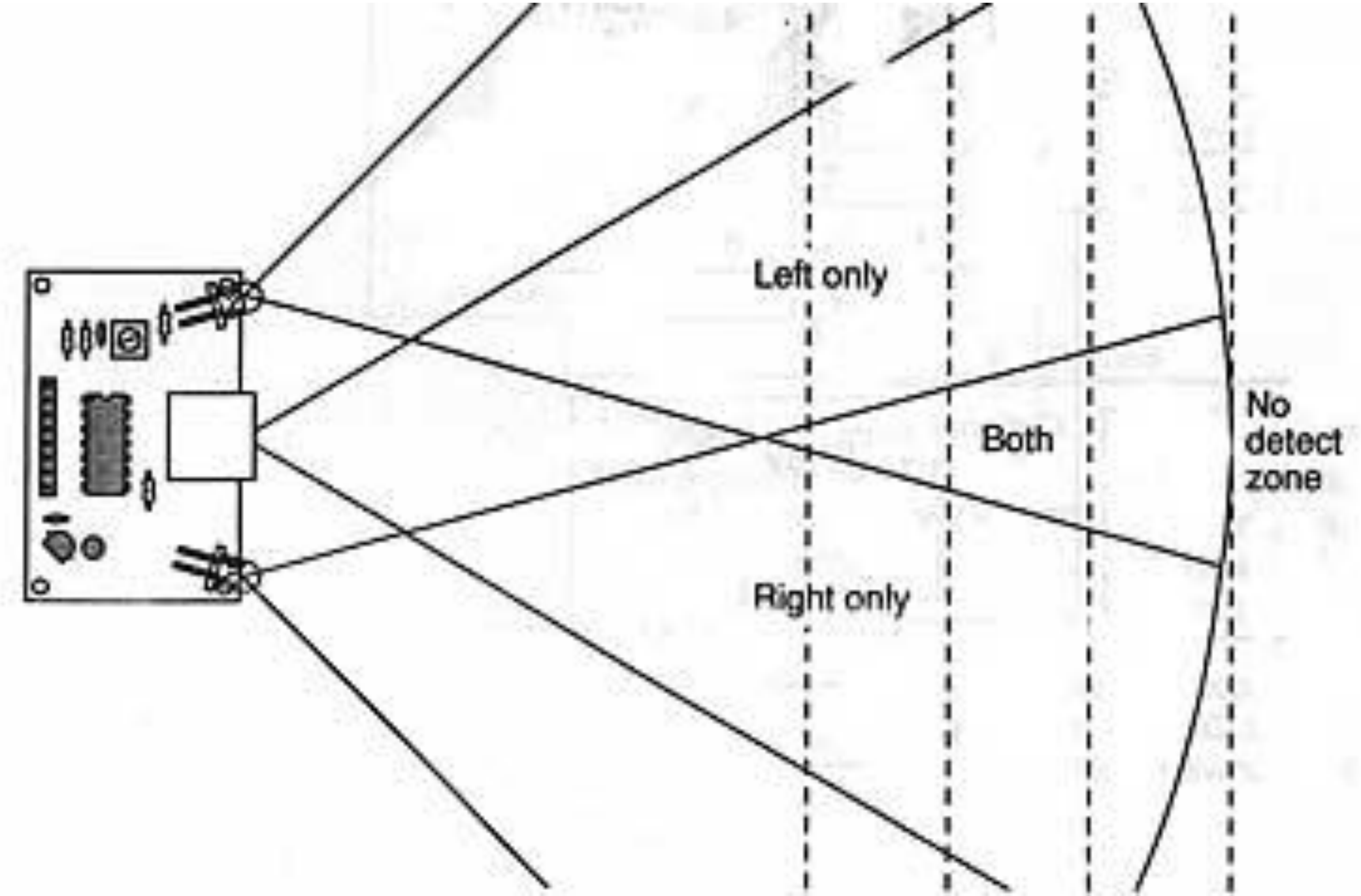
Serial LCD Display

- Power, ground and a single data connection
- Serial information is sent via the data line
- The serial display is back lit and displays 16 characters on two lines. (total of 32 characters)

IRPD

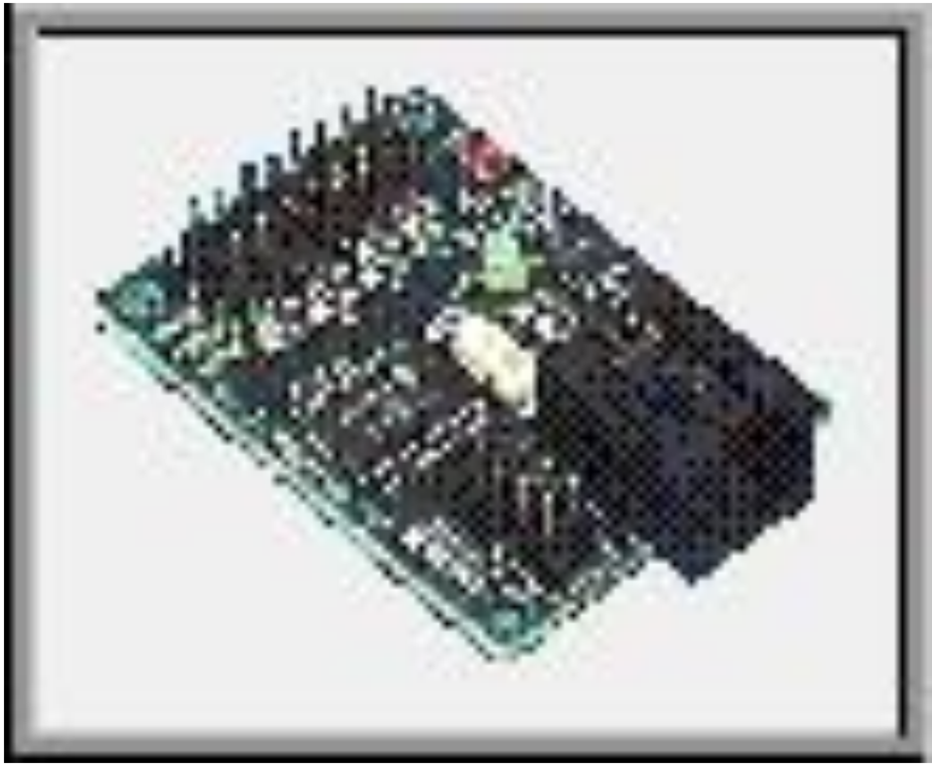
- IRPD = Infra Red Proximity Detector
- Connected to power and ground
- Three I/O ports:
  - Left source
  - Right source
  - Detector

Infra Red Proximity Detector



MiniSSCII servo controller

- Receives serial data:
  - Which servo
  - Move to what position
- Control 8 servos per controller
- Configurable by jumper settings:
  - Addressable for more controllers
  - Change the baud rate
  - Adjustable range of motion of servos

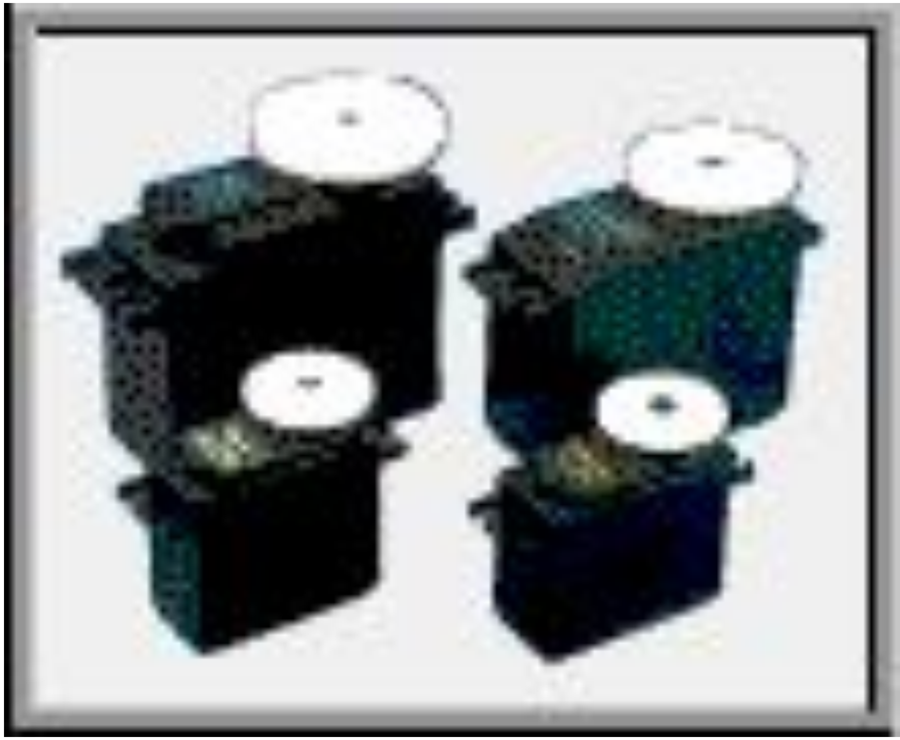


Hexapod II Configuration

- Two MiniSSCIIs working together
- Six servos per controller:
  - one controller: 0 to 5
  - another controller: 8 to 12
  - There are two unused pinouts
- Different serial data lines

Servos

- Components:
  - Electric motor
  - Gearing
  - Potentiometer
  - Difference amplifier
  - Power amplifier



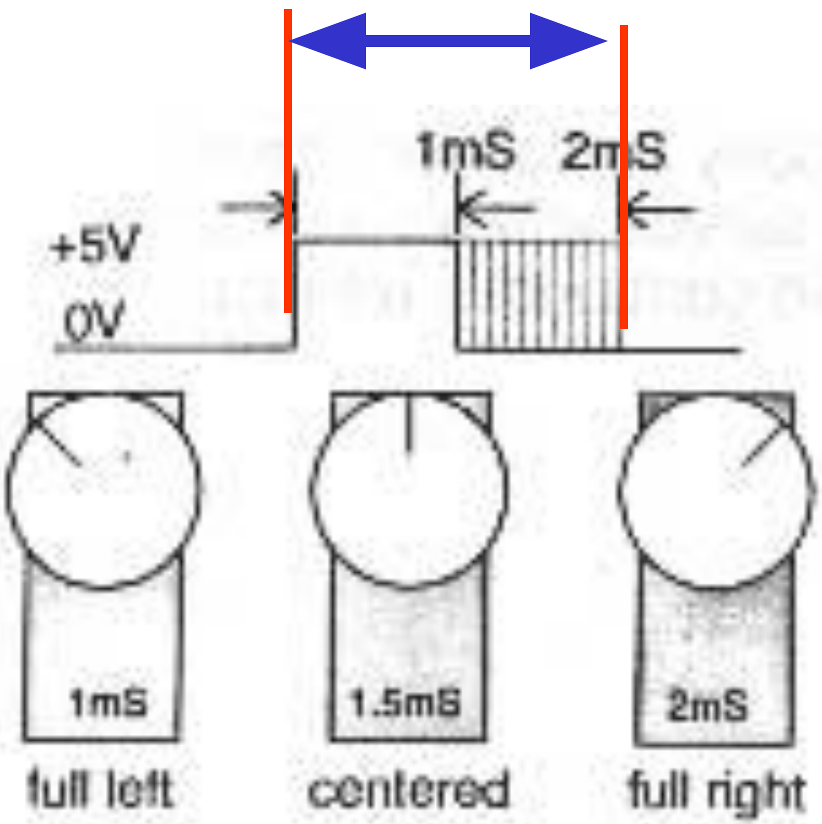
Servo Operation

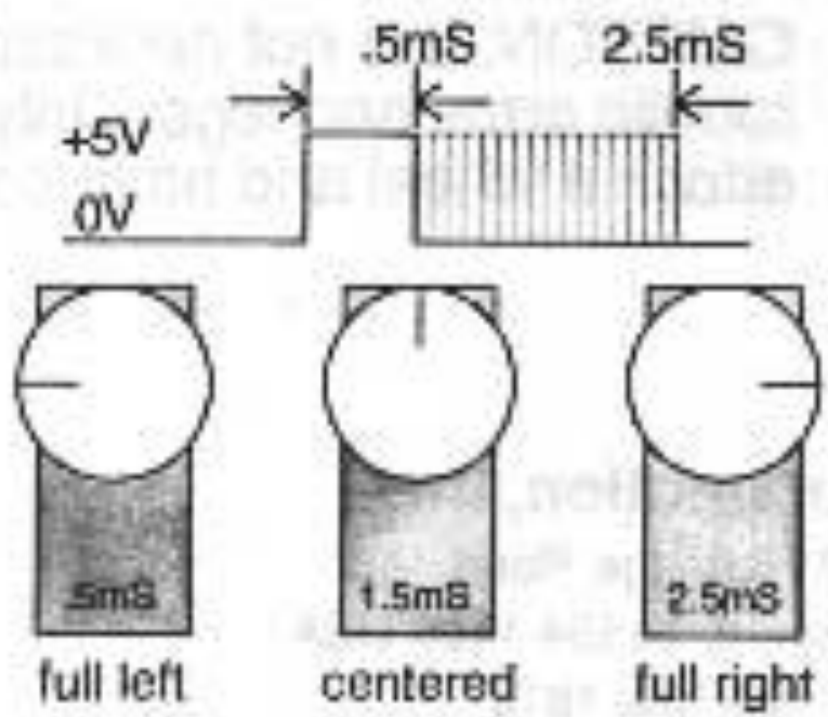
- Potentiometer measures output shaft position
- Input signal is sent in
- Difference amplifier compares values of input and output values
- A driving signal is generated
- Signal is amplified
- It powers the motor
- Output shaft changes potentiometer value
- Driving signal changes
- Process repeats until the difference signal is zero

Pulse Width Modulation

When "high" for 2mS, stays in right

By controlling the pulse width you change the angle



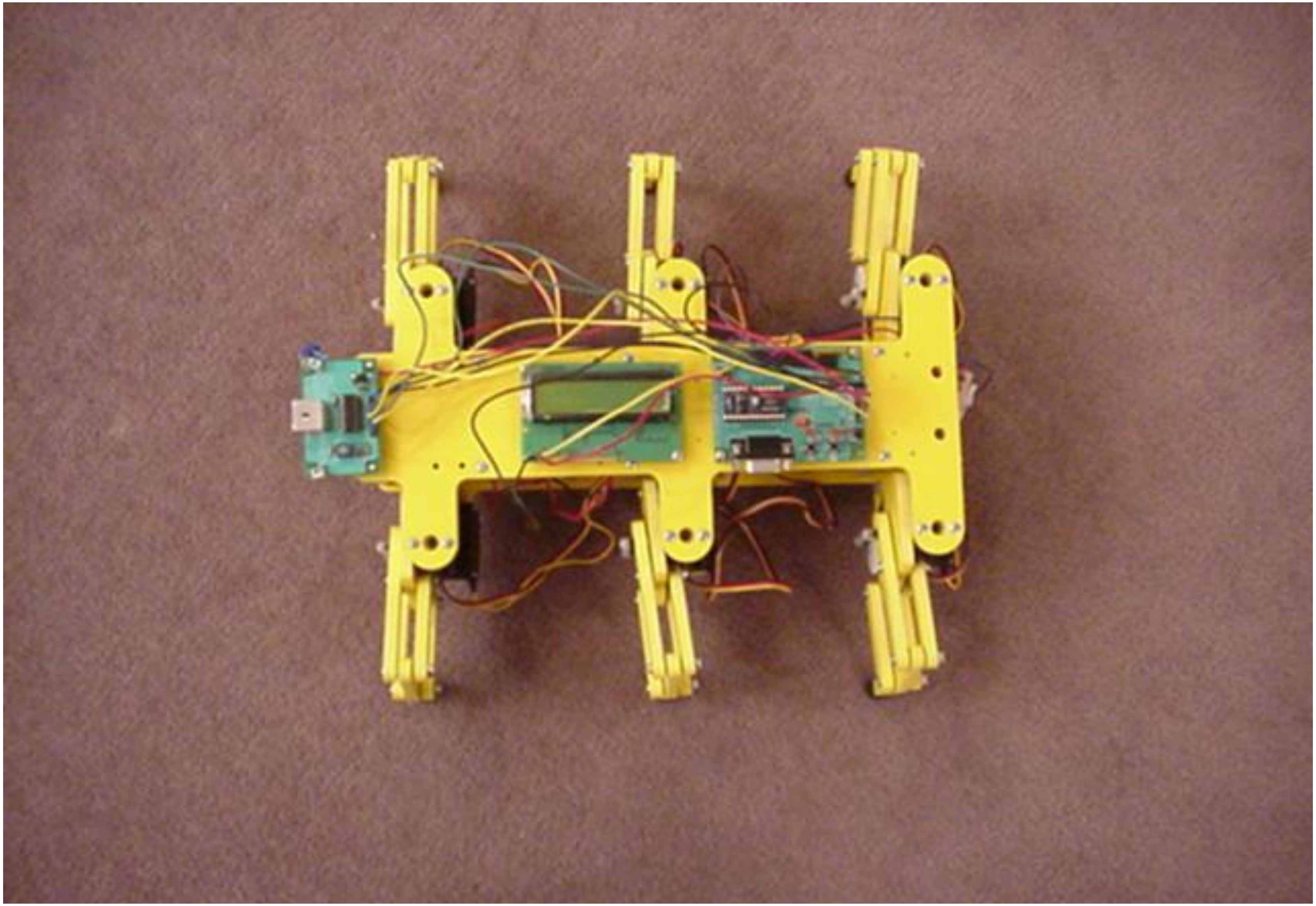


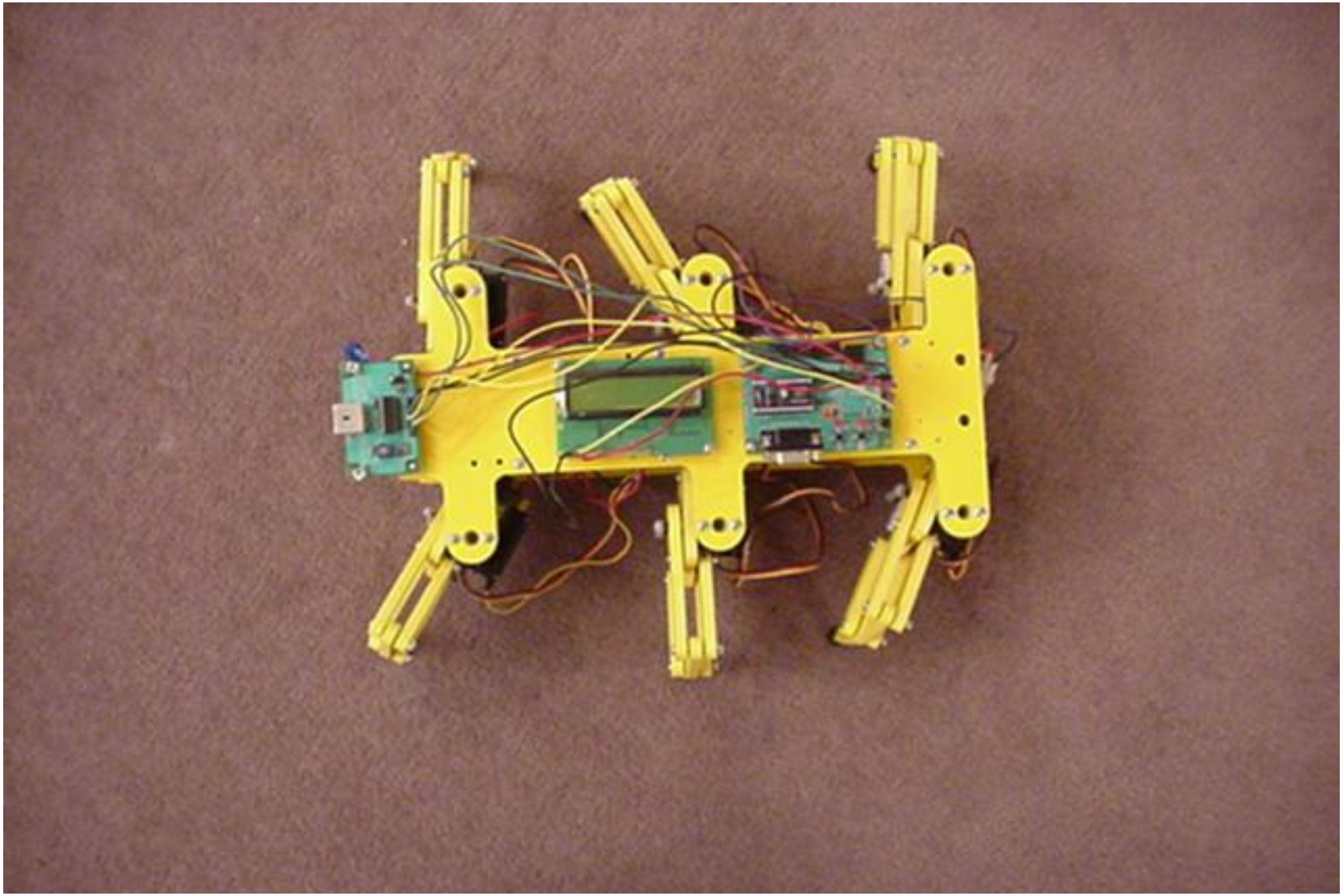
Notable Features

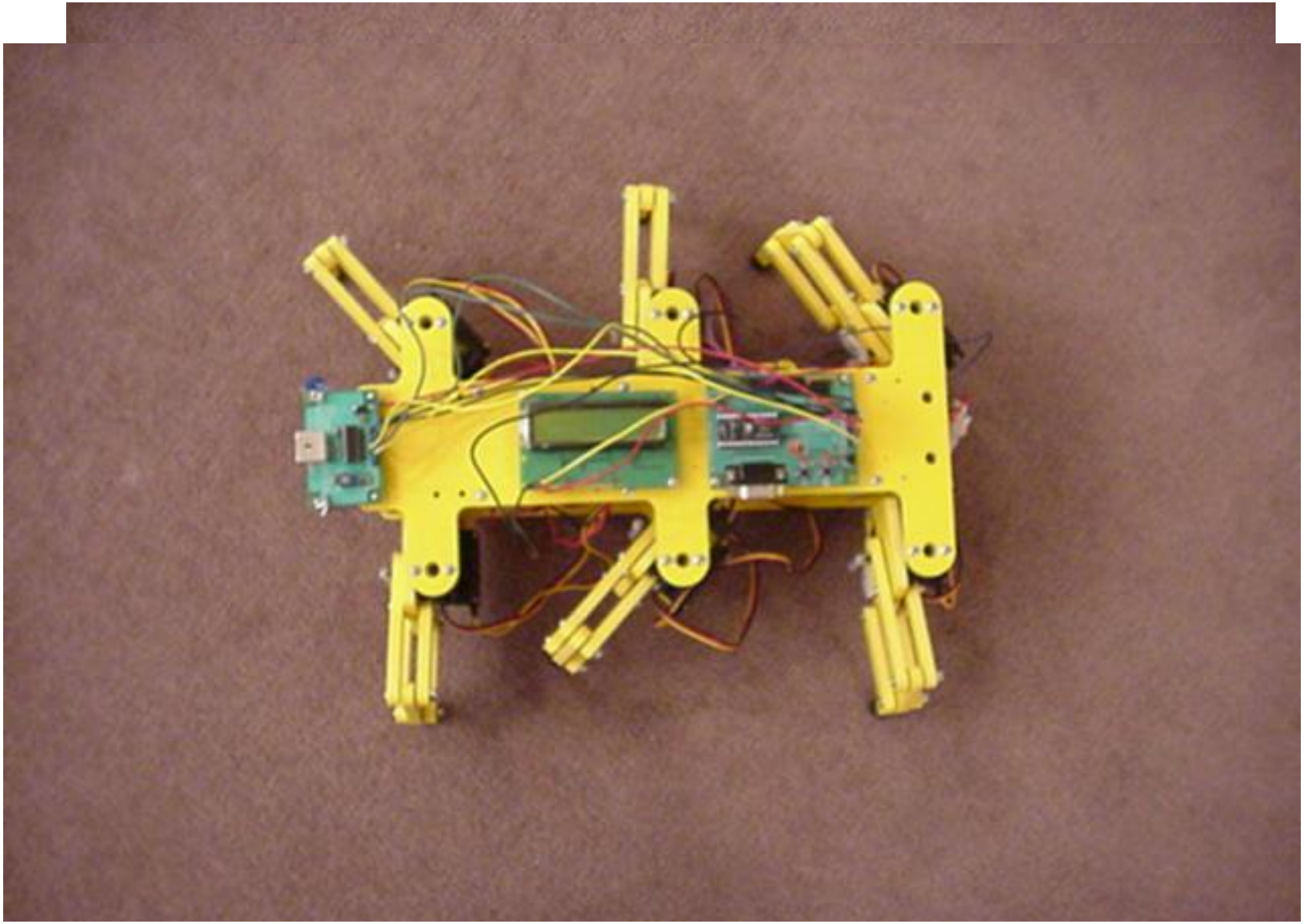
- Variable speed
- Input signal is pulse width modulation
  - Pulses ranging from 1 to 2 milliseconds long repeated 60 times a second

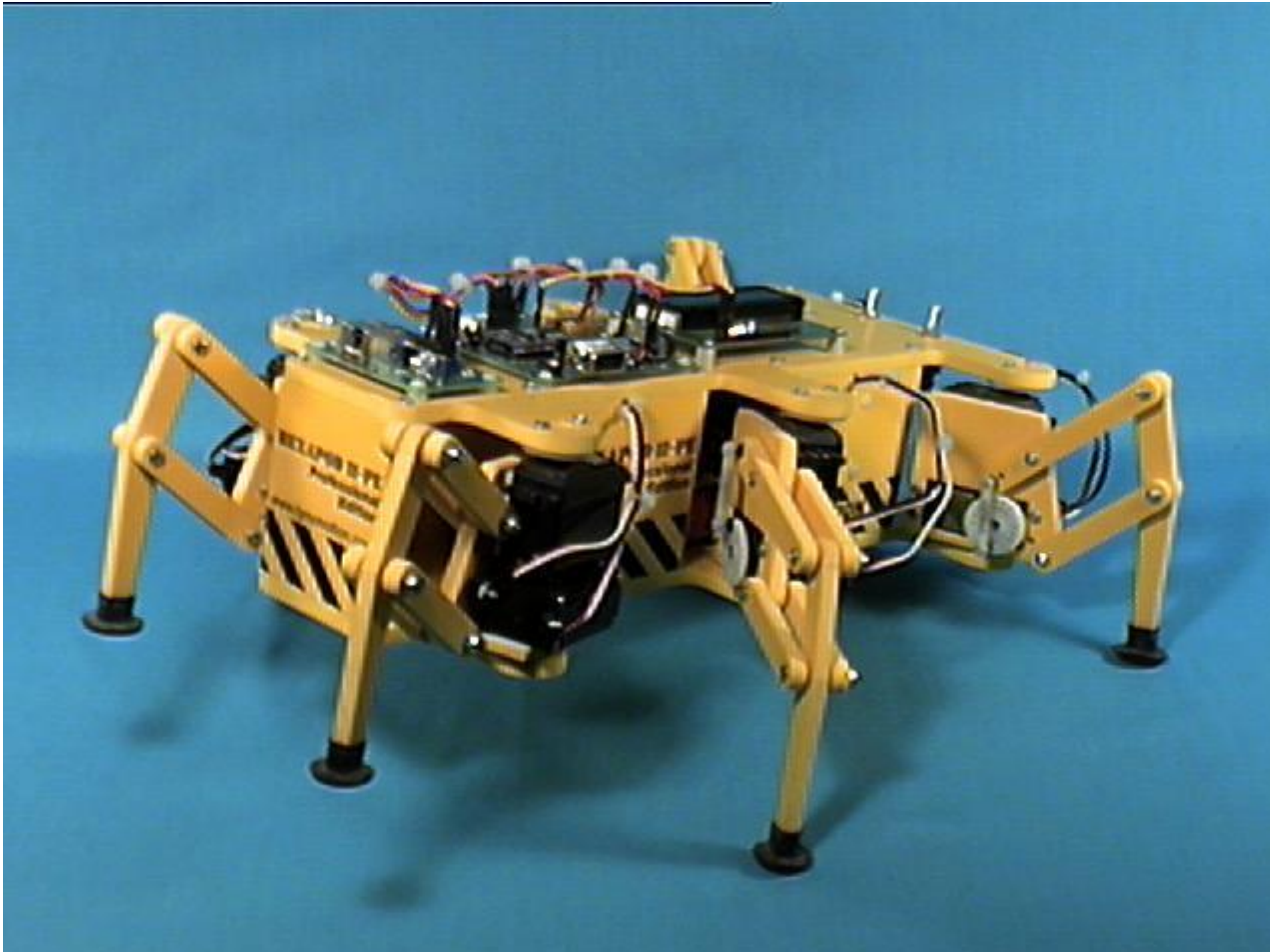
Batteries & Switches

- 9 volt battery for the next step
- 9 volt battery for the MiniSSCII
- 7.2 volt Battery pack to power the servos
- On off switches for each source









Programming

- PBasic programming language
- Syntax described in book
- Provided text editor
- Compiles on PC and downloads via serial port

What have we added?

- 2 Radio frequency transceivers
  - Computer serial port
  - Onboard robot I/O pin
- Video feed to computer
- Vision system analysis
- Signals to control robot

Hexapod Kit **Purchasing**

- The Lynxmotion Hexapod II Professional Edition Combo kit
- Their company web page www.lynxmotion.com
- The Mondotronics Robot Store at www.robotstore.com
- Current street price: $766.35

Problems with Lynxmotion hexapods

- **Weight**
  - Servos make the vehicle quite top heavy and may add to instability. Is there a way of replacing servo with muscle?
- **Turns**
  - How?
- **Sensing**
  - There ain't any! What happens on uneven ground?
- **Speed**
- – Unstable at higher speeds

Other Hexapods

Rhex Hexapod Robot

- RHex 0 is the first prototype in the RHex series of hexapod robots.
- It has been built in July-August 1999 over a period of roughly 6 weeks at McGill University.

- Inspired by hexapodal insect locomotion, RHex 0 uses an alternating tripod gait.
- As such, RHex 0 can run over various types of surfaces ranging from carpet to gravel at speeds up to 0.6m/s.
- It can traverse obstacles of heights up to 22cm, or roughly 220% of its ground clearance.
- Using the same controllers, it can go over higly irregular "fractal" surfaces with little impact on performance.
- Future controllers will also enable RHex 0 to climb stairs and leap.

Dimensions	body dimensions leg length ground clearance	0.53x0.20x0.15 m 0.175 m 0.10 m
Mass	frame&legs electronic hardware motors batteries **total**	1344 g 2205 g 2018 g 1680 g **7247 g**
Power	source capacity robot endurance	2 lead acid batteries 2.2 Ah @ 12 V 48 mins standby 18 mins running
Control	source frequency user interface	on board 486DX100 local PD at 1 Khz R/C unit
Actuation	source rated output (stall)	6 Maxon RE 118751 20W DC brushed motors with Maxon 114473 33:1 two stage planetary gearhead 3.614 Nm (50% eff.)
Sensing	6 optical encoders voltage & current sensors	leg rotation speed at motor shaft battery voltage and current

One more hexapod to build

Japanese hexapod

Introduction to Japanese hexapod

- This is a hexapod robot powered by 18 RC servomotors.
- The degree of freedom of each leg is 3.
- Built to study the control software for 6 legged locomotion.
- This robot can walk in every direction,
  - but the maximum speed of progress depends on the direction.
- Equipped with radio control transmitter and can accept control by radio.
- Connected to PC's parallel port for downloading or/and controlled from PC with umbilical cable.

Introduction to Japanese hexapod

Length	550 mm
Width	350 mm
Hight	350 mm
Weight	2600 g
Actuators	(18) Sanwa PWM servos (model SRM-1301)
Battery	Ni-MH battery
CPU	Z84C1106 (signal generator) PIC16C84-04 (RC interface) Win 95 PC (for development)

Introduction to Japanese hexapod

Mechanical Structure and Arrangement

The robot consists of 3 major parts:

1. "The Cover",

2. "The Frame",

3. "The Leg-unit".

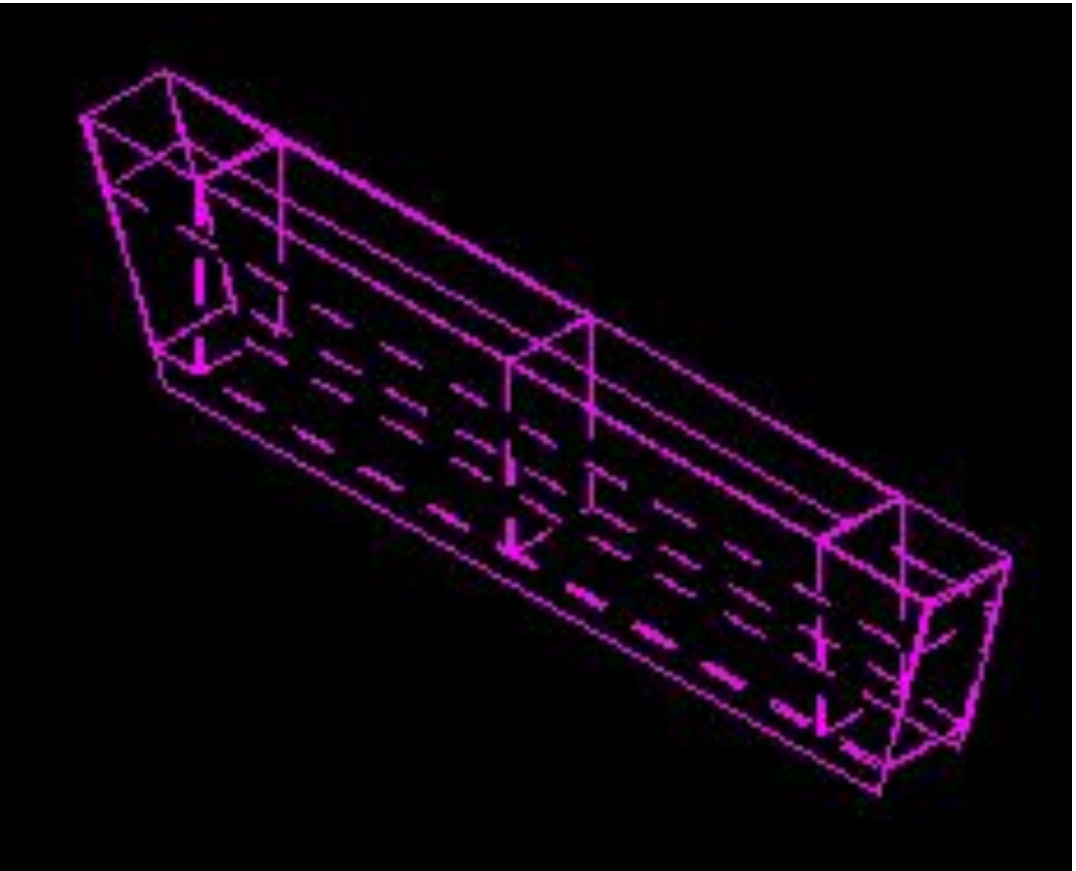
Built to have enough strength and reduce the weight.

Cover

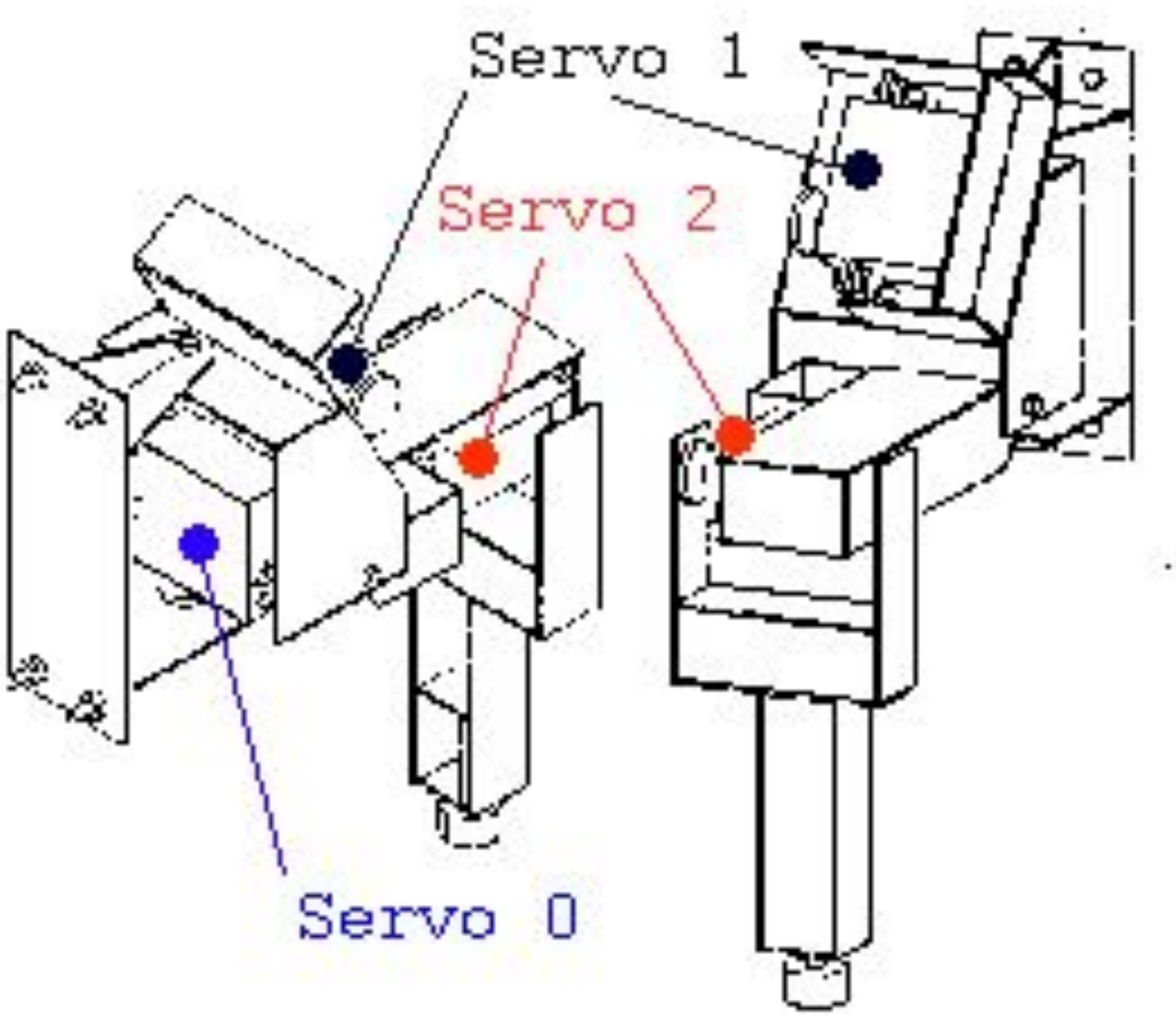
This is the part that looks like tank.
It is made from plastic plate.
The thickness of the plate is 1(mm) and 0.3 (mm).
The structure is similar to ship's skeleton.
Underside of the cover.
This picture shows how the cover keep its shape.

Frame

The frame is made from plastic plate.
(Thickness is 1 mm)
The frame is just an empty box that has three bulkheads at the base of a leg-unit.

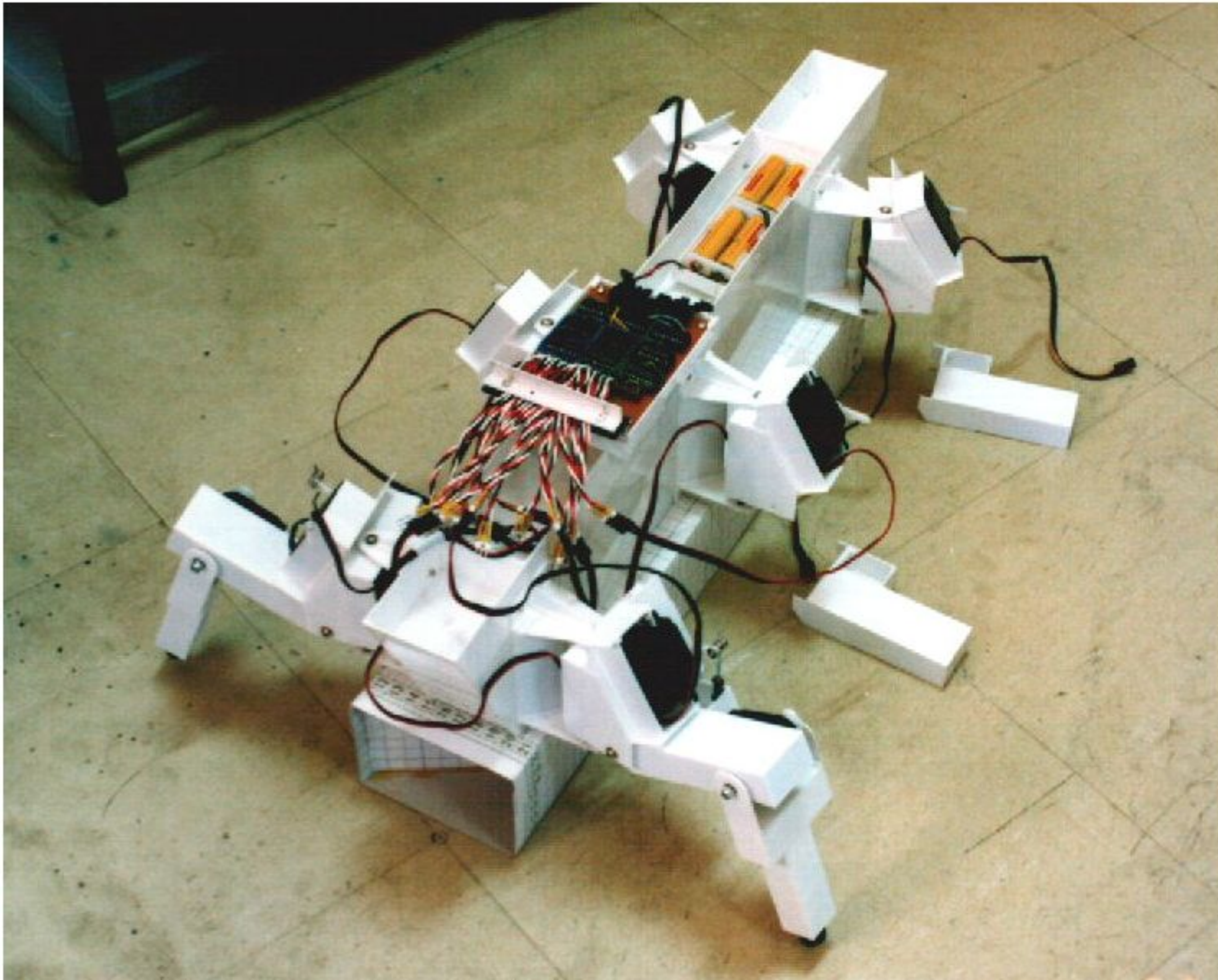


Leg-unit



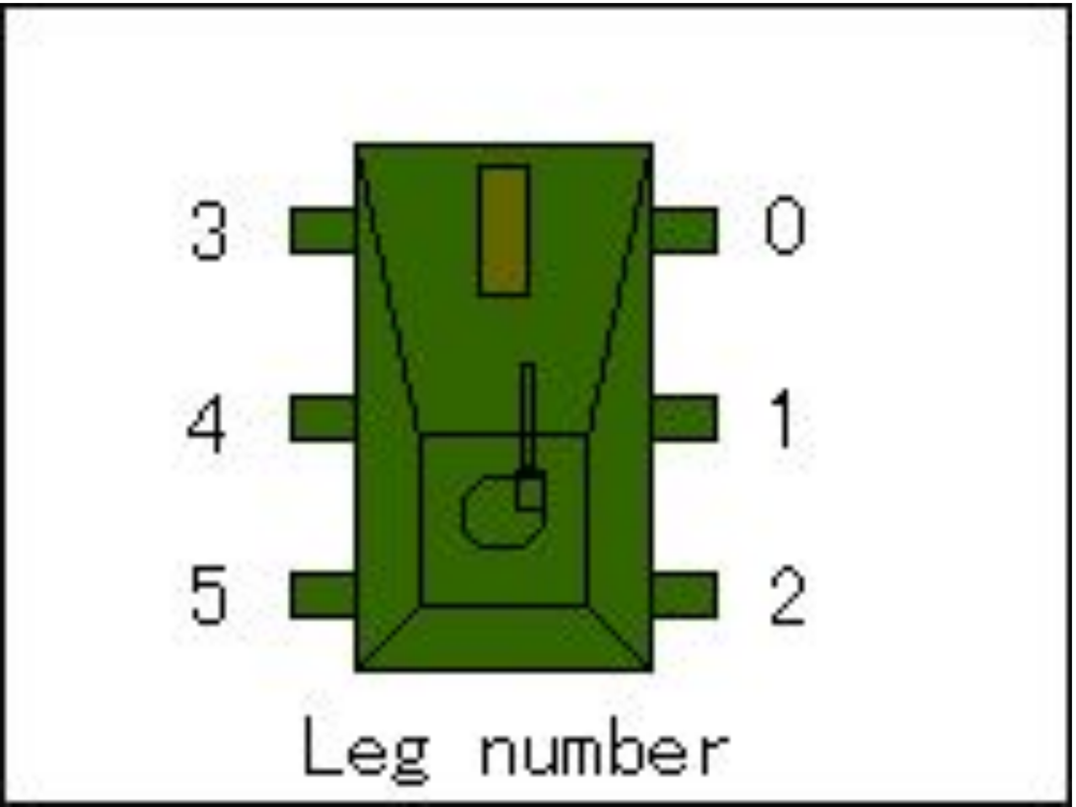
Layout of servomotors

- To increase inertia of parts to be actuated is not good from the point of stability and power consumption of a robot.
- All the servomotors are inserted inside of each leg-unit for making it easy to change the arrangement of the legs and to reduce the complexity of the mechanism.
- No. 0 and No. 2 servo is connected directly to acquire wide range of the joint movement.
- No.1 servo is connected to No.1 joint via a linkage to support the weight of the robot.
- This picture shows the leg-unit and the frame.



Arrangement of the leg-units

- The leg-units were arranged in line not to interfere each other.
- When the robot supports its own weight with three legs (ex. 0, 2,4), leg 4 must generate two times as much force as leg 0 and 2 generate.
- So the maximum total weight of the robot is restricted by the power of leg 1 and 4 for this arrangement.

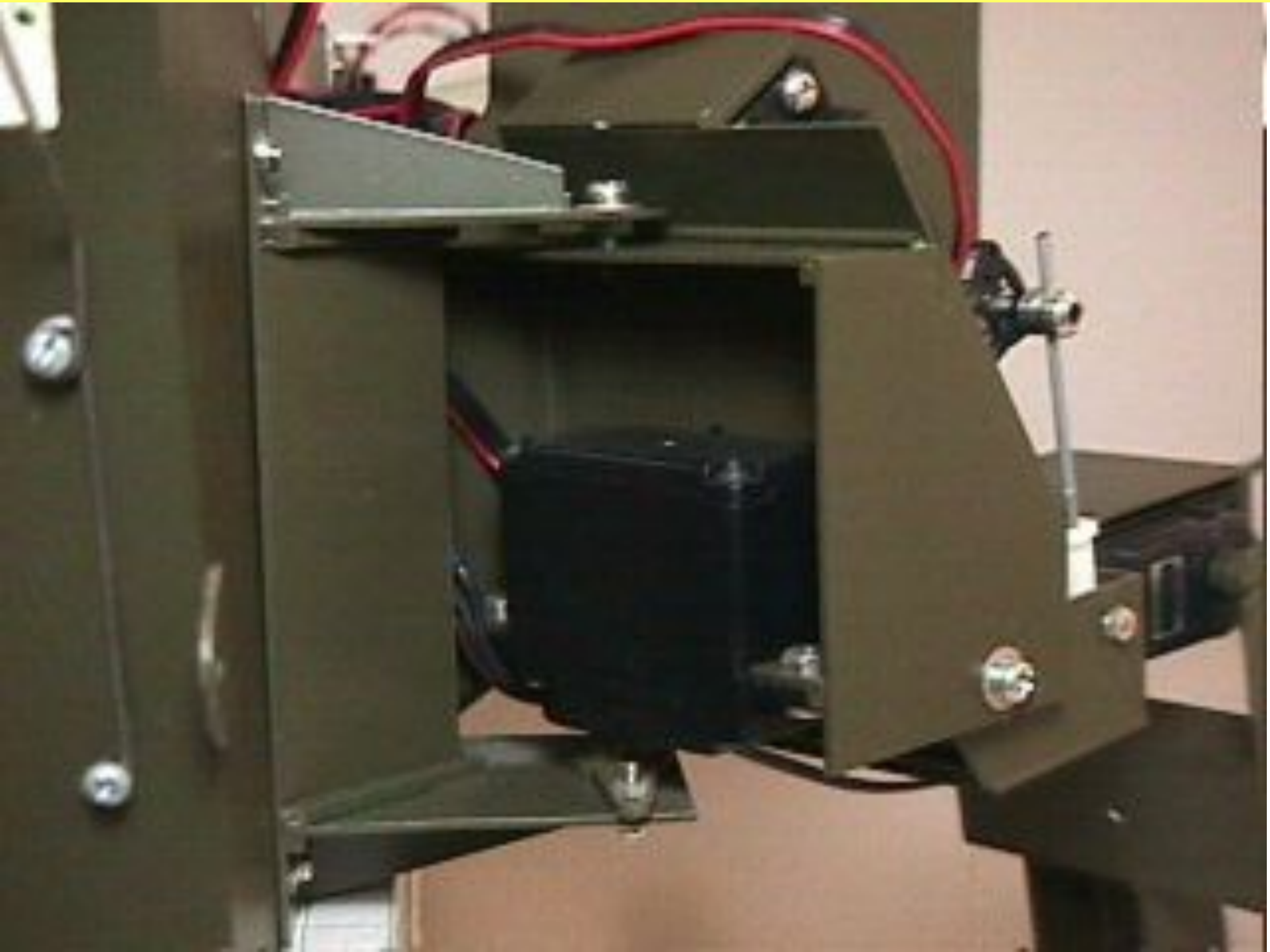


Mechanism of the joints

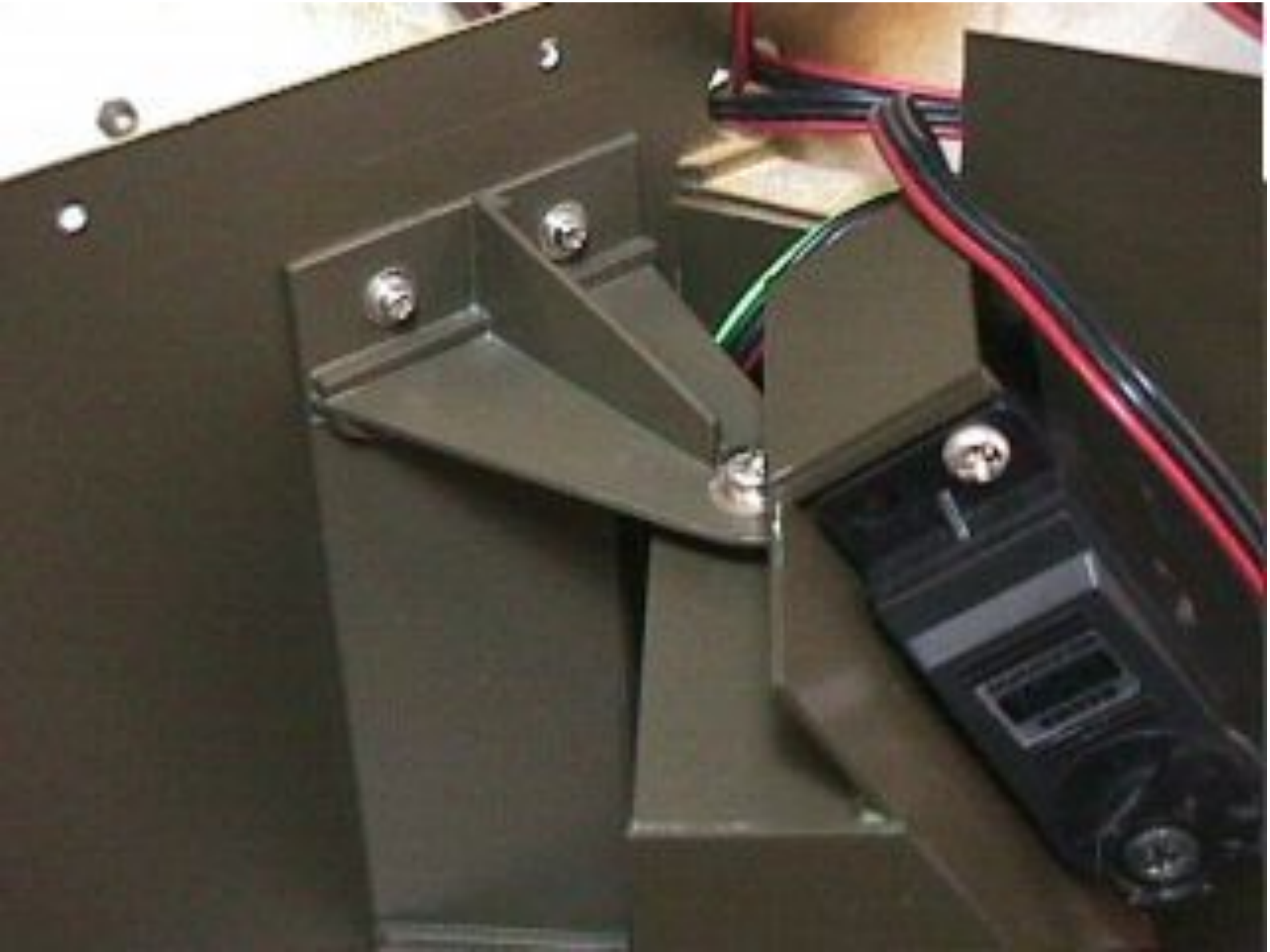
- All the axles that are opposite side of servomotors have a simple mechanism to reduce the cost for the construction and increase productivity.
- Don't expect these axles long life.
- The axle consists of 3mm-diameter bolt and a hole on plastic plate.

Joint 0

This picture shows how servo 0 is mounted.



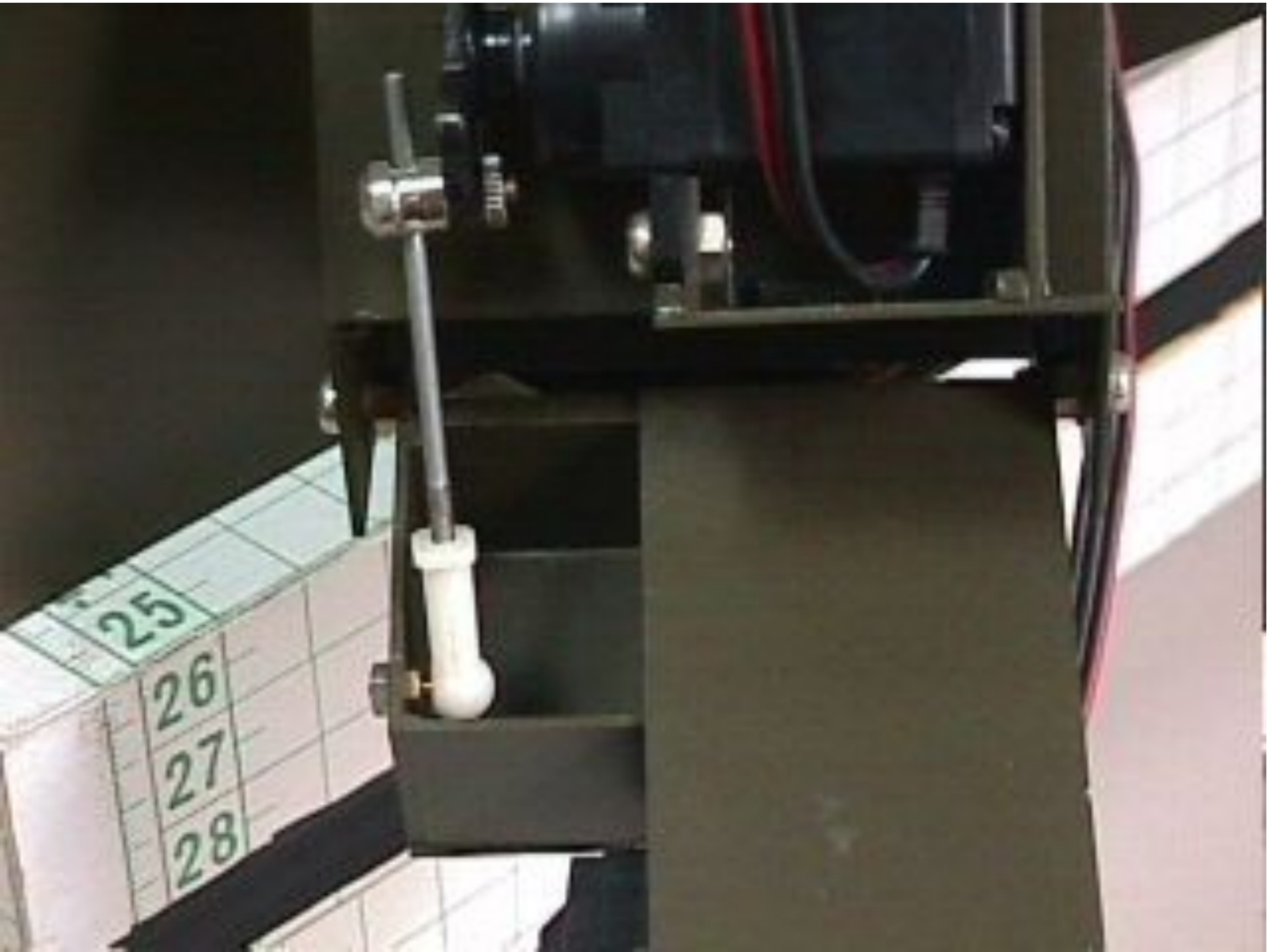
- This picture shows around joint 0. The leg-unit is mounted to the frame with 4 2mm-diameter bolts



- Joint 1

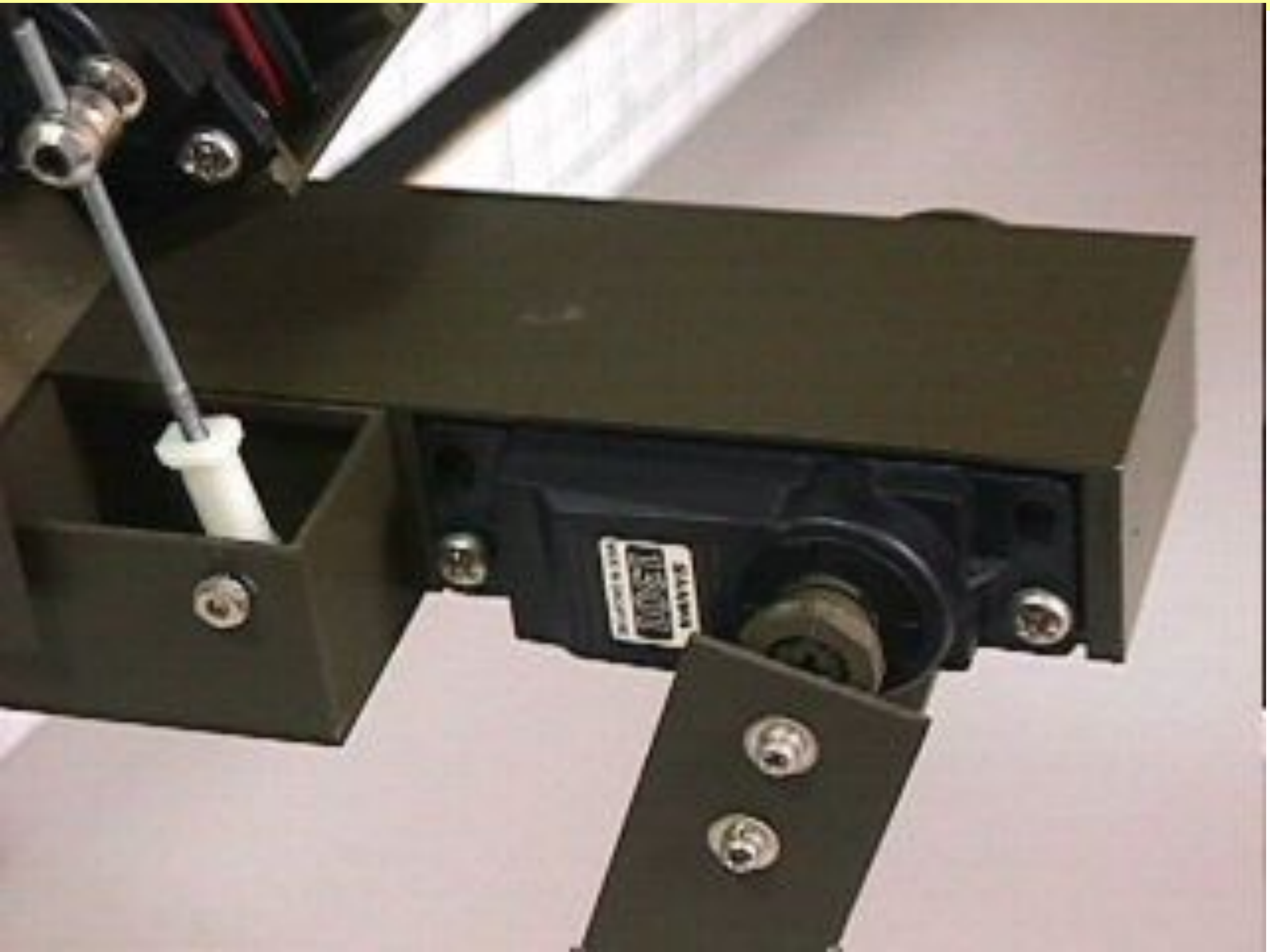
- This picture shows how servo 1 is mounted.
- The servo is mounted to the leg-unit with 2 3mm-diameter bolts.
- Use a part for RC aircraft to connect the servo-horn and the servo-rod.

- This picture shows around joint 1.
- Use a part for RC car to connect the leg and the servo-rod



• Joint 2

• This picture shows how servo 2 is mounted. The servo and the part 3 is connected with 2 2mm-diameter bolts



This picture shows the opposite side of servo 2.

- This picture shows the opposite side of servo 2.
- The joint is disconnected

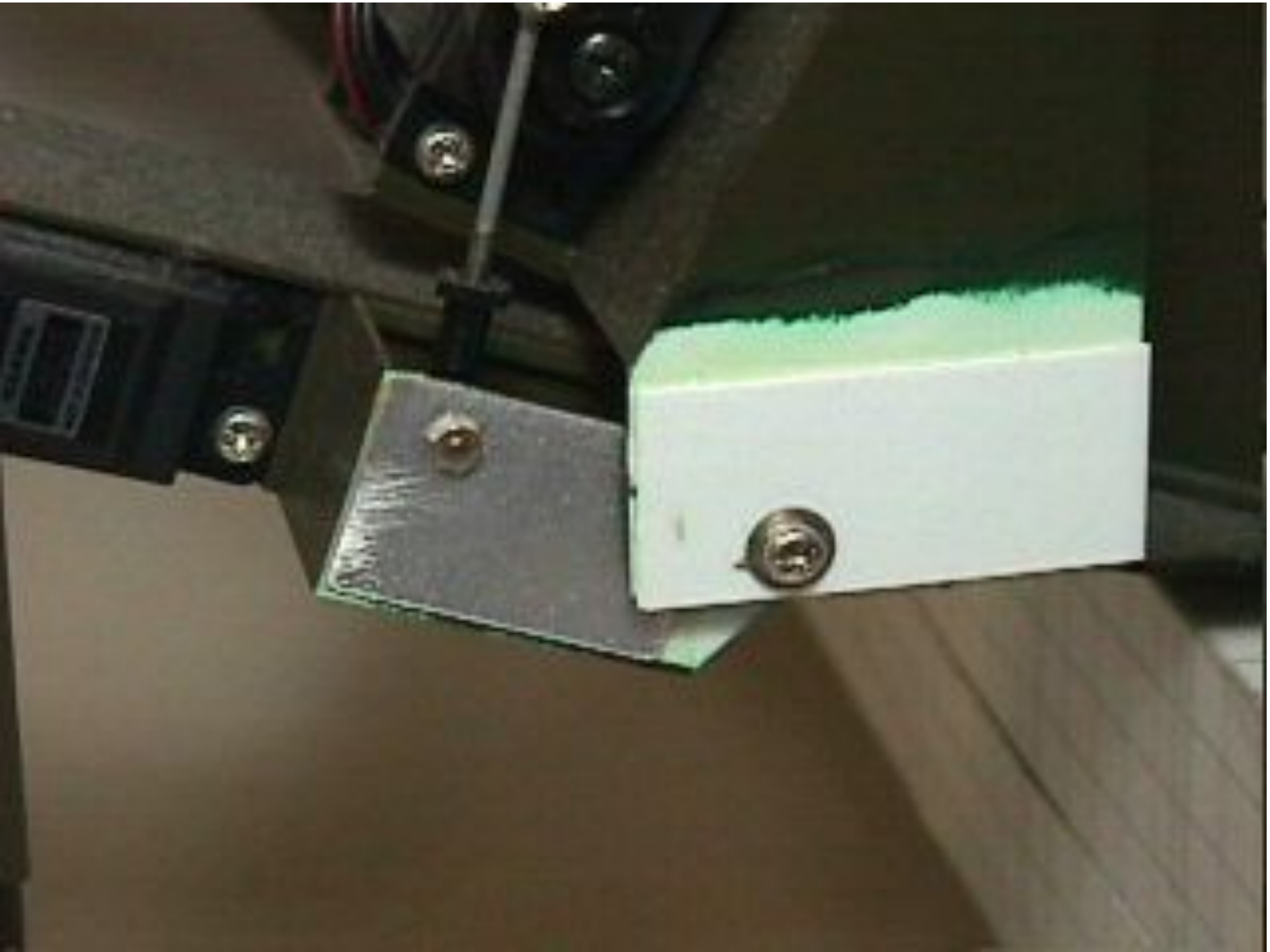
- This picture shows underside of the leg-unit with no servomotors.

Reinforce of the joints

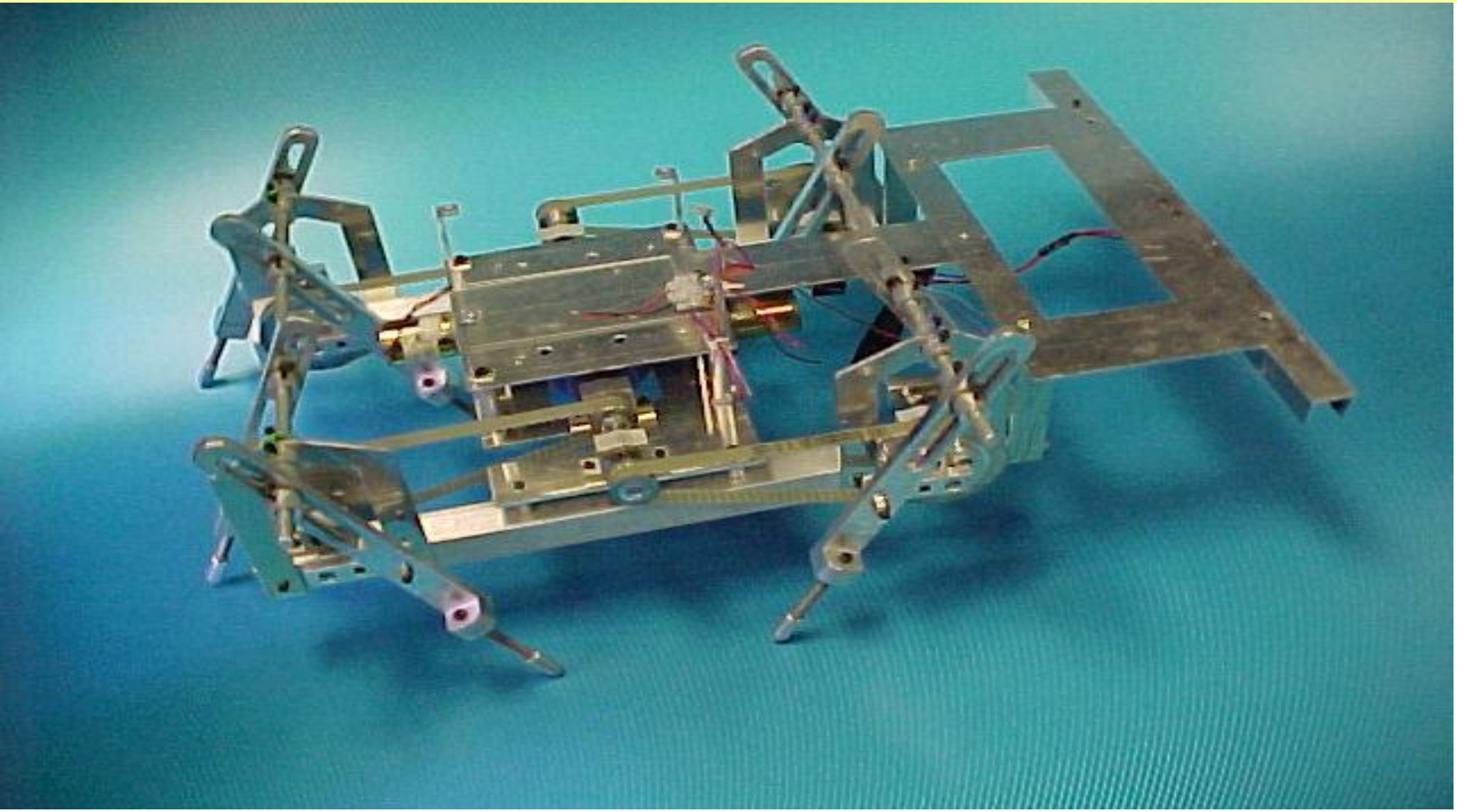
- These pictures show how leg-unit is reinforced.
- The servo-controller for the robot created the signal to move servomotors out of the moving range, when the batteries exhausted. This can break the leg unit.

- Upper part of the joint 0 is reinforced with aluminum plate of 0.5mm-thickness.

- The joint 1 is reinforced with plastic plate of 1.0mm-thickness.
- The base of the servo-rod is reinforced with aluminum plate of 0.5mm-thickness



Big Foot Quadruped from Singapore



Undressed working prototype

Project Description

Autonomous eight-legged robot specially designed to complete a ten meters track of unknown configuration.

It can sense straight and curved paths and is able to clear obstacles as high as two inches.

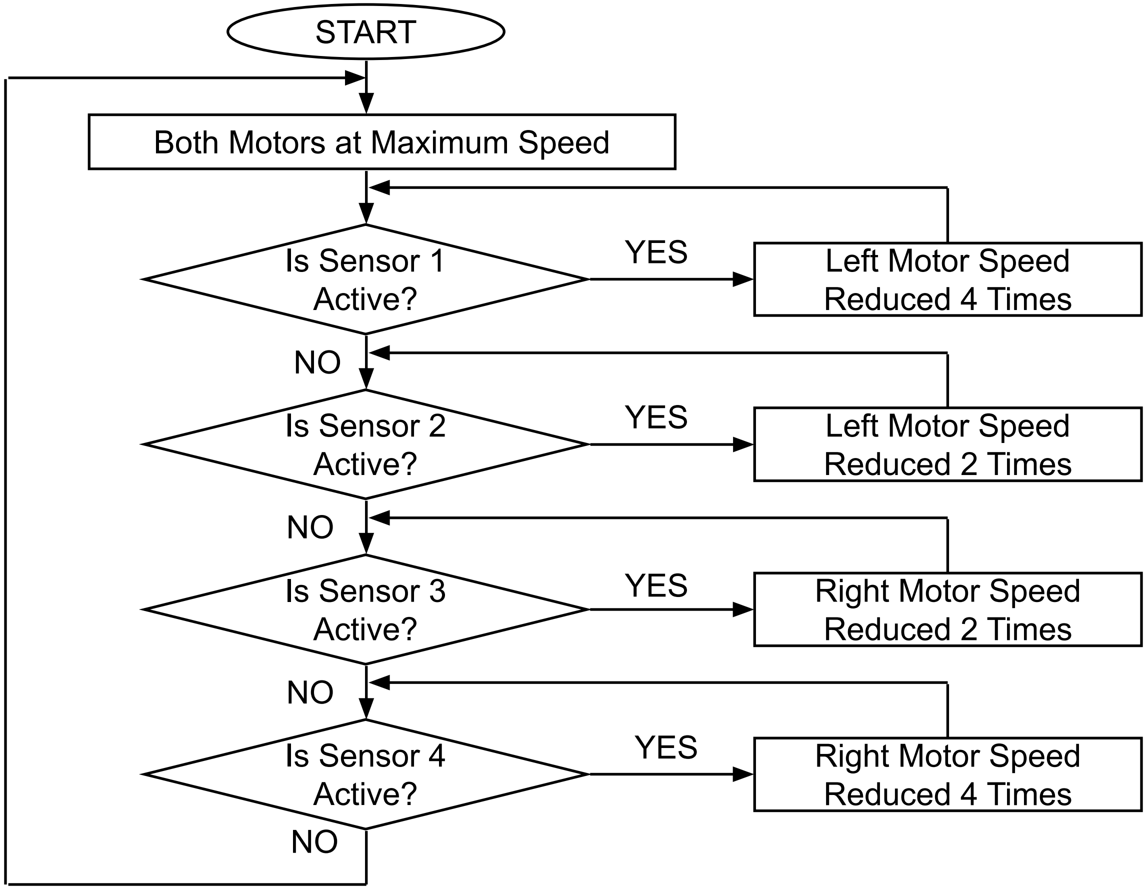
Whenever one of its sensors at the front encounters a reflective surface, a signal is sent to the micro-controller, which in turn instructs the motors to move forward.

Big Foot Quadruped

Key Features

- Is autonomous
- Is compact
- Has special retro-reflective sensors for tracking purposes
- Has micro-controller and driver circuit to control motor

TEMASEK ENGINEERING SCHOOL
21 Tampines Avenue 1 Singapore 529757
Tel: 7882000 Fax: 787764



Technical Specifications

- Rechargeable power source
- 12 volt dc supply
- Infrared remote wireless control
- Range of up to 10 meters
- Weight 8.5 kg

Control of the Singapore quaduped: Sequence of operations

Students: Chung Chin Chuen
Hoo Meng Chan, Jackie
Koh Chor Kiat

Supervisors: Ms. Siu Yee May, May yeemay@tp.edu.sg
Mr. Lee Teck Chin teckchin@tp.edu.sg

Big Foot Quadruped

Adaptation of Mekatronix Hexapod

Design of the Control System

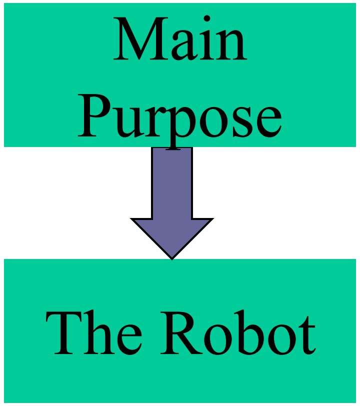
Multi-legged Mobile Robot

Main
Purpose

Design and implement an efficient control system that will allow a six-legged mobile robot demonstrate its mobility, autonomy and versatile characteristics.

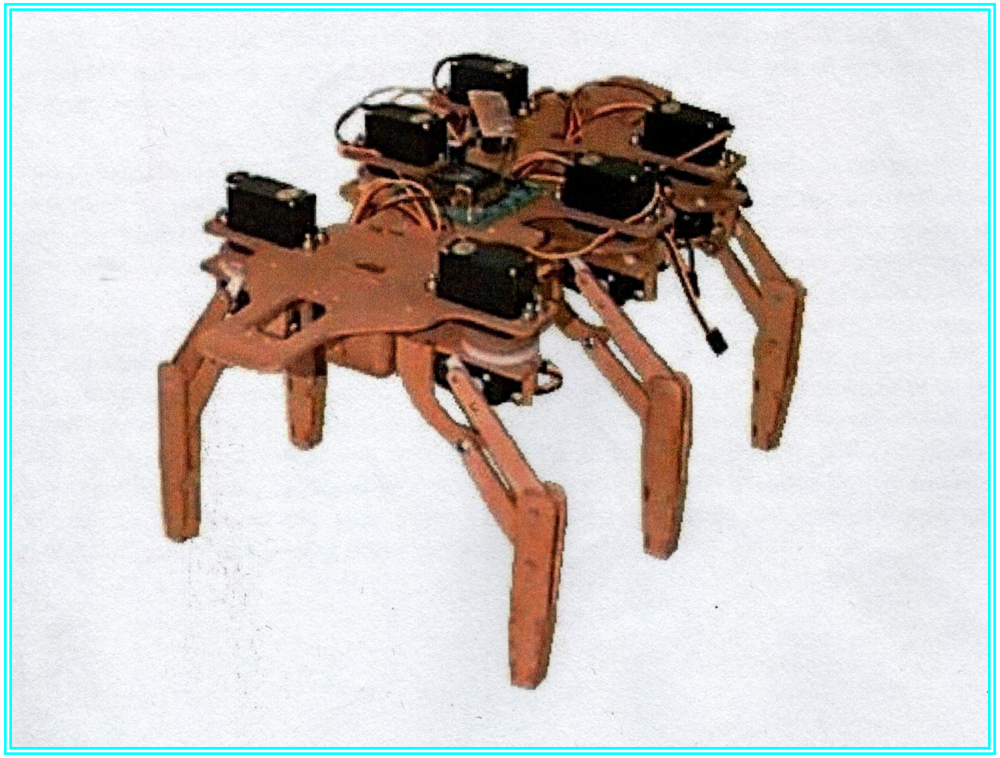
Reasons why this robot is efficient and reliable

- Autonomy
- Individual Sub-Control Systems
- Economical

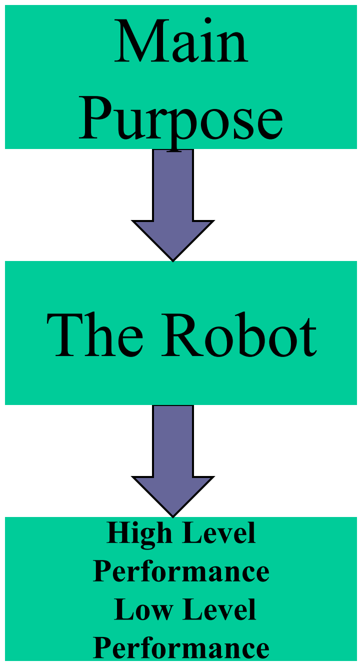

Main Purpose
The Robot

The Hexa-Pod Autonomous RoboBug

The Hexa-Pod Autonomous RoboBug



Picture courtesy of Mekatronix: "Copyright 1999"


Main Purpose
The Robot
High Level Performance
Low Level Performance

LOW LEVEL PERFOMANCE

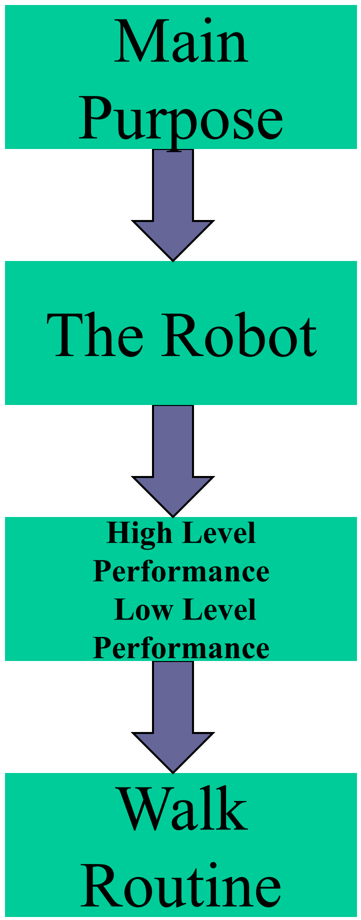
Controlled by Peripheral Interface Controllers

- Synchronized Motion Routine

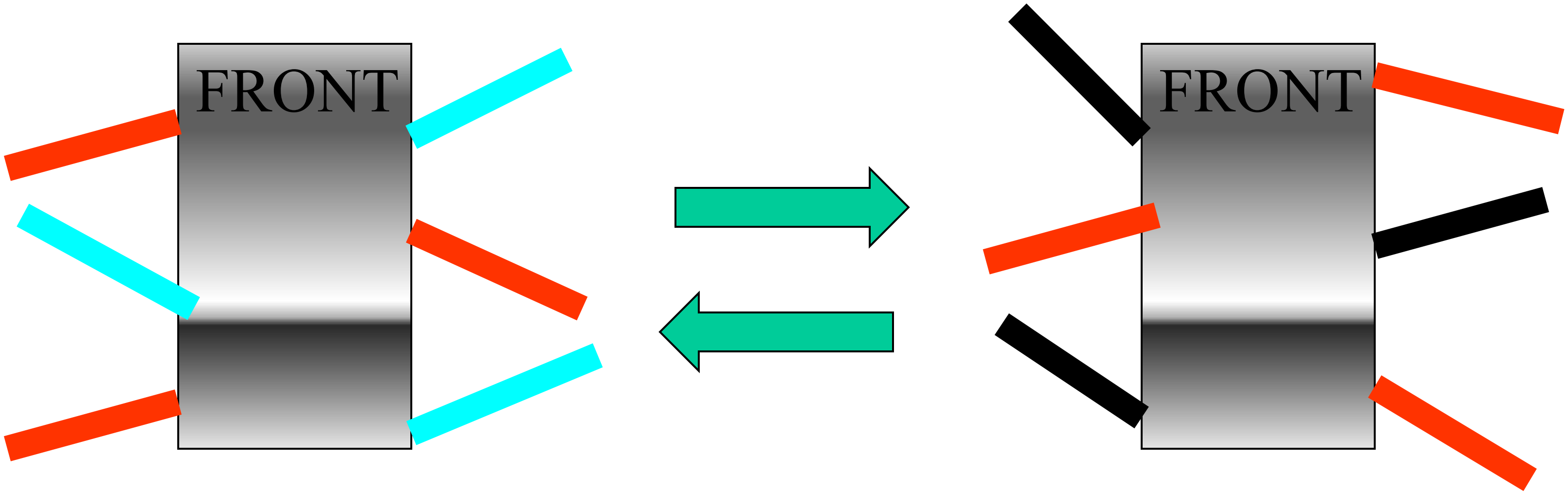
HIGH LEVEL PERFOMANCE

Controlled by Motorola 68HC12

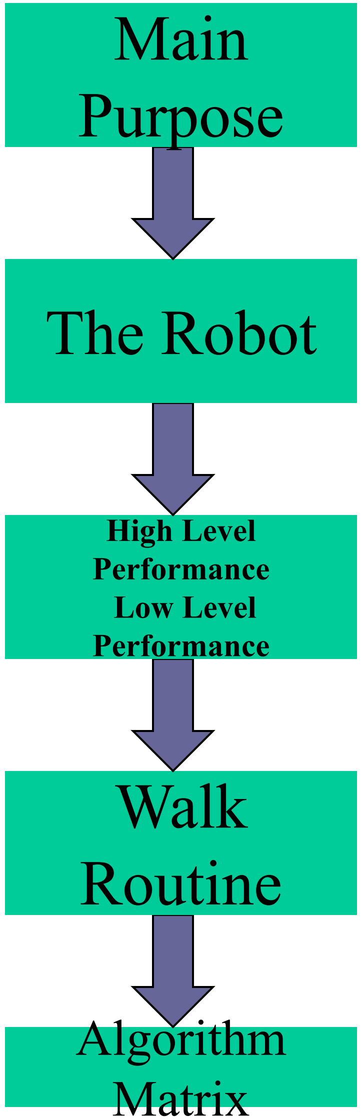
- User Interface
- Orientation System
- Navigation System
- Sensor Systems
- Overall Motion Control


Main Purpose
The Robot
High Level Performance
Low Level Performance
Walk Routine

TRIPOD WALK



- Provides great static & dynamic stability
- Fastest & most efficient walk used by 6-legged animals


Main Purpose
The Robot
High Level Performance
Low Level Performance
Walk Routine
Algorithm Matrix

Walking Algorithm

	Front Legs				Middle Legs				Back Legs			
	Right Leg		Left Leg		Right Leg		Left Leg		Right Leg		Left Leg	
Step	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
1	↓	X	↓	X	↓	X	↓	X	↓	X	↓	X
2	↑	X	X	X	X	X	↑	X	↑	X	X	X
3	X	←	X	→	X	→	X	←	X	←	X	→
4	↓	X	X	X	X	X	↓	X	↓	X	X	X
5	X	X	↑	X	↑	X	X	X	X	X	↑	X
6	X	→	X	←	X	←	X	→	X	→	X	←
7	X	X	↓	X	↓	X	X	X	X	X	↓	X

Legend

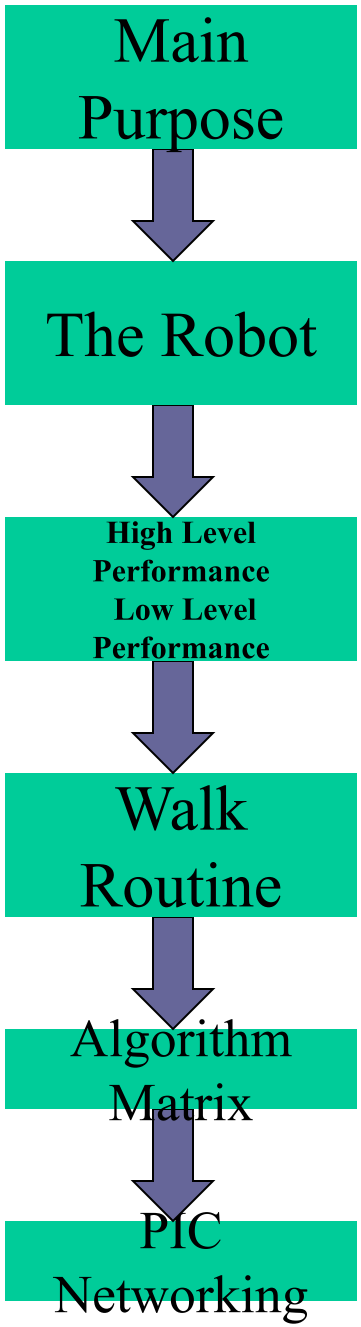
↑ ....Up

↓ ....Down

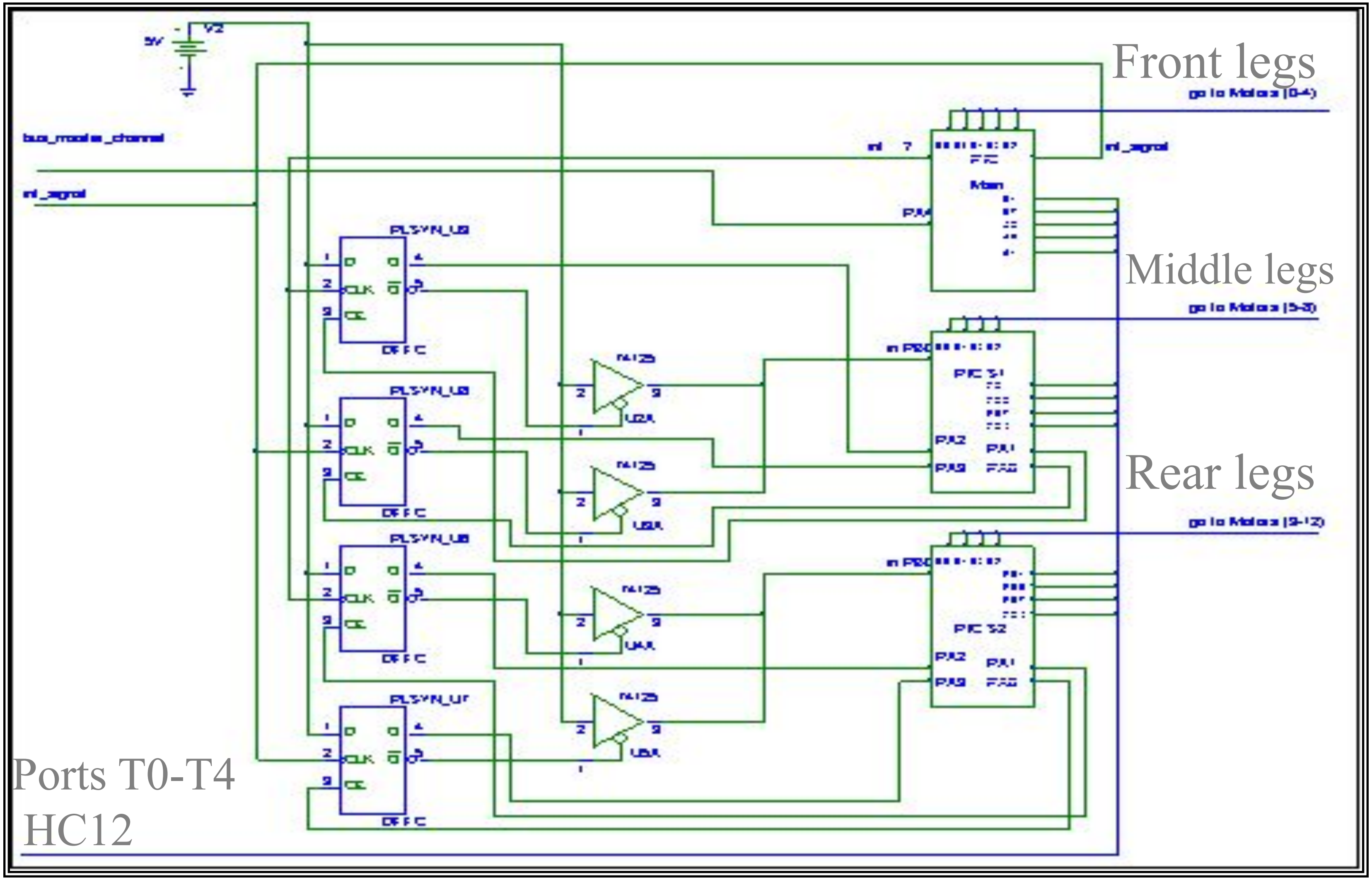
← ...... Forward

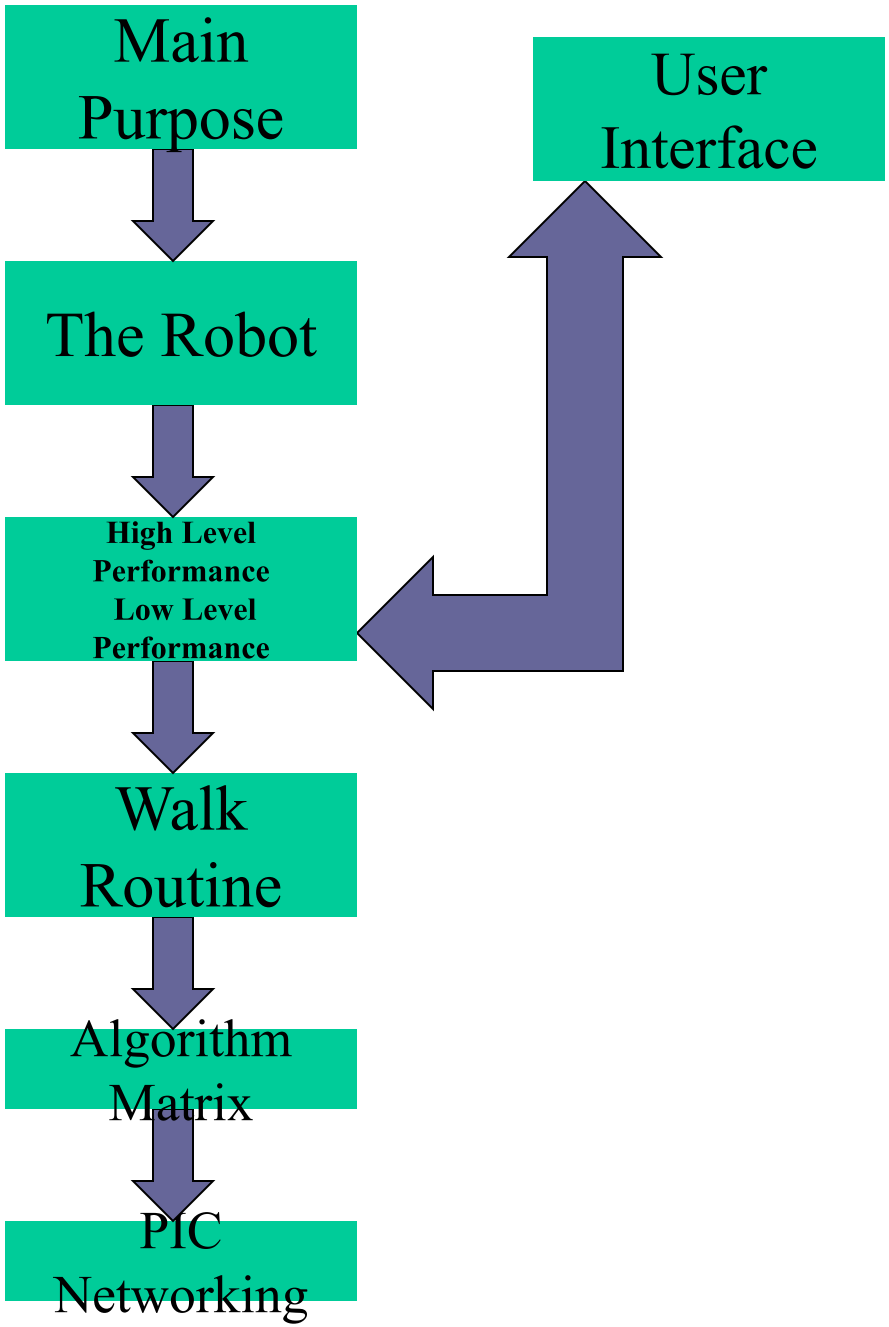
→ ..... Reverse

X ...... Don't Change

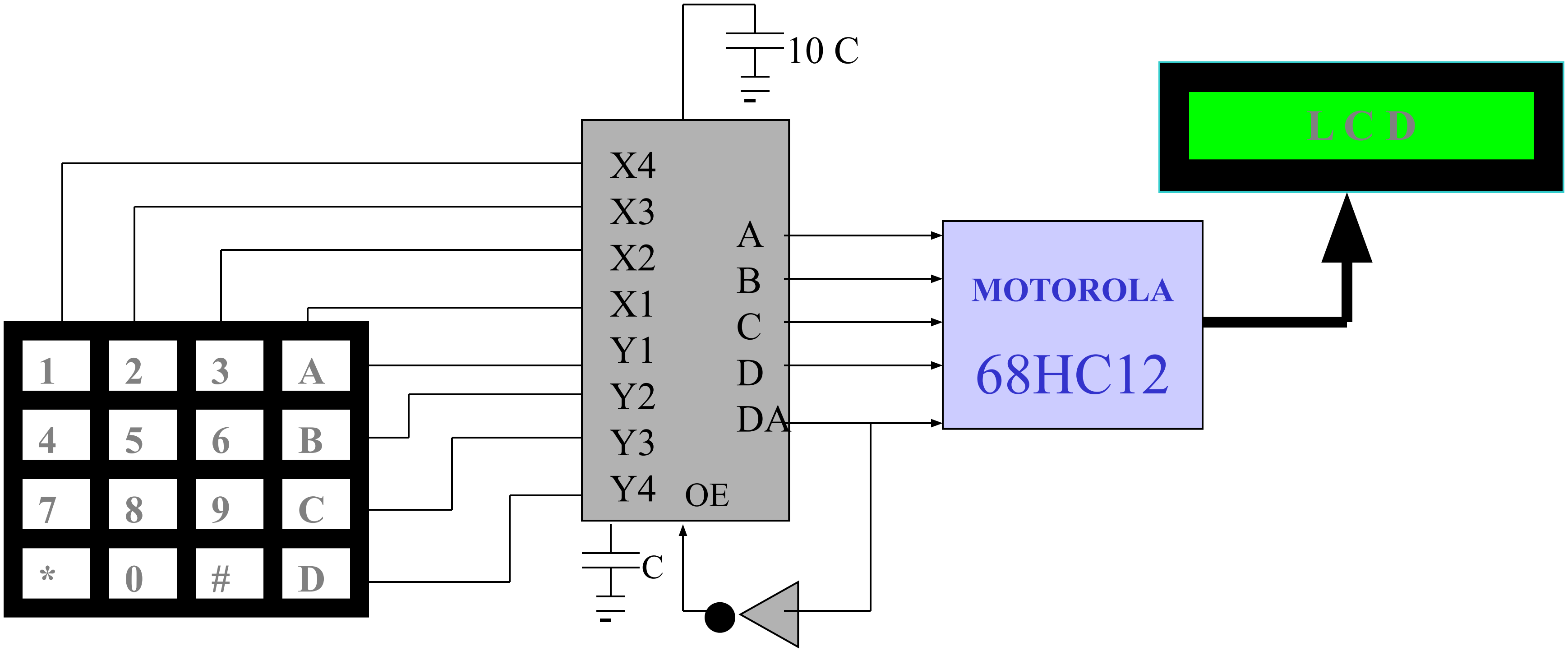

Main Purpose
The Robot
High Level Performance
Low Level Performance
Walk Routine
Algorithm Matrix
PIC Networking

PIC's Networking Module

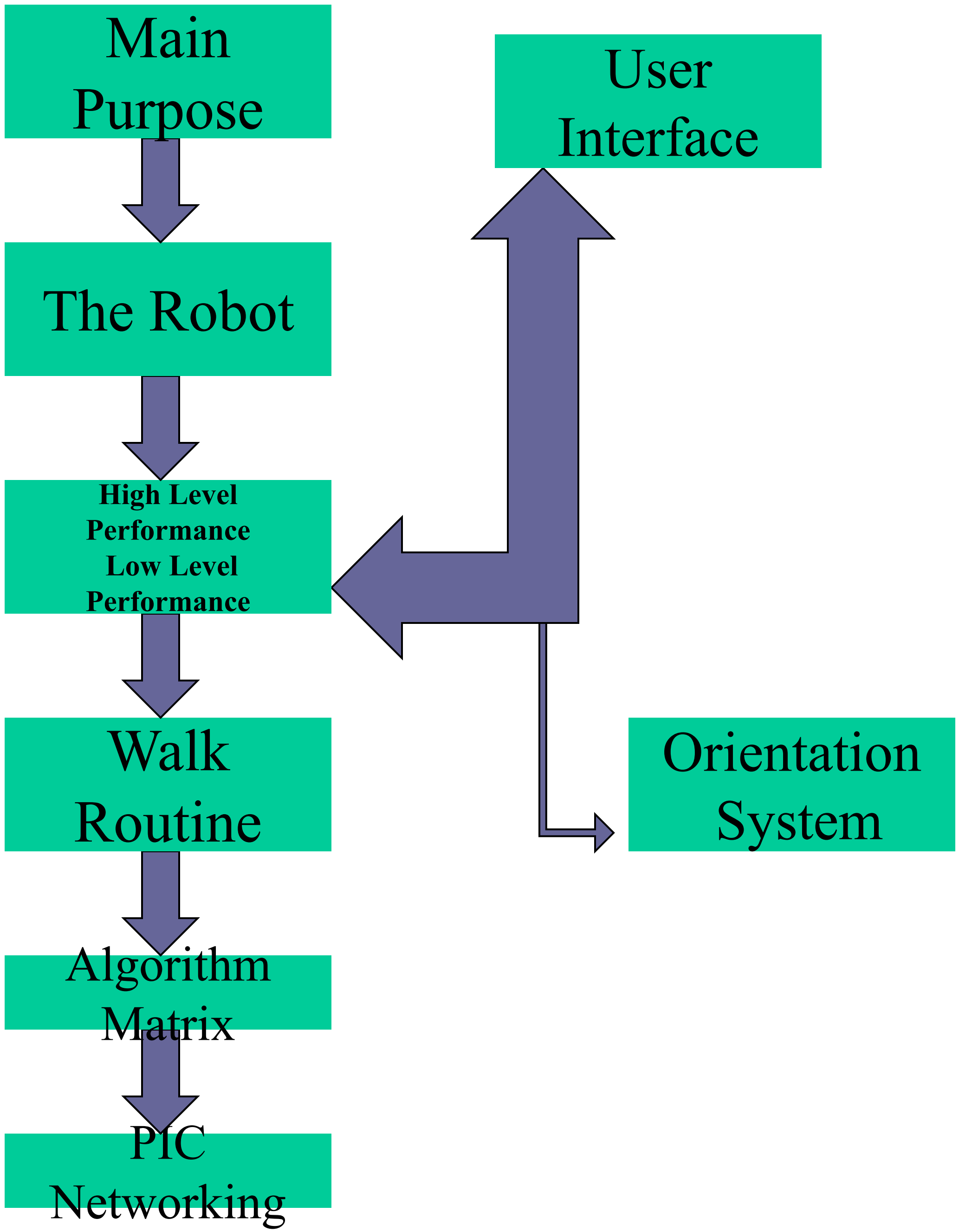



Main Purpose
User Interface
The Robot
High Level Performance
Low Level Performance
Walk Routine
Algorithm Matrix
PIC Networking

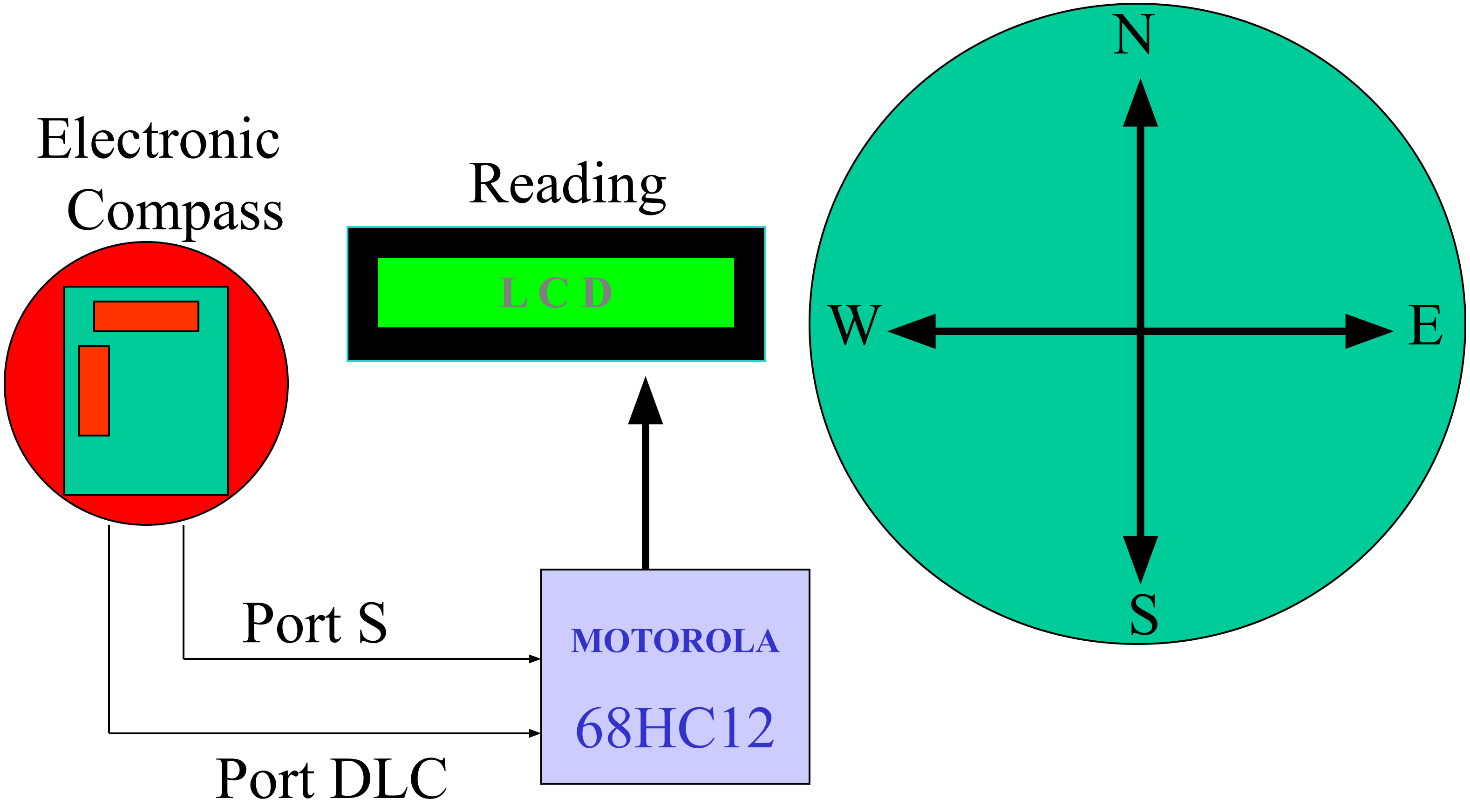
User Interface LCD & KeyPad

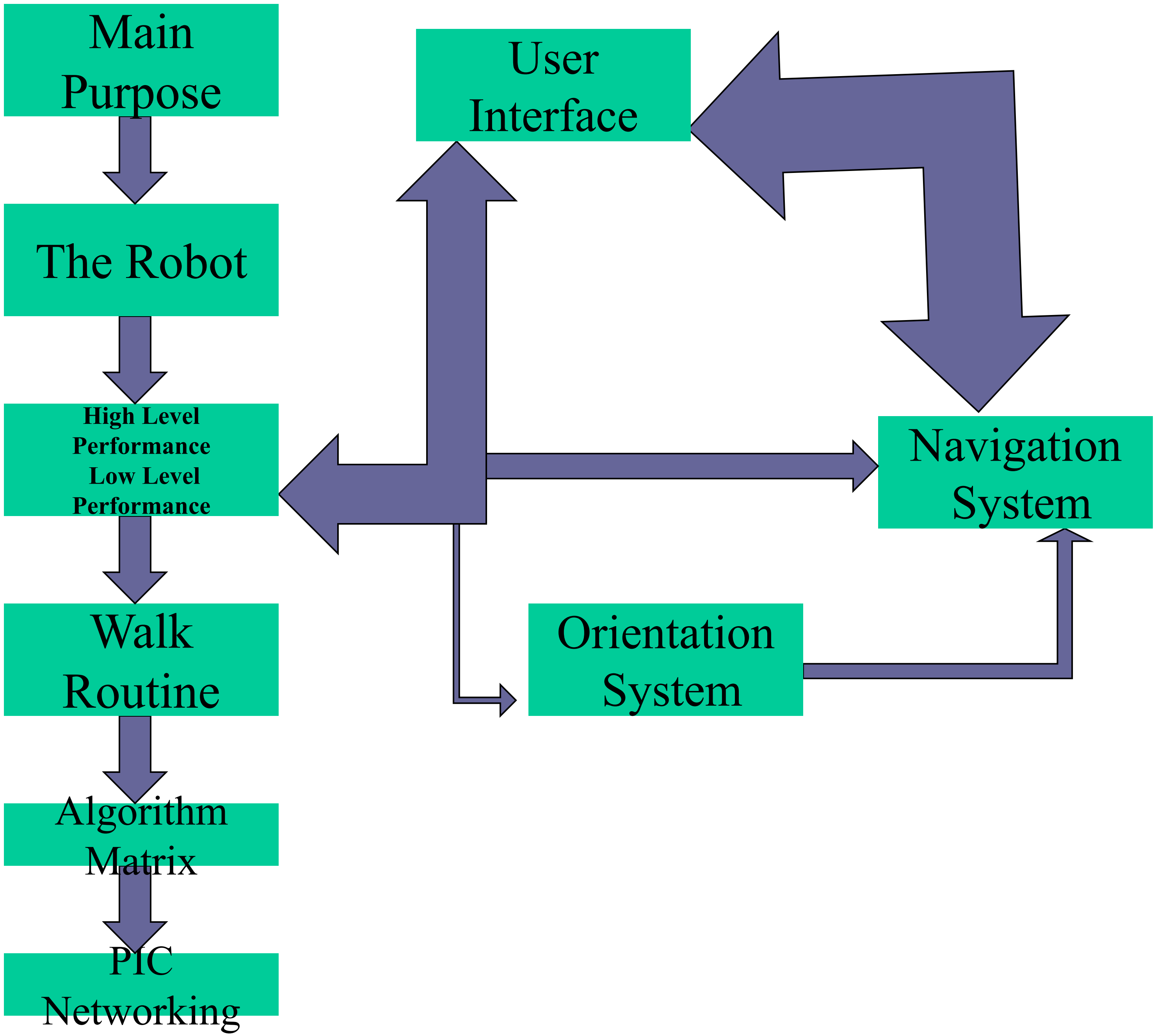


- Provides global coordinate system
- Provides software relieve
- Low hardware in HC12

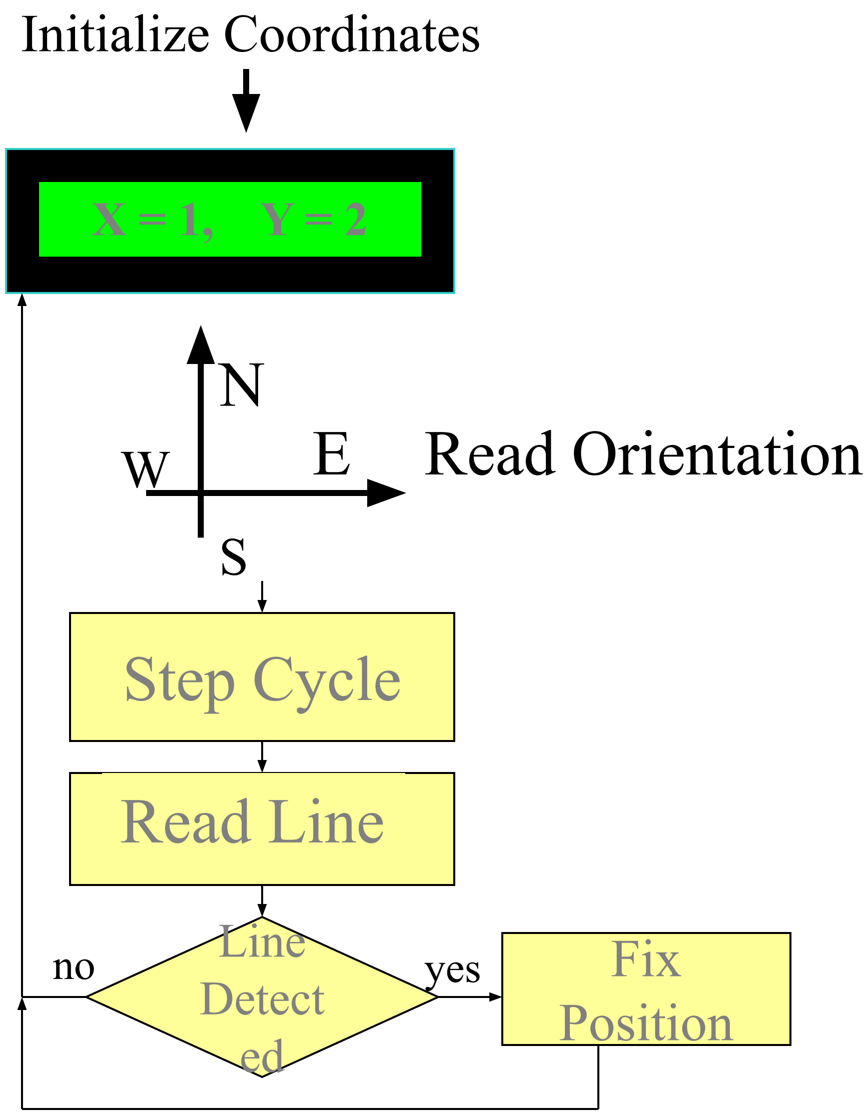

Main Purpose
User Interface
The Robot
High Level Performance
Low Level Performance
Walk Routine
Orientation System
Algorithm Matrix
PIC Networking

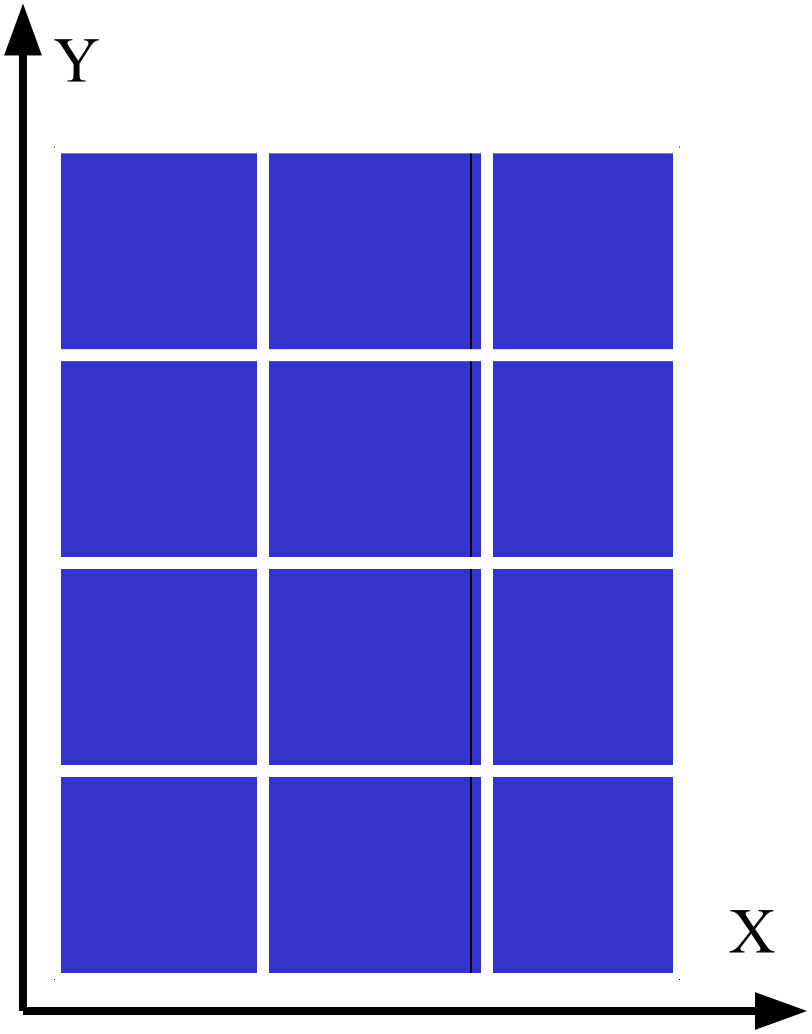
Orientation System

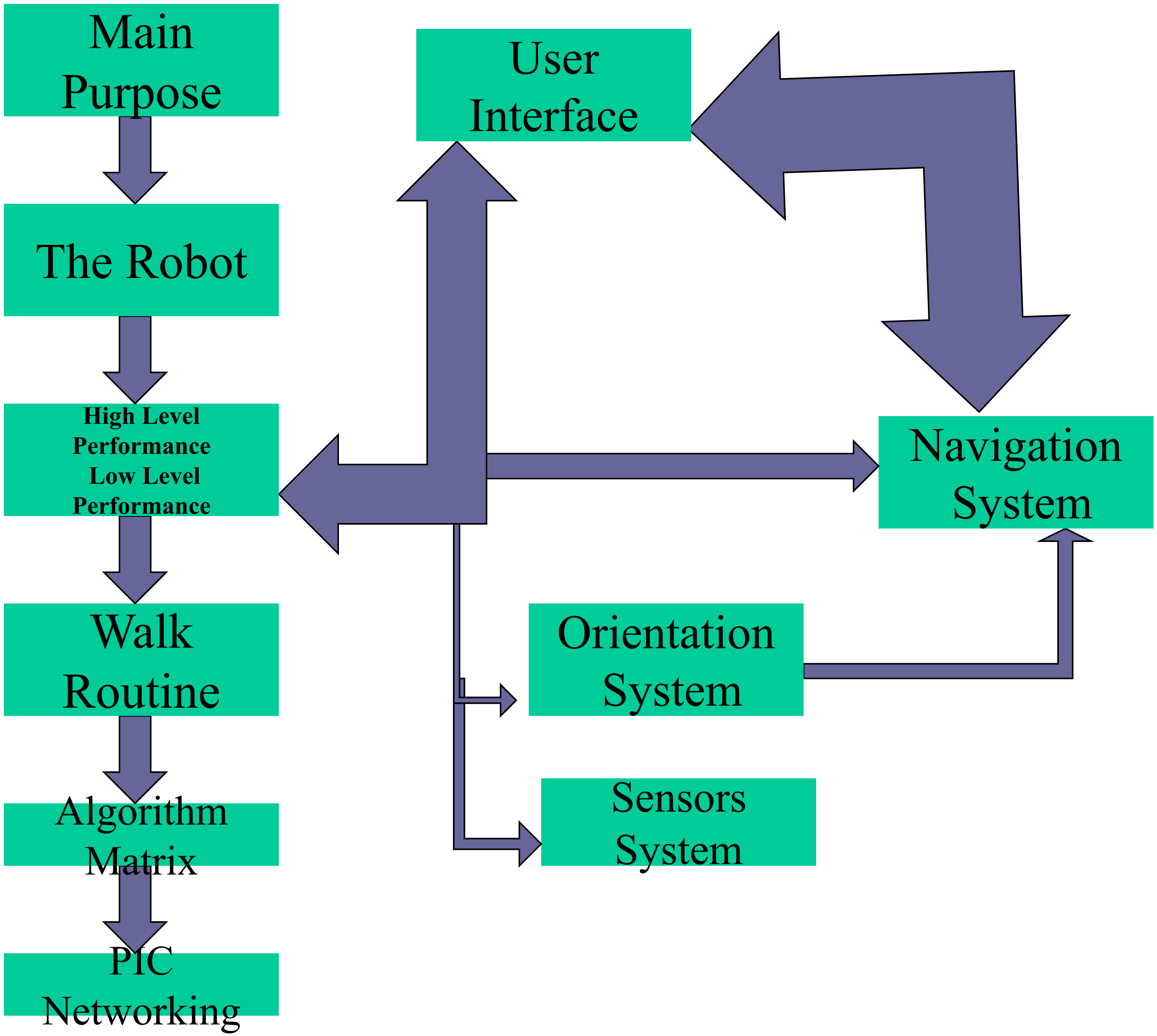



Main Purpose
The Robot
High Level Performance
Low Level Performance
Walk Routine
Algorithm Matrix
PIC Networking
User Interface
Navigation System
Orientation System

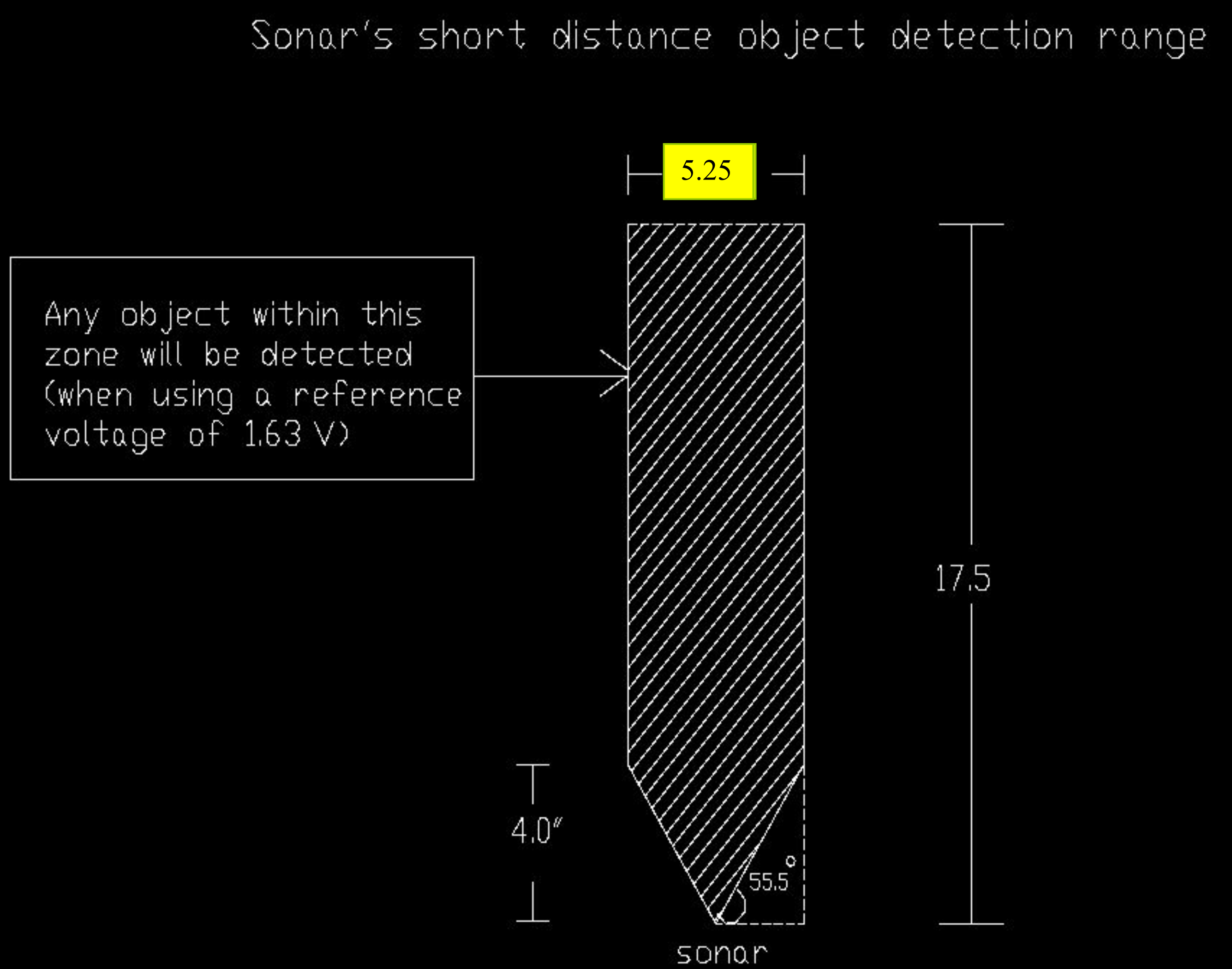
Navigation System



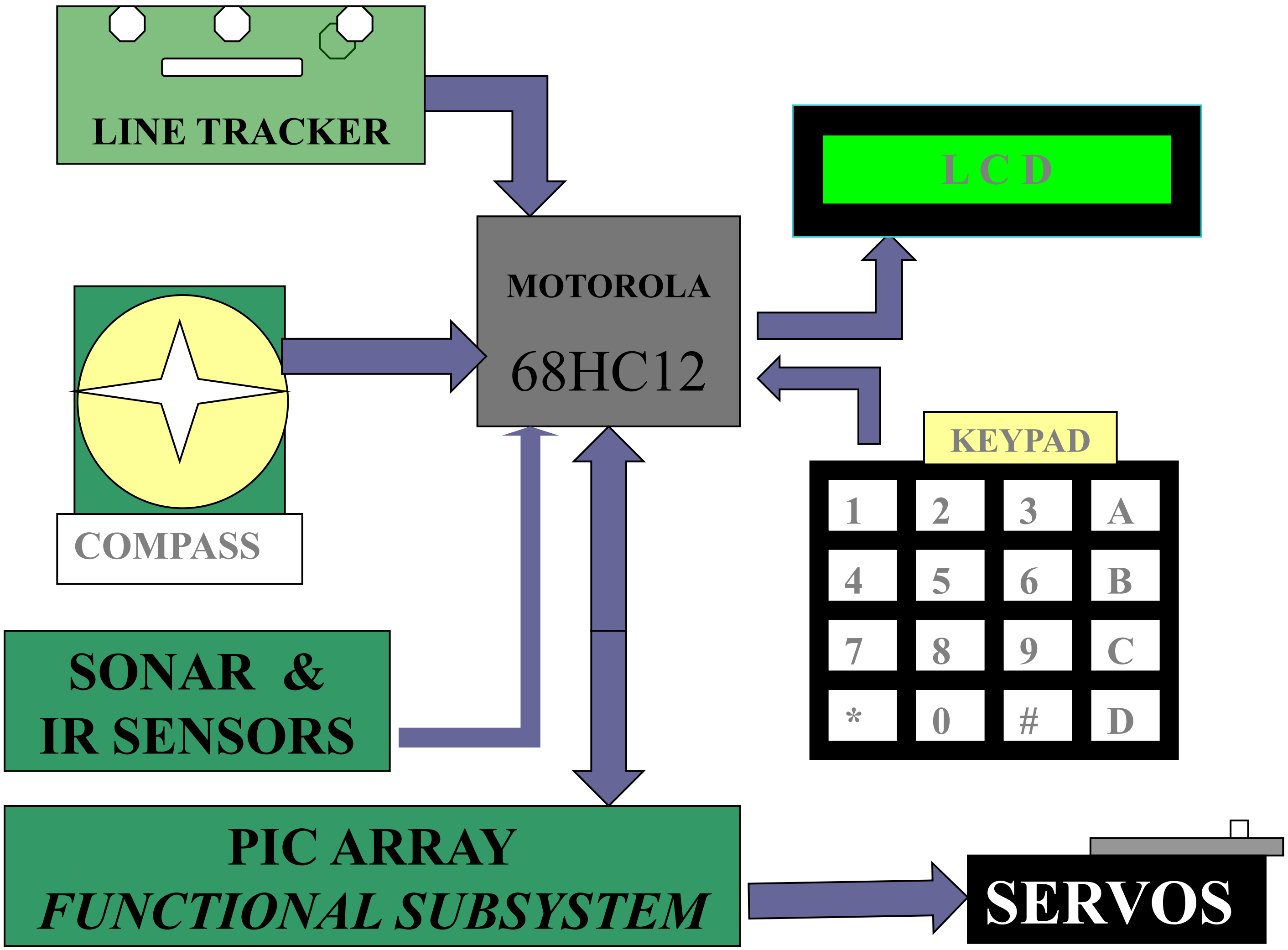



Main Purpose
The Robot
High Level Performance
Low Level Performance
Walk Routine
Algorithm Matrix
PIC Networking
User Interface
Navigation System
Orientation System
Sensors System

Sensors System



Overall System Diagram



WMC Competition Overview

SAE Walking Machine Challenge:

Colorado State University, WMC 2002

Polyphemus - Competition

- Complete all events:

  Dash, Load Retrieval, Slalom, Trip Wire, Object Retrieval, Obstacle Course, Object Seeking and Hill Climb

- Compete at Autonomous Level 2 in a maximum number of events

8-Legged Polyphemus

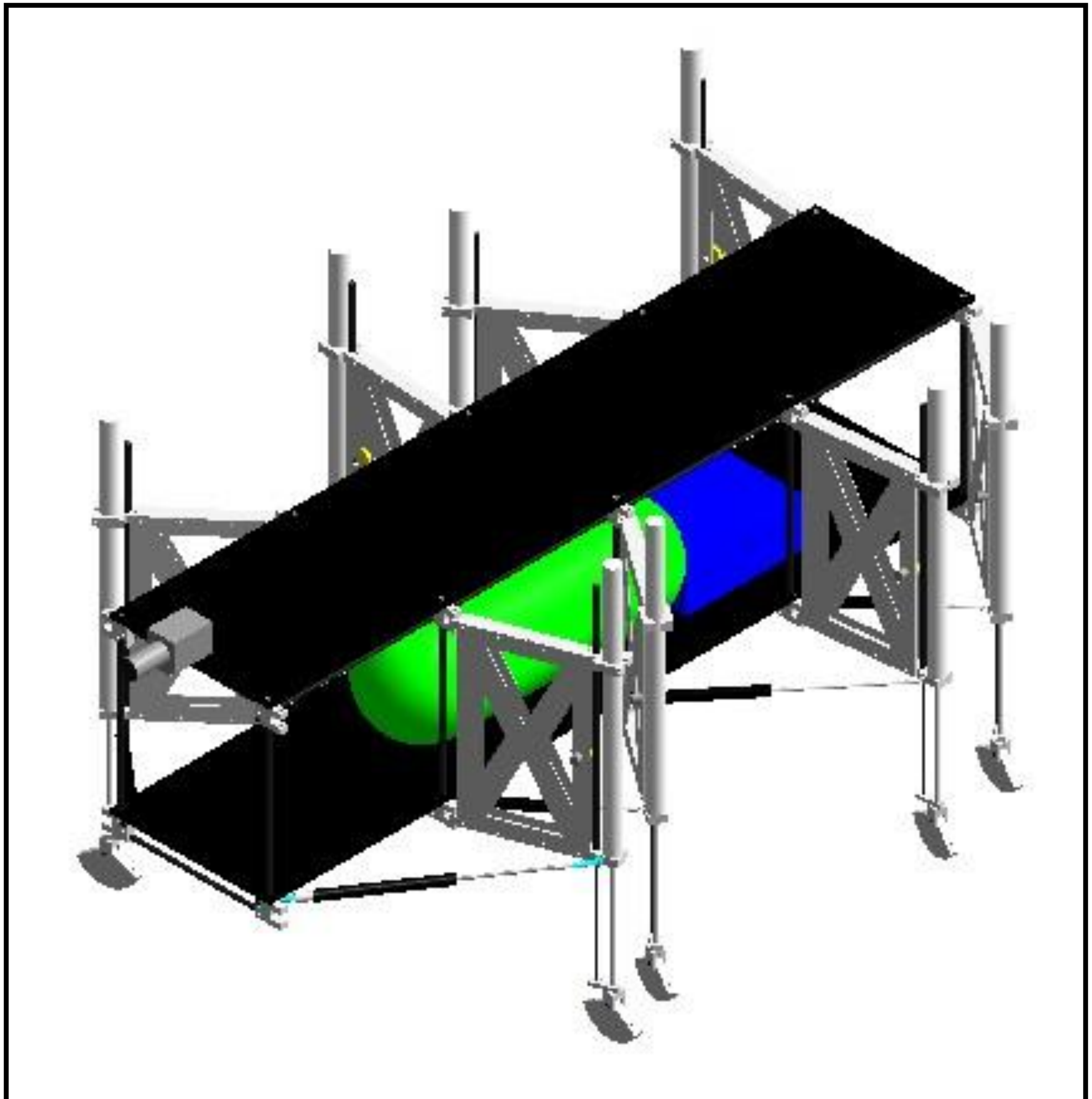
Articulated "Legs"

On-board Power

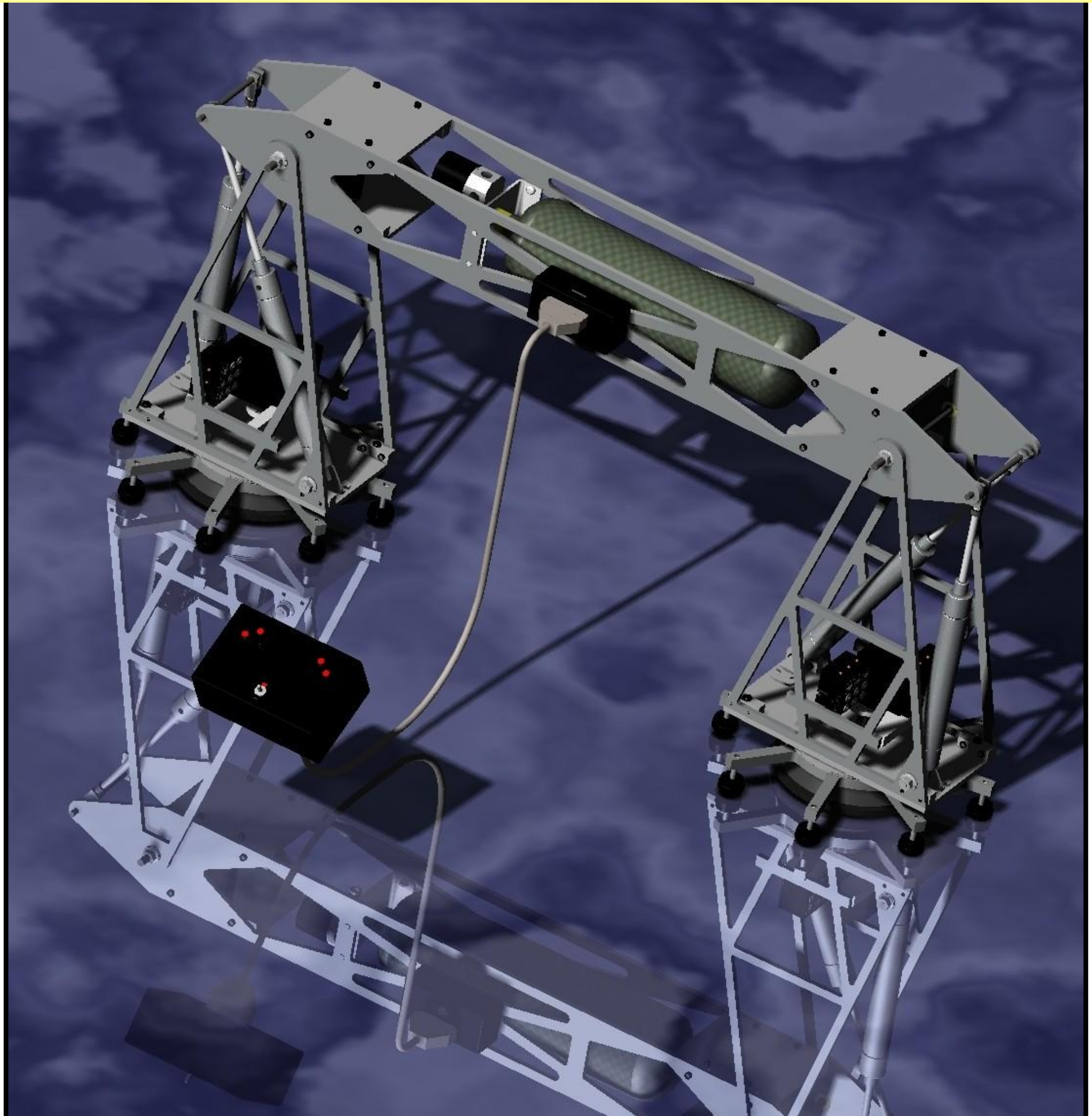
Self-Contained (tethered)

Analogy in Nature

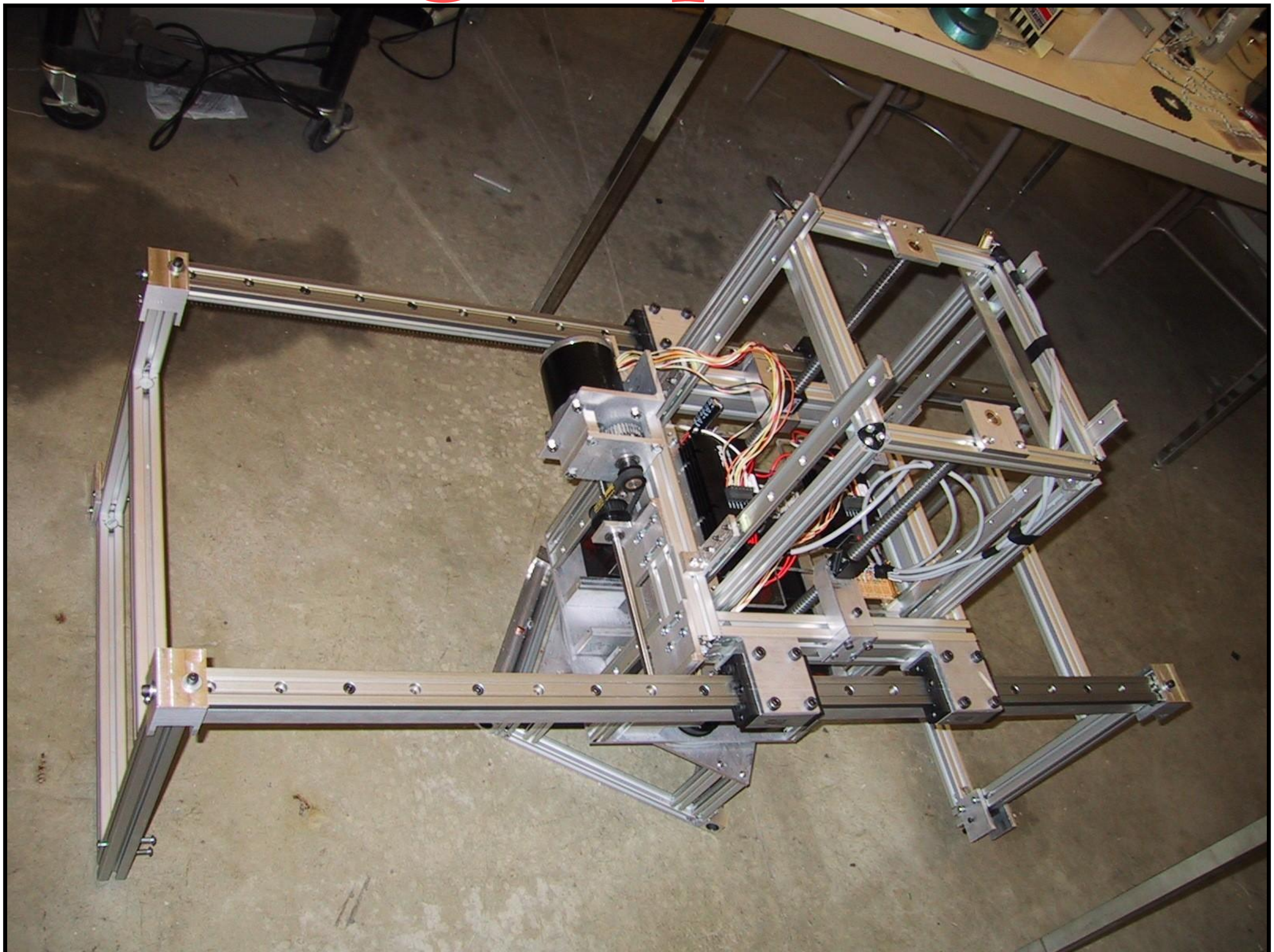
Design Options:



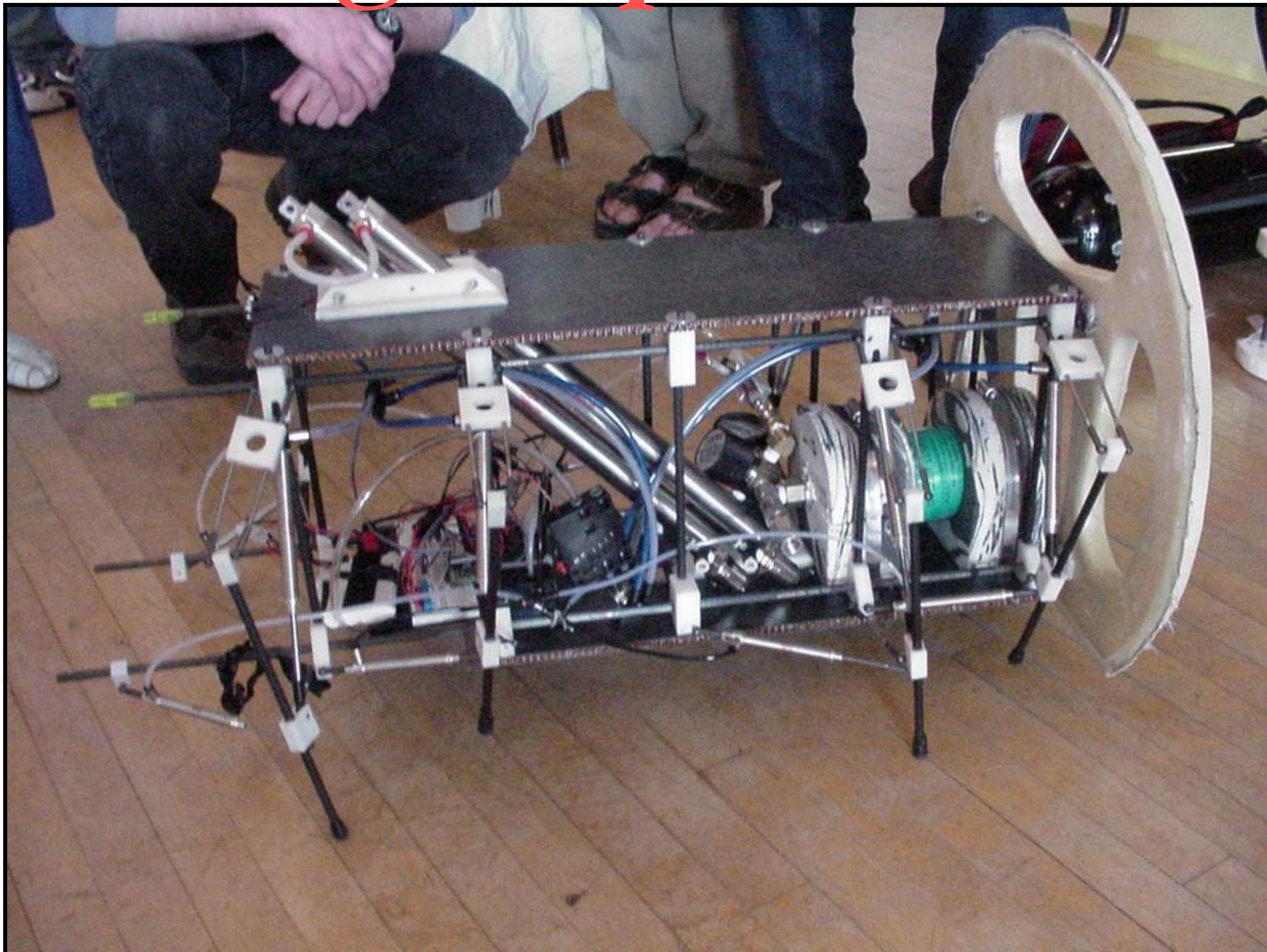
Design Options:



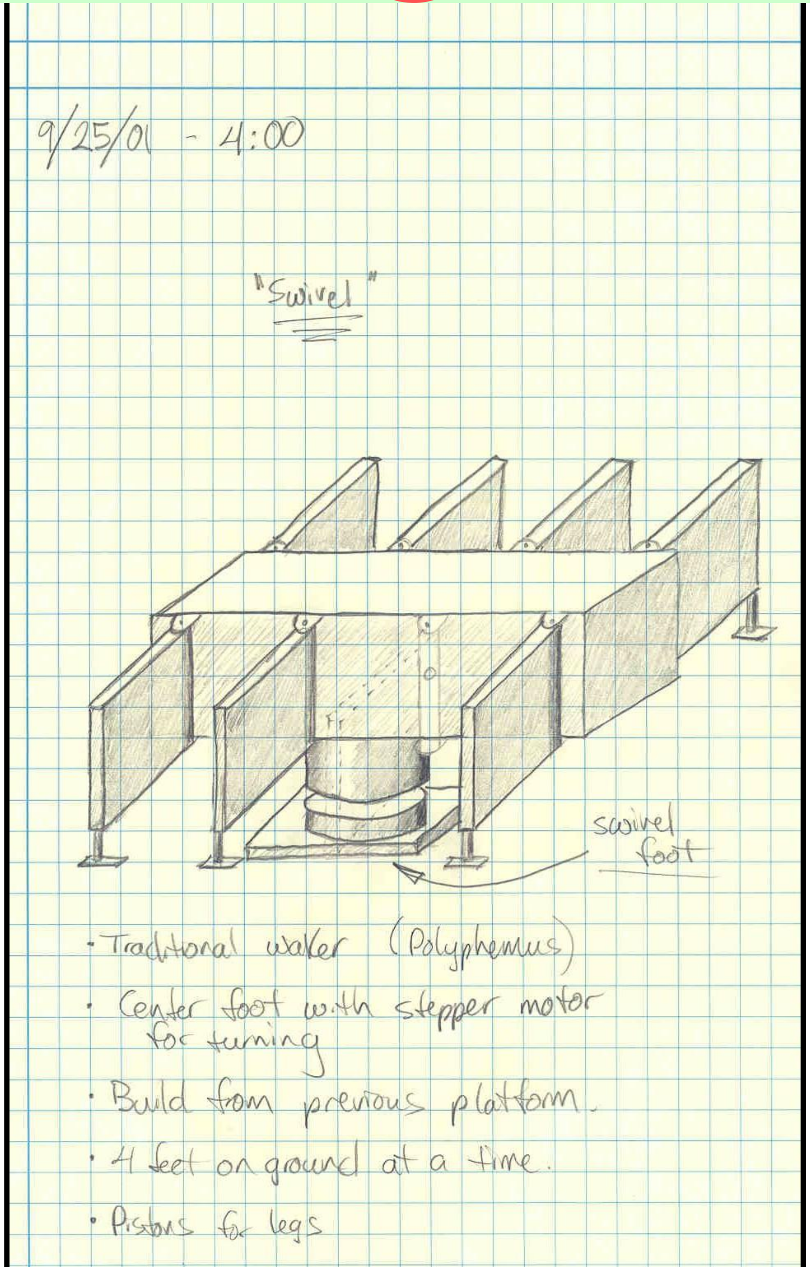
Design Options:



Design Options:



Design Selection Overview:



- Eight Pneumatic Legs
- Central-pivot Turning Control
- Automated Leveling

Polyphemus – Conceptual Design

- Mechanical
  - Vision system constraints
  - Task defined functionality
- Controls
  - Decision/execution architecture
  - HL – navigation
  - LL – motion

Mechanical Design Elements

- Vision system constraints
  - Stability
  - Consistent height and angle
- Task defined functionality
  - Negotiating obstacles
  - Repeatable steps

Mechanical Design Solution

- Pneumatics
  - Low cost and environmentally inert
  - Difficult to control closed-loop
- Locomotion
  - 8 Legs – fully independent
  - Vertical foot cylinders
    - Momentary contact switches
    - Rotary Potentiometers
    - 2-axis digital level chips

Controls Design Elements

- Parallel development
- Architecture
  - High Level
    - Image acquisition
    - Navigation decisions
  - Low Level
    - Mechanical status and control
    - Maneuver execution

Controls Design Solution

- HL – Matrox 4sight
  - Embedded NT: Object oriented c++
  - Imaging: Blob Analysis
  - Navigation: SW Compass
- LL – Stamp IIsx
  - Feedback inputs: MUX
  - Code segmentation
- Instructions from HL to LL via RS232

Polyphemus - Evaluation

- Retained design concepts
  - Variable foot extension
  - Basic control architecture
  - Optical position feedback
- Design evolution
  - Reengineered structure
  - New LLC hardware
  - Added imaging and navigational functionalities

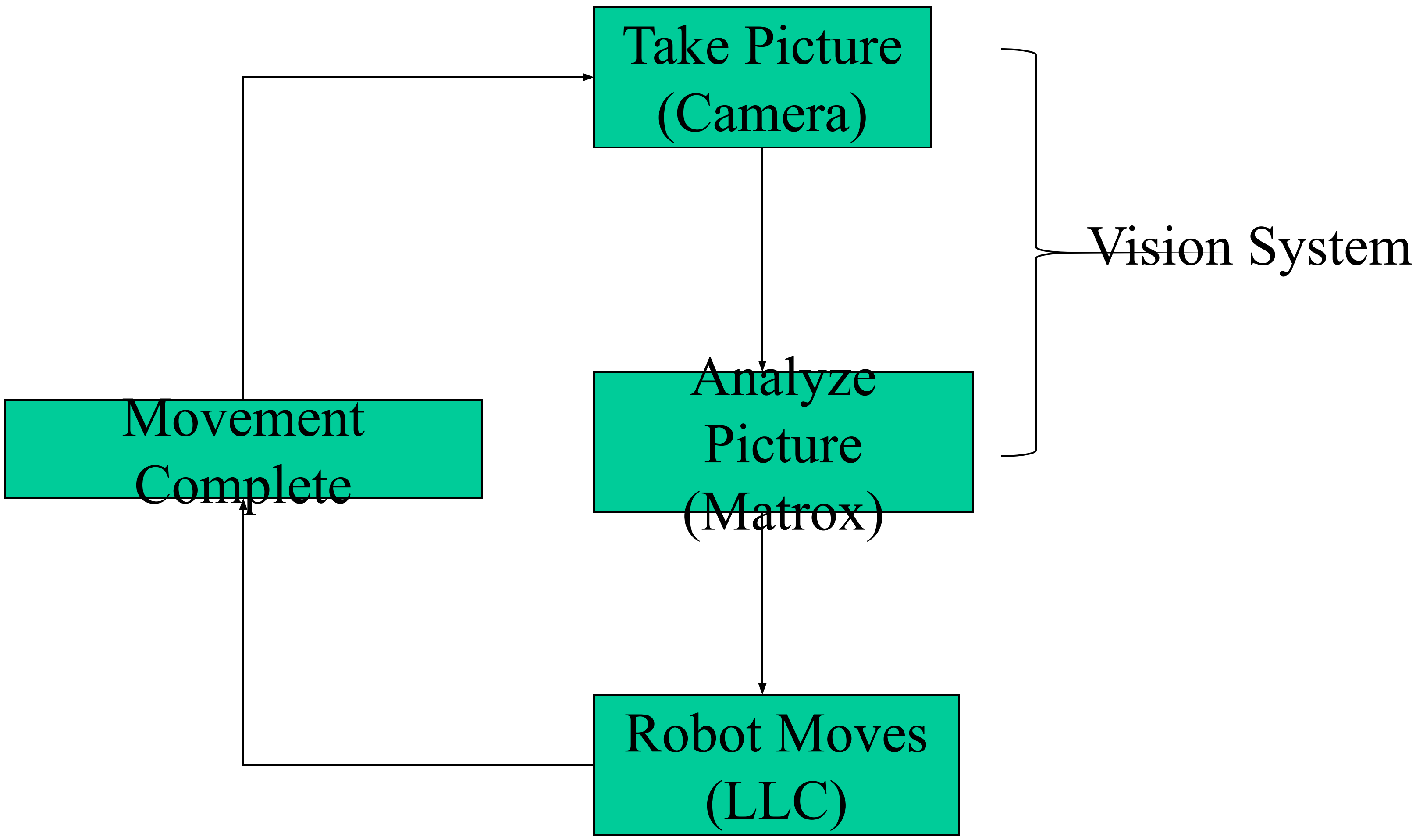
Vision System

- PULNiX black-and-white camera (TM-7CN)
  - Able to adjust focus and brightness levels
- Matrox 4Sight hardware
  - Embedded Windows NT
  - Mouse/keyboard/monitor ports
  - Parallel/Serial ports
  - Ethernet network interface
- Matrox software
  - Matrox Imaging Library (MIL)

Costs of the Components

- PULNiX camera (TM-7CN) - $793
- Matrox 4Sight hardware - $2,470
- Matrox software - $3,995

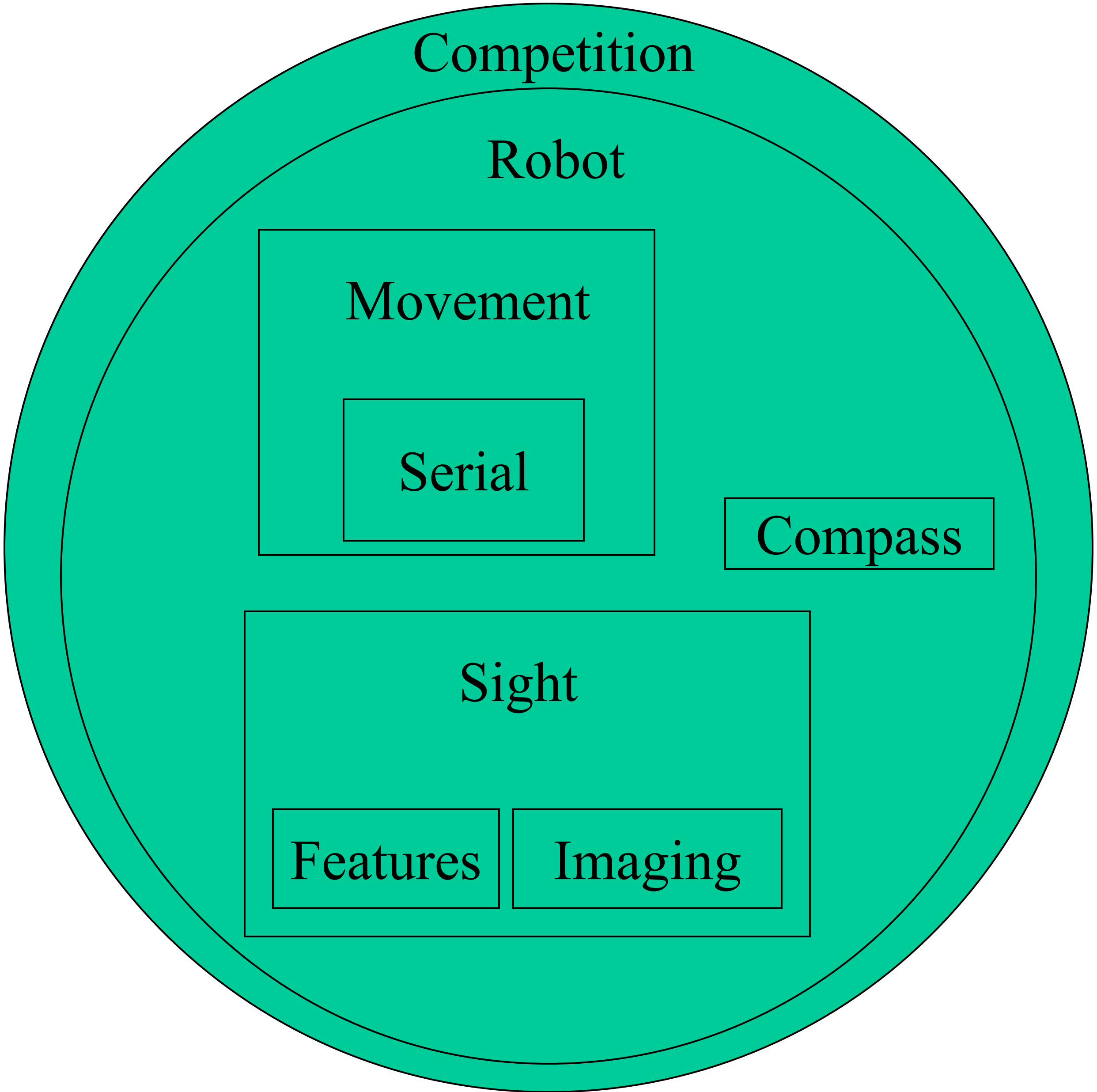
How the Vision System Works



Existing Code

- C++
  - Microsoft Visual C++
- Coding done in classes
  - More than one person can work on code at a time

Class Relation



Matrox Imaging Library (MIL)

- Foundation of the vision system
- “Blob Analysis”
  - Allows the robot to see numbers or objects as “blobs”
  - Blob features:
    - Area
    - Density
    - Location on screen

MIL Example: Continuous Image

```
#include <stdio.h>
#include<mil.h>

void main(void)
{
 MIL_ID MilApplication, MilSystem, MilDisplay, MilCamera, MilImage;

MappAllocDefault(M_SETUP, &MilApplication, &MilSystem, &MilDisplay, &MilCamera, &MilImage);

MdigGrabContinuous(MilCamera, MilImage);

printf("Continuous grab in progress.  Adjust your camera and press <Enter> to stop grabbing.");
getchar();

MdigHalt(MilCamera);
printf("\nDisplaying the last grabbed image. Press <Enter> to end.\n");
getchar(

MappFreeDefault(MilApplication, MilSystem, MilDisplay, MilCamera, MilImage);
}
```

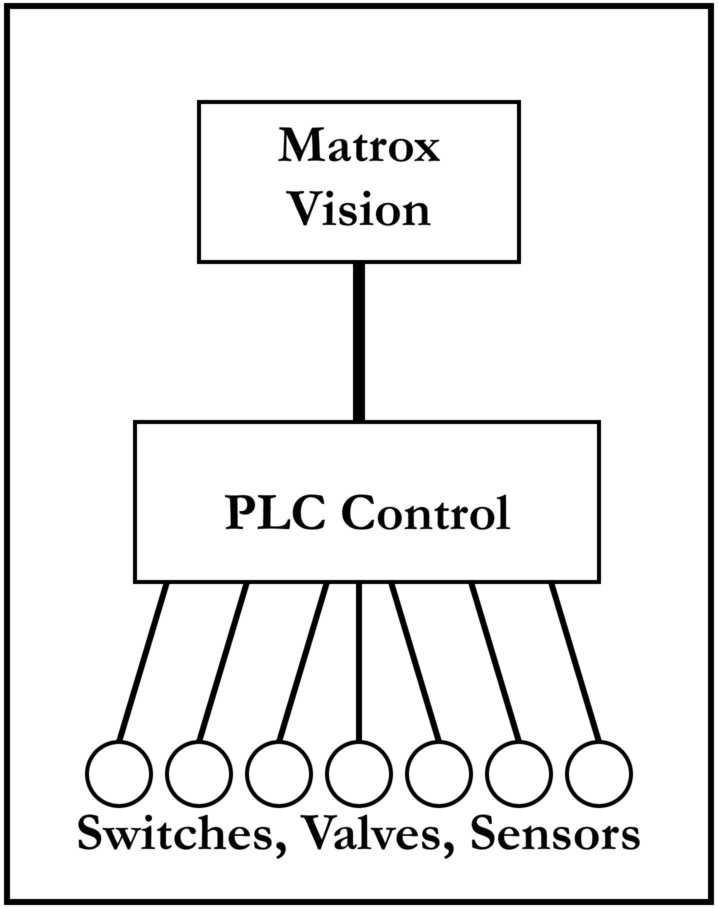
Optical Character Recognition (OCR)

- Very powerful library
- Would allow robot to recognize numbers on the course
  - Tries to match an image to a known character/pattern
- Would be able to start anywhere on the course and know where to go
- Remains a team goal for next semester

Low-Level Controls

- The low-level controller controls the walking algorithm for the robot
- Items being controlled:
  - Pneumatic valves
  - Turning Swivel Motor
- Feedback to the Controller:
  - Leg Position
  - Leveling Information
  - Touch Sensing

What Are We Controlling?



Low-Level Control Options

- Last year's low-level controller: **Parallax Stamp IIsx**
  - Limited I/O capabilities
  - Code was not documented at all!
- Decision made to find a better low-level controls solution for this year's robot
- Two options were presented: **PICs** or **PLC**

PIC *(Programmable Integrated Circuit)*

- Built in A/D channels plus discrete I/O channels
- Programmed in BASIC
- **Idea:**
   - cascade several PICs, each controlling a different task (one PIC for each pair of legs for example)
   - One "master" PIC to read feedback and send commands to the lower level PICs
- **Drawbacks:**
   - Not self-contained
   - Would have required external circuitry such as relays, resistors, and capacitors

PLC *(Programmable Logic Controller)*

- Industrial controller used for applications such as motion control, process control, and automation in general
- They are robust systems and can be customized in terms of I/O, power supply, and programming
- It is a completely self-contained unit (No external circuitry needed besides power)

Walking Machine I/O Requirements

- **Outputs:**
  - Maximum of 28 discrete DC outputs (valves, swivel foot, and retrieval device included)
- **Inputs:**
  - 8 analog inputs for vertical positioning of legs
  - 4 analog inputs for horizontal positioning of legs
  - 8 discrete DC inputs for touch sensors on each foot
  - Serial in from Tilt Sensor
  - Serial in from Vision System for walking commands

GE Fanuc Series 90-30 PLC

Main Rack Slot 0: 24 VDC power supply

Main Rack Slot 1: Series 90-30 CPU

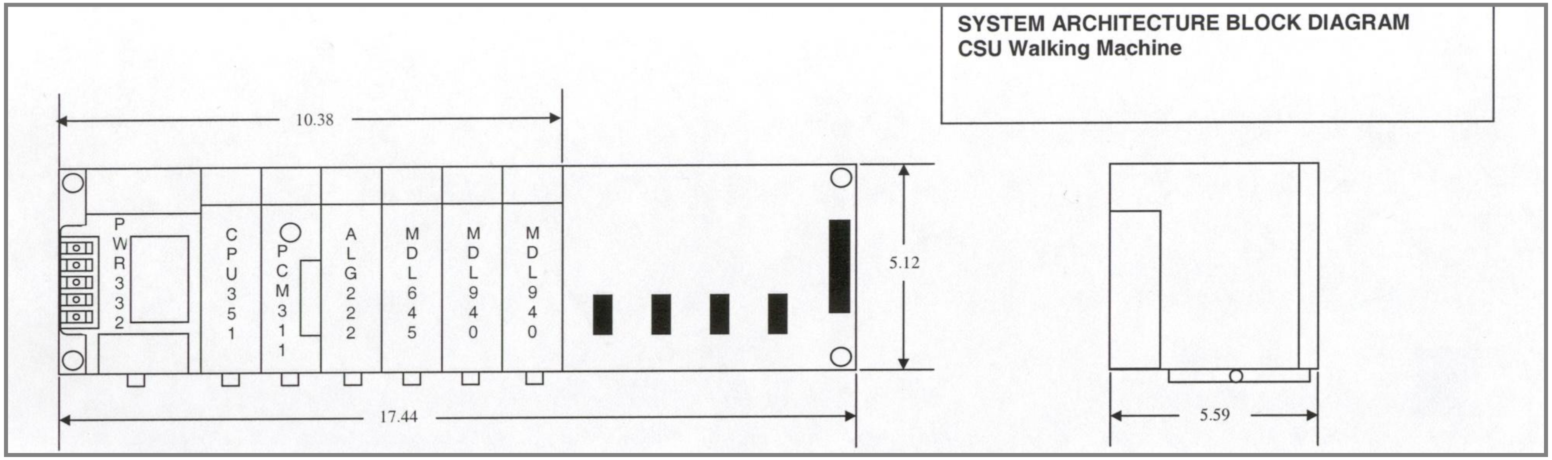
Main Rack Slot 2: Programmable Co-processor (RS-232 compatible)

Main Rack Slot 3: 16 Circuit Input Analog Voltage

Main Rack Slot 4: 16 Circuit Input 24 VDC

Main Rack Slot 5: 16 Circuit Relay Output

Main Rack Slot 6: 16 Circuit Relay Output



Series 90-30 Programming

- Programming is done with Ladder Logic
  - Flows like an electrical diagram
  - Simply controlling the opening and closing of contacts at certain times using built in timers
- ***VersaPro*** - Graphically based ladder logic programming software (drag-and-drop implementation)
  - Programming done in Windows environment then downloaded directly to the PLC
- Learning ladder logic has begun and will continue into next semester

PLC Cost Analysis

Qty	Part Number	Description	Unit Net	Extended Net
Cables				
1	IC690CBL701	Cable, PCM to IBM-PC/XT Class Computers, 10 feet	$65.40	$65.40
Manuals and InfoLink				
1	GFK-0255	Series 90 Programmable Coprocessor Module & Support Software User's Manual	$75.00	$75.00
1	GFK-0771	C Programmer's Toolkit for Series 90 PCM User's Manual	$150.00	$150.00
1	GFK-0772	PCM C Function Library Reference Manual	$150.00	$150.00
Software				
1	IC641SWP063	Series 90 PCM Support S/W, Term. Emulator/File Transfer (TERMF)	$299.00	$299.00
Software Toolkits				
1	IC641SWP709	C Toolkit for Series 90 (Standard)	$1,082.00	$1,082.00
1	IC641SWP710	C Developer's Toolkit for Series 90 PCMs	$3,786.00	$3,786.00
Series 90-30 Products				
Analog Input Modules				
1	IC693ALG222	Analog Input, Voltage 16 Single/8 Differential Channels	$1,028.00	$1,028.00
Bases / Racks				
1	IC693CHS391	Base, CPU, 10 Slots, Use With CPU331/CSE331 and above	$261.00	$261.00
CPUs				
1	**IC693CPU341**	**CPU 341 Module (80K Bytes user memory), 10K** Registers, .3 msec/K, The battery for the CPU is now included in the CPU backplane box.	**$1,728.00**	**$1,728.00**
Discrete Input Modules				
1	IC693MDL645	24 Vdc Input, Neg/Pos Logic (16 Points)	$217.00	$217.00
Discrete Output Modules				
2	IC693MDL940	Relay Output, 2 Amp (16 Points)	$265.00	$530.00
Manuals				
1	GFK-0356	Series 90-30 Programmable Controller Installation	$75.00	$75.00

PLC Cost Analysis (continued)

Qty	Part Number	Description	Unit Net	Extended Net
Manuals				
1	GFK-0467	Series 90-30/90-20 Programmable Controllers Reference Manual	$75.00	$75.00
Power Supplies				
1	IC693PWR322	Power Supply, 24/48 Vdc, Standard. Battery not included. Battery is now included in the CPU backplane box.	$350.00	$350.00
Special Function Modules				
1	IC693PCM300	Prog. Coproc. Mdl., 160 KB (35 KB Basic Prgm), w/Port Exp. Cbl.	$1,180.00	$1,180.00
Series 90-70 Products				
3.4 Manuals				
1	GFK-0646	C Programmer's Toolkit for Series 90-70 User's Manual	$150.00	$150.00
		VersaPro Programming Software		
		VersaPro Standard Edition		
1	IC641VPH300	VersaPro Standard Edition - Windows Programming Software with Programming Cable for Series 90-30 and VersaMax PLCs	$683.00	$683.00
		Total Net		**$11,884.40**

- Very expensive, but GE Fanuc has agreed to fully sponsor our team
- **New total cost:** **$0.00**

Integration of Low Level Controls

- Learn and code PLC via VersaPro and C++ toolkits
- Create serial communication capability for system

- Connect system to hardware via digital/analog output modules
- Test communication between PLC and hardware with verifiable commands (tether program)

Reintroduction of Vision System

- Integration into low-level controls via serial connection
- Verification of initial coding functionality (robot can function at a level at least that of previous year)
- Modification of code for event completion and addition of new turning and navigational functionalities

Debugging of Full System

- Expected to be most time consuming stage
- Debugging of software for vision, step calculation, turn calculation, error handling and event choice
- Debugging of hardware including leg movement, leveling, turning, and pneumatics
- Testing of integrated system with all controls and viable high-level capabilities included

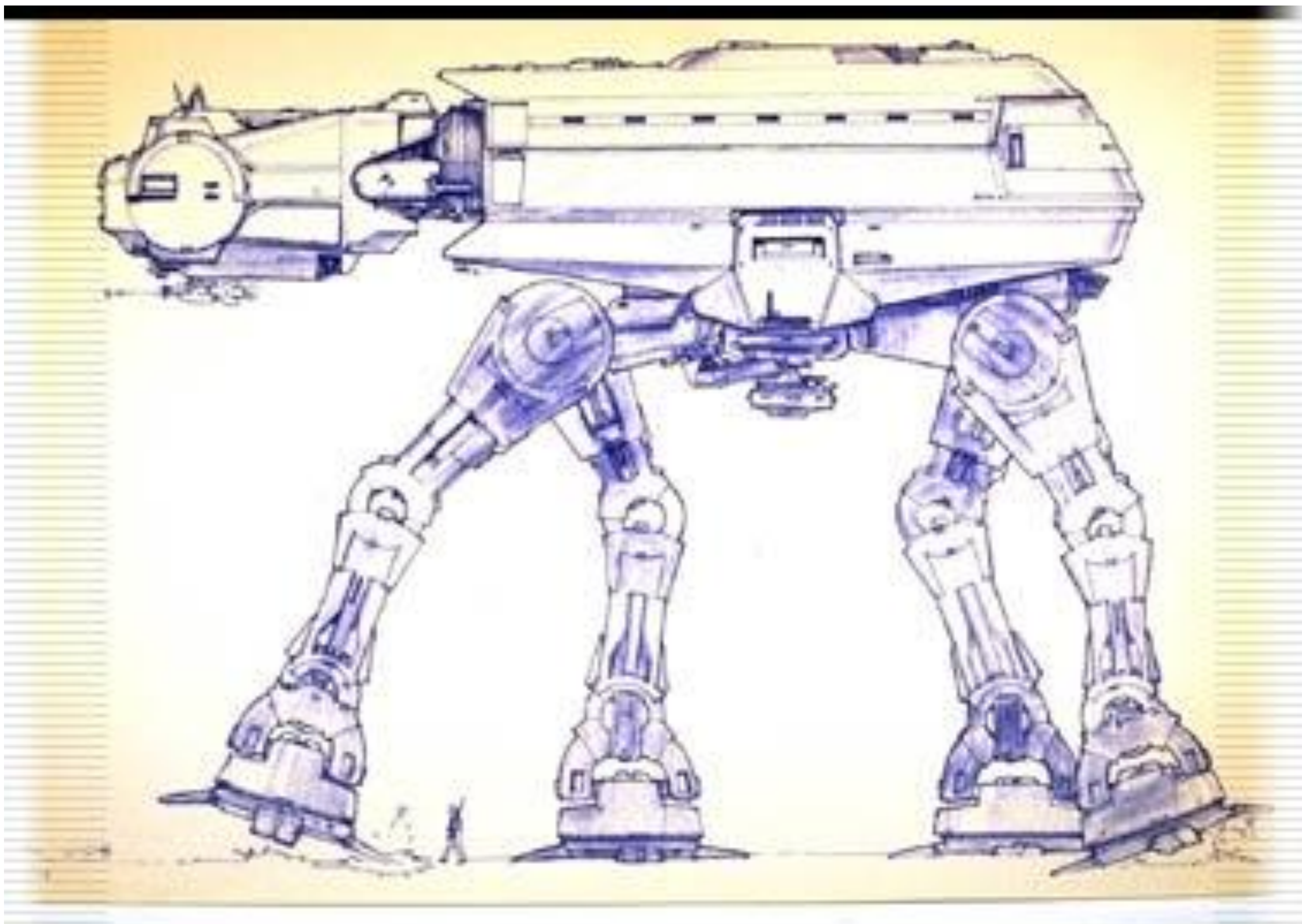
Goals for Second Semester

- Fabrication of physically functional robot
- Implementation of PLC as low-level controls
- Creation of Optical Character Recognition code
- Modification and implementation of existing vision code for new turning and movement capabilities
- Implementation of real-time navigation
- Taking first place at Walking Machine Challenge

Projected Timeline

- Feb. 1, 2002 date of proposed integration of controls, robot, and vision system
- Mid-February have machine together and ready for event-debugging
- Beginning of March begin working on OCR capabilities
- End of March evaluate OCR and robot functionality and determine priorities for competition
- Beginning of April have robot ready to compete in each event
- April 26-27, 2002 compete in SAE Walking Machine Competition

Once the previous goals are accomplished the CSU Walking Machine Team will once again dominate the world (of autonomous robot competition).



Problems to Solve for PSU class

- 1. Give examples of each of the following joints in real-life mechanisms:
  - pins,
  - hinges,
  - bearings,
  - bushings,
  - sliders.
- 2. Give examples of robots using each of the above joints. If you do not recall a robot with them, invent a robot with such joints.
- 3. Give examples of pivots and cranks.

Problems to Solve

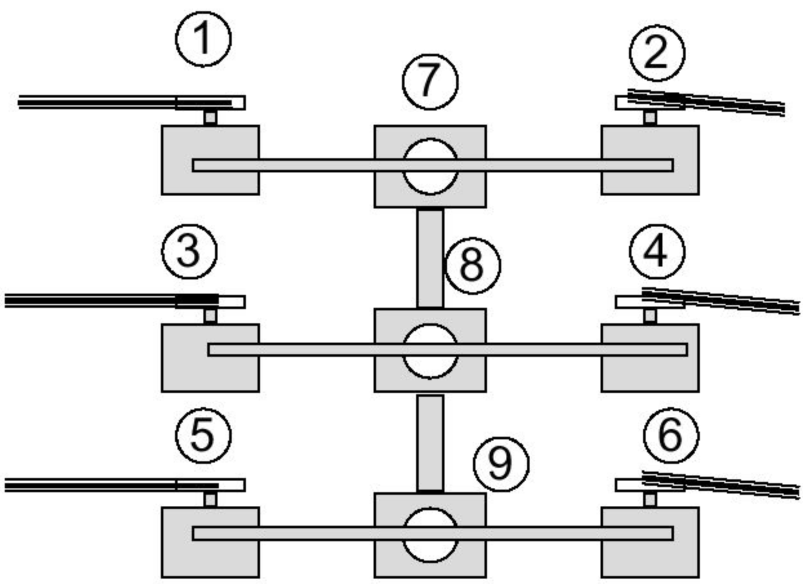
- 1. Describe human hand as a kinematic model. How many degrees of freedom.
- 2. How to build translation using simple servo motors?
- 3. Sketch plans how to use our servo/Robix/Lynxmotion technology to design a model of human arm and hand. How many DOF can you reach?
- 4. Give the example with non-controllable DOF. How to control it?
- 5. Think how to use the SoccerBot design of Karl Kuchs for a more general walking robot design.
- 6. Make a plan of a simplest possible useful redundant robot.

Problems to Solve

- 7. Describe a holonomic model of human-like simplified hand.
- 8. Modify it to make it redundant
- 9. Modify it to make it non-holonomic.
- 10. Analyze kinematics and inverse kinematics of a model car with one motor, analyze parking in a tight spot from the point of view of inverse kinematics (tough).
- 11. Think what are the possible methods to solve inverse kinematics problem. Use knowledge of various classes of algorithms introduced in this class, for instance Genetic Algorithm.

Problems to Solve

- 12. How to solve practically in the simplest way the inverse kinematics problem for the OWI arm? You just want to grasp an item in point (x1,y1,z1) and put it back in point (x2,y2,z2). Accuracy not required.
- 13.
- A).Write a set of cyclic generators for the hexapod from the right.



- B). Consider going forward, backward, turning left and turning right as the minimum.
- C) Propose a new movement that we do not see on our other hexapods

Sources

- **Prof. Maja Mataric**
- **Dr. Fred Martin**
- **Bryce Tucker and former PSU students**
- **A. Ferworn,**
- **Prof. Gaurav Sukhatme, USC Robotics Research Laboratory**
- **Paul Hannah**
- **Reuven Granot, Technion**
- **Dr. Raul Torres**
- **Department of Electrical and Computer Engineering, Colorado State University, Senior Design, Fall 2001,**
- ***Carlos González, Jardiel Marrero, Carlos Ortiz, Adalberto Santiago***

- John P. Brach
- Jon E. Kappes
- Todd K. Kaulukukui
- J. Owen Kremzier
- Dan C. Malyszko
- Peter Young Ph.d.

Ryan Fredricey, Jeff Townsend, Joslyn Bollinger, Maile Ceridon, Nicholas Fernandez, William Brennan, Wade Troxell Ph.d.