Cooperative Spacecraft Performing In-Space Assembly

Peter Will,
Fellow USC/ISI
Director USC Microsatellite Systems Center

USC/Microsatellite Systems Center

MSC is an organized research unit (ORU) in the USC Viterbi School of Engineering that focuses on the science and technology of microsatellites in: research, design, manufacturing and space applications

<u>Vision</u>

- To build responsive microsatellites, to expand the use of space and to bring the "personal computer revolution" to space through research and building small, functional, affordable satellites to operate alone, or in formations and constellations.

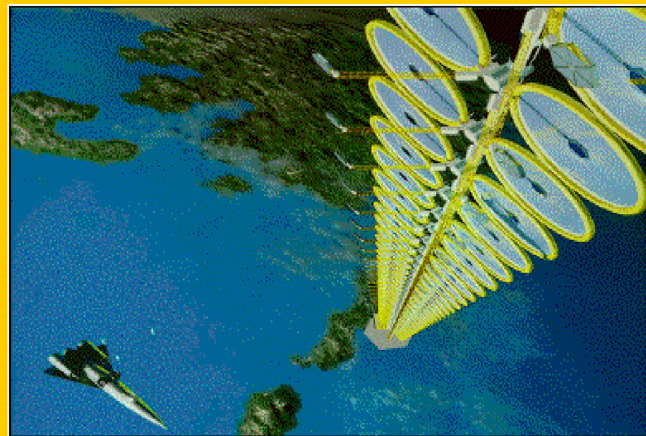
<u>Mission</u>

- *Research*
  - MSC engages in research in microsatellite-centric science and technology. New miniaturization technology is encouraging new thinking across the entire scale of spacecraft and their applications, but nowhere more than in micro and small satellites.
- Build and Fly
  - The MSC mission includes building experimental microsatellites and placing then on orbit to test, evaluate and validate the research.
- Education
  - Students, working as members of MSC R&D teams, will acquire experience highly valued by Industry and Government R&D centers. The Center will provide a stimulating research environment and will give both undergraduate and graduate students hands-on experience to prepare them to be the Space Workforce of the Future.

Self-Assembly in Space

NSF and NASA supported

- NAS study said NASA should take a new look at the problem
- Giant set of solar arrays, microwave or laser to the earth
- Multiple launches: assemble in space
- Cost Effectiveness
  - For a 10km long x 2km wide SSPS
    - >2,500 hours of astronaut space walk
      - 4/11/2002, girder assembly (26 hours)
    - >$5 billion for assembly cost
- Needs automation

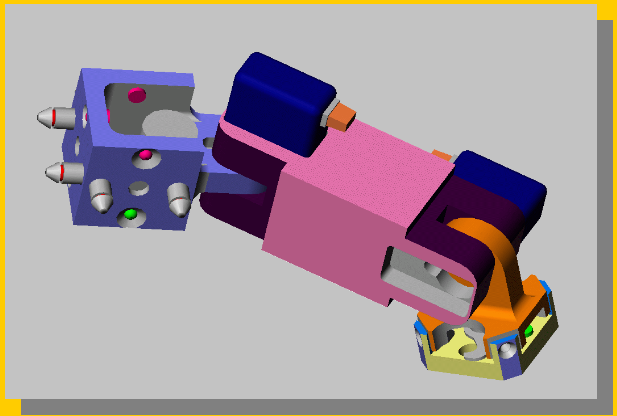


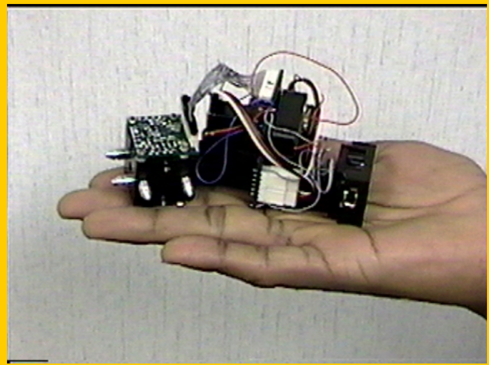
Assembly Tasks

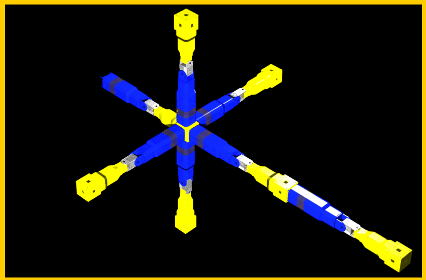
- Assembly issues: terrestrial or in-space…
  - Where are the parts, how big are they, task accuracy, robot accuracy, what kind of gripper, how are the parts fed, how are they to be grabbed, how are they be fixtured? Etc.
- In-Space
  - Decided to do assembly using tethered spacecraft on an air-bed to simulate zero-gravity
  - Fixturing issues led to tethers
  - Delta-V issues led to using tethers as an electric motor driven tension- only delta-v

Modules and Interconnect

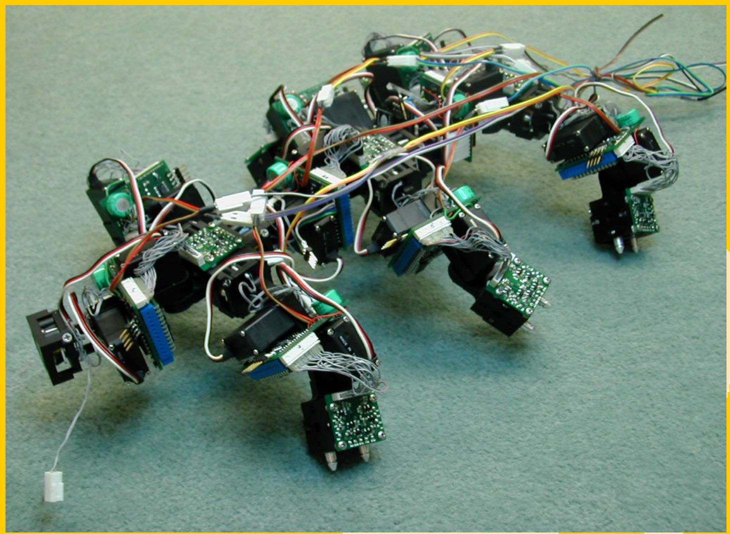
(Prior DARPA supported work)





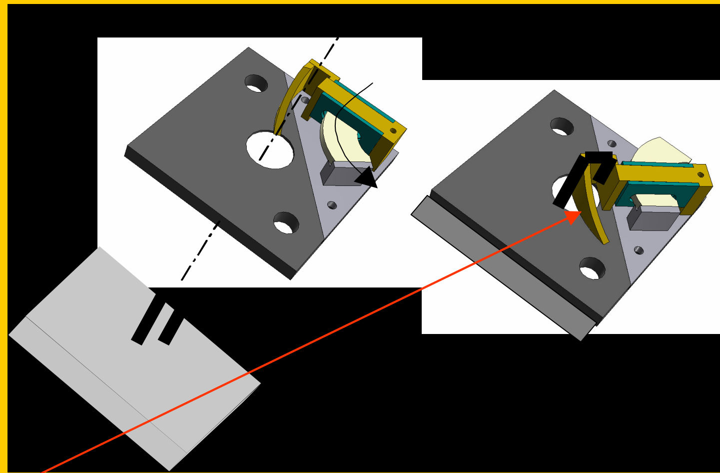


- Distributed Computation
- No electrical connection
- IR communications, RS 232
- Topology discovery
- Message routing
- Automatic docking/de-docking using a mutually cooperative protocol
- Wireless for off system communications
- Self contained power -- batteries
- Possible power-sharing
- When plugged together, locomoted as a robot



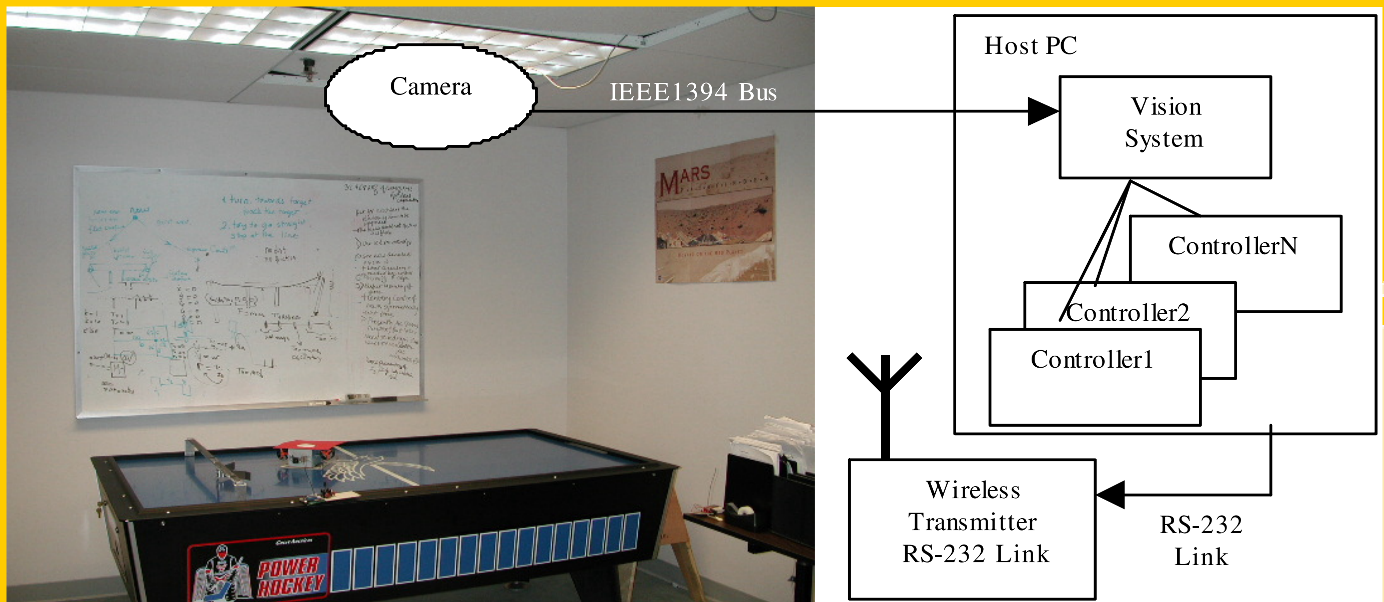
Docks for Reconfigurability
spacecraft and components

- 1” square x ¼ “ thick
- Loose initial grab self-tightening using the inclined plane
- Motor opens dock
- Spring closes and tightens using the inclined plane



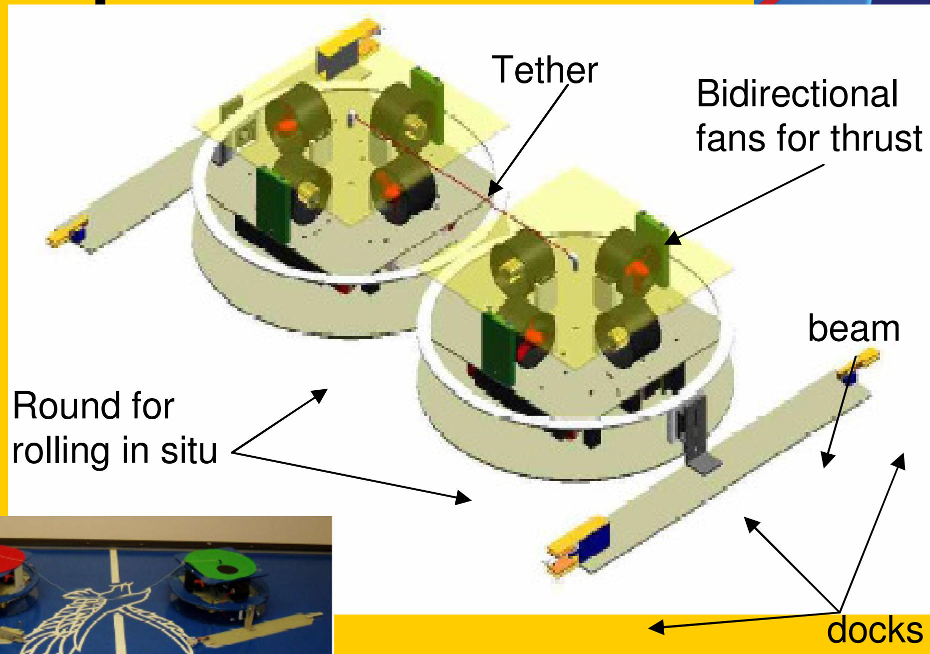
Air-table experiments

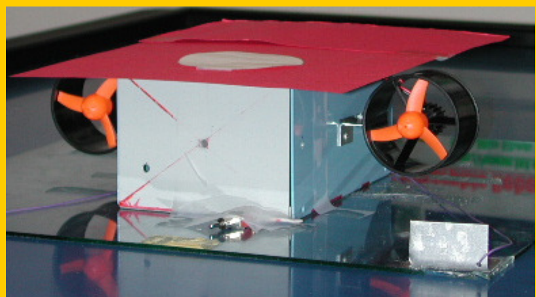
- Used several spacecraft on a commercial air-hockey table
- Spacecraft used many of the robot module components control computers, I/O, wireless links etc
- Overhead camera for positioning
- Target on the spacecraft
- Tethered spacecraft



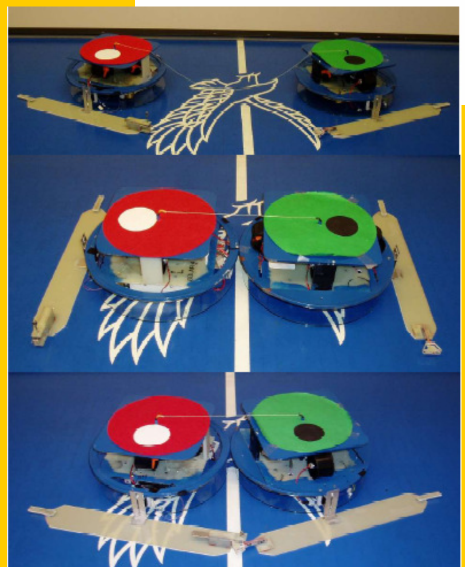
Tethered Spacecraft

- Several spacecraft with tethers and targets
  - white on red
  - black on green
  - For position and heading





First cut with 2 fans for non-holonomic control



Peter Will ISI

Spacecraft Control Model

M(**n**)**n**' + C(**n**)**n** + D**n** + g(**h**) = **t**

M(**n**) is the moment of inertia matrix,
C(**n**) is the centrifugal and Coriolis forces,
D is the damping matrix,
and **n** =[u v r]' is the velocity vector
and **h**=[x y y]' is the configuration vector
g(**h**) is the vector of gravitational and buoyant forces
and **t** = [Tu Tv Tr] is the control forces and torques

Movies

- All movies located at
  - http://www.isi.edu/robots/media.html
  - Then go to the SOLAR project and look for the titles listed below

- Movies to be shown
  - Diagonal across the table --- shows noise in the table
  - Closed loop docking maneuver
  - Precision Assembly with 2 new beams --- assembles two beams using the tether and a mirror roll
  - 2-beam joint lock --- makes a v-structure
  - Triangle Joint Lock --- assembles a triangular truss