Control Algorithms For *Space Tug* Rendezvous

16.622 Final Presentation

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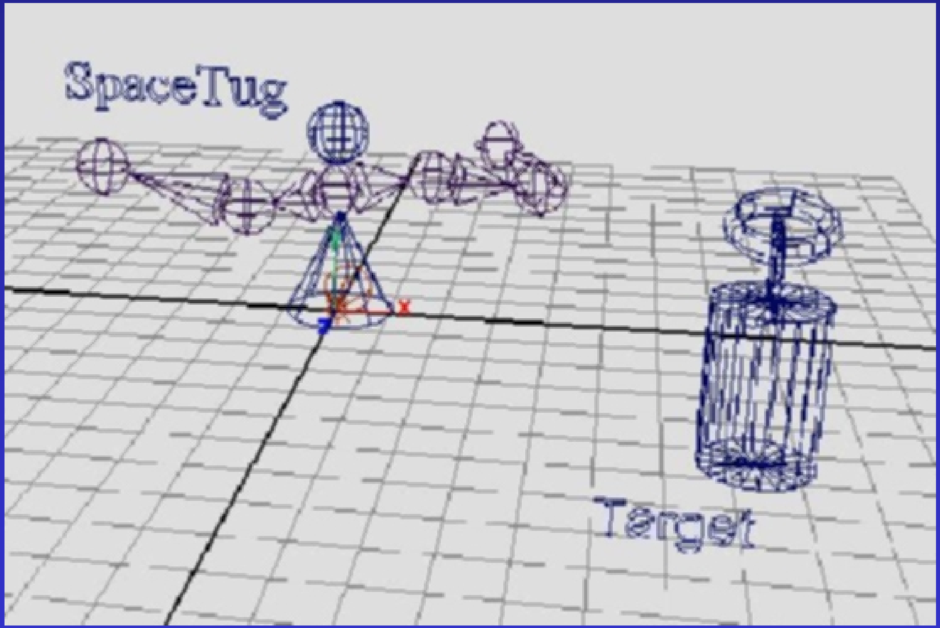
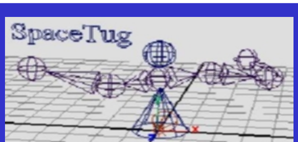
Introduction

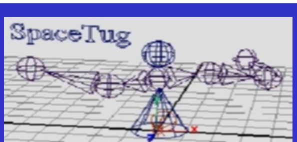
- What are we trying to do?
  - Optimize two-dimensional search for an inert target
- How are we accomplishing that?
  - Research search strategies
  - Implement models in code
  - Run the code with Lego MindStorms©





Background and Motivation

- The *Space Tug* (Orbital Servicer) – a joint LAI and DARPA project to develop:
  - capability to service satellites
  - economic solution to the high-energy problem in space
  - universal grappling capability
  - find target efficiently
- Our 62x project is a subset of the general problem
  - Has that been done before?

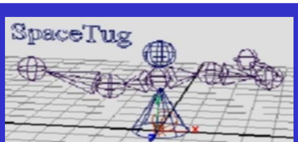


Hypothesis

The use of a semi-autonomous search system with human in the loop is the algorithm that will be the most effective for rendezvous and docking strategies, in terms of time and energy consumption.

Possible Strategies are:

- Random sensor-less search
- Semi-autonomous, human in the loop
- Fully autonomous search

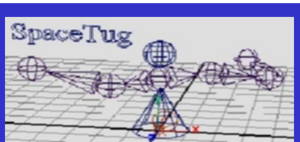


Objectives and Success Criterion

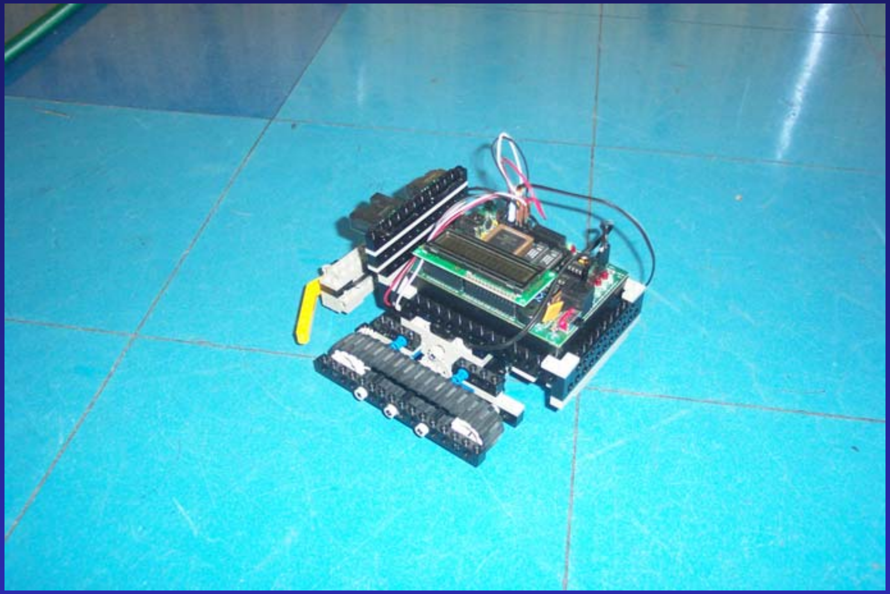
- Develop, implement and test the three different strategies for two-dimensional, non-cooperative target search

- Compare these strategies based on the trade-off costs between time and energy

- Success is a clear definition of whether or not the semi-autonomous search system is the most effective algorithm for rendezvous and docking strategies in terms of time and energy consumption.



Description of Hardware



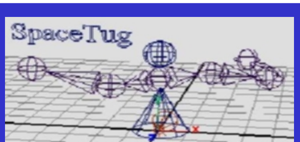
- The Tug uses a Handyboard on-board computer:
  - 4 motor ports
  - 16 analog sensors ports
  - Motorola 68HC11 Processor

- Tug sensors
  – Long range Infrared
  – Short range Infrared
  – Touch

- Tug communicates with command computer through serial port interface

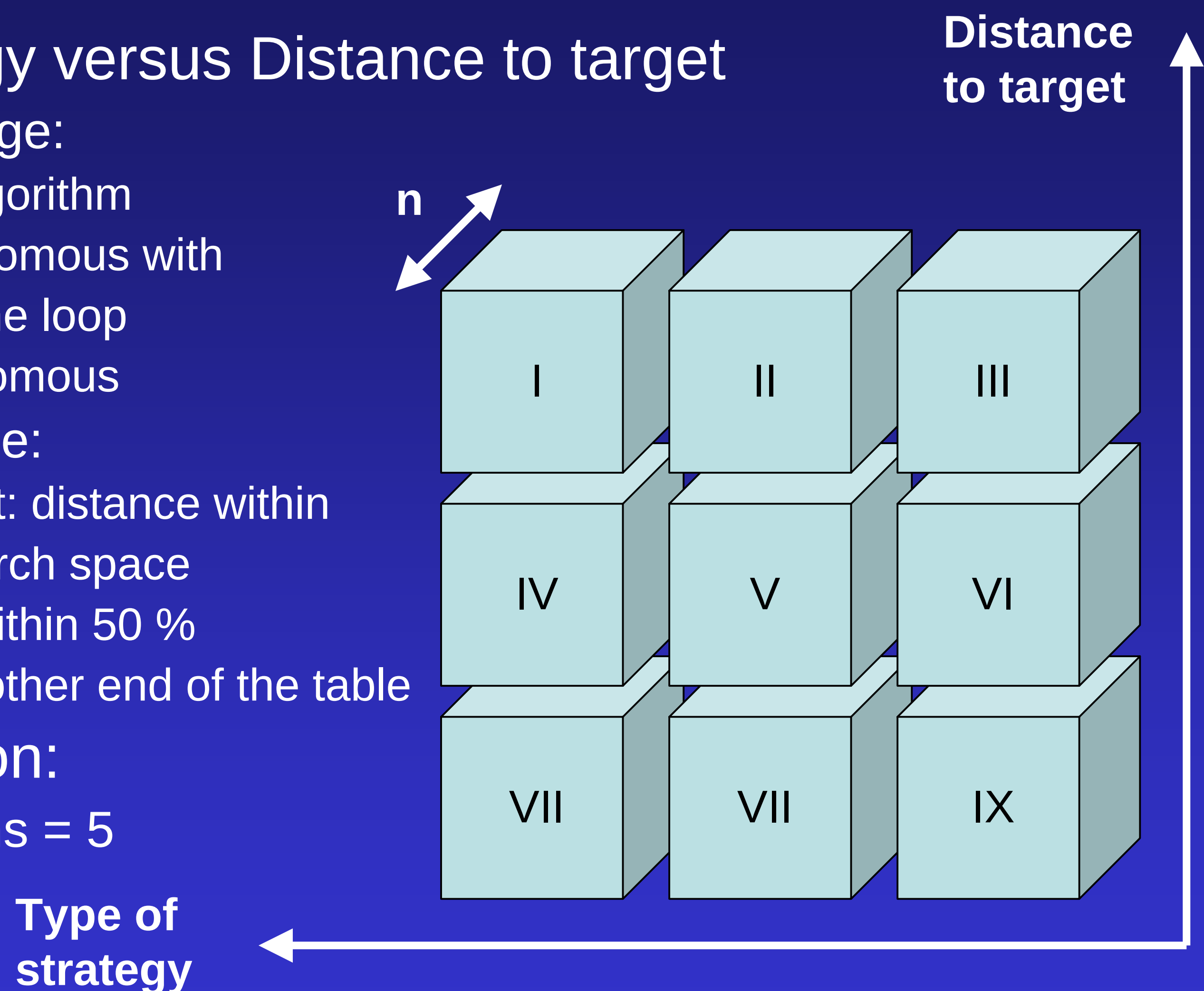
Description of Software

- Matlab Simulations
  - All logic developed in MatLab modules
  - Test cases run in MatLab in parallel with on-site testing
- Tug Control System code
  - Interactive C
  - Using standard C language in addition to some custom functions to use sensors and motors

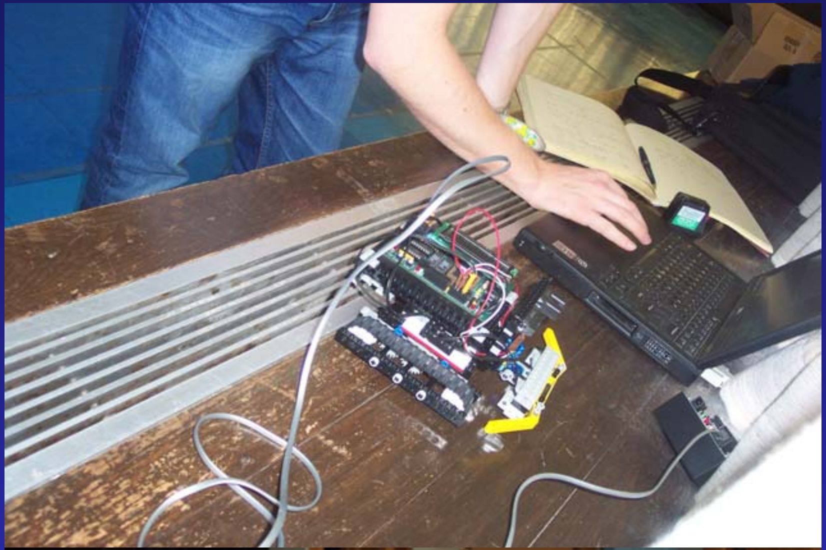


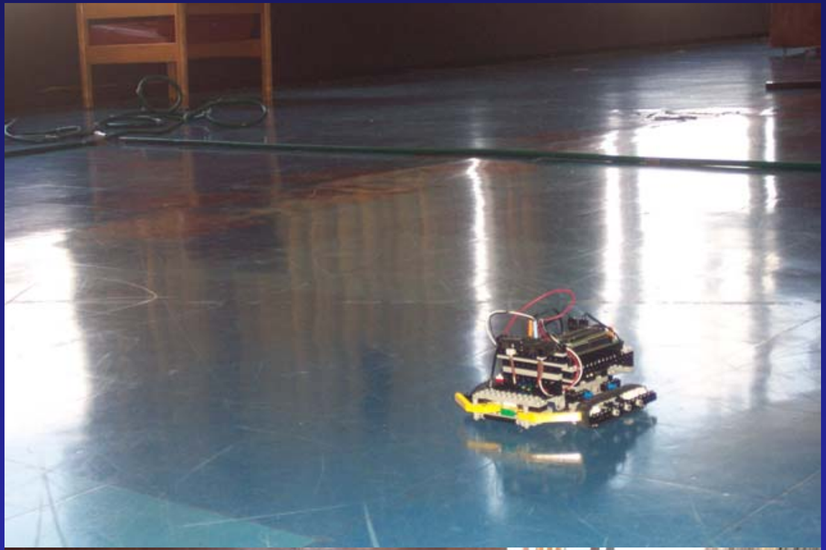
Test Matrix

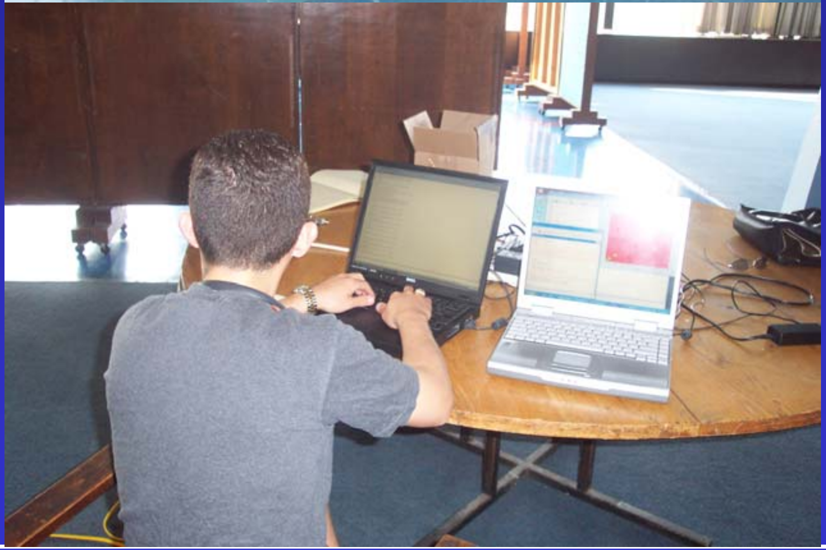
- Type of strategy versus Distance to target
  - Strategies range:
    - Random algorithm
    - Semi-autonomous with human in the loop
    - Fully autonomous
  - Positions range:
    - Close target: distance within 10 % of search space
    - Half-way: within 50 %
    - Far: at the other end of the table
- Third Dimension:
  - Number of runs = 5



Experiment



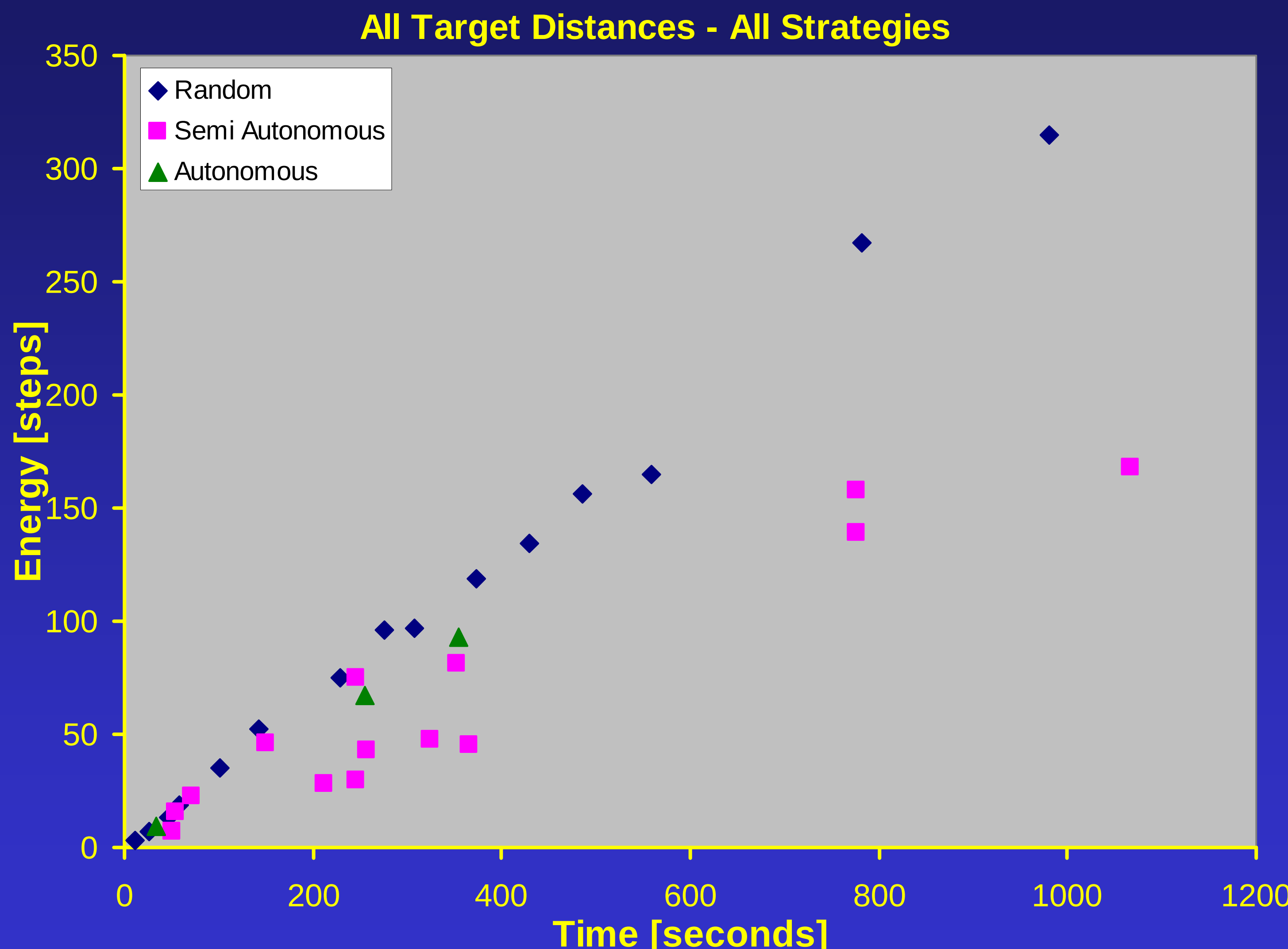


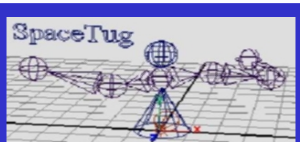


The Data

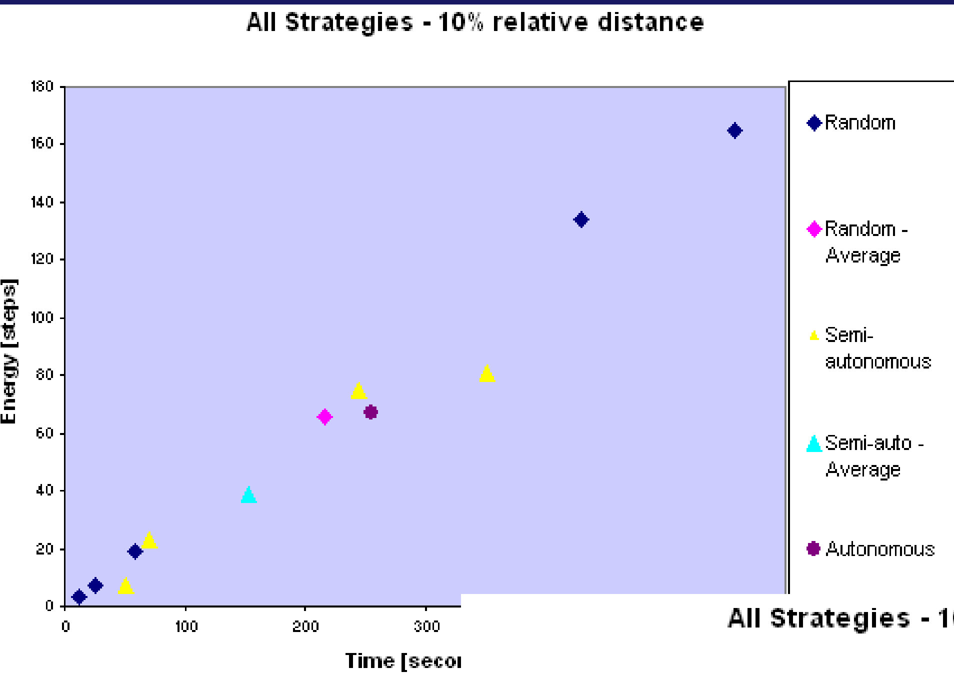
	target @ 100%		target @ 50%		target @ 10%	
	time, sec	*steps*	*time, sec*	*steps*	*time, sec*	*steps*
random search	485.561	156	47.194	13	429.363	134
	182.174	267	275.101	96	12.055	3
	143.372	52	229.308	75	58.114	19
	373.704	119	981.1969	315	25.982	7
	308.311	97	101.552	35	558.075	165
autonomous	354.35	93	33.05	9	254.9	67
semi-auto search	775.515	150	245.842	30	352.357	81
	1060.1	168	211.544	28	70.511	23
	776.787	139	53.877	16	49	7
	256.169	43	150.246	46	245.653	75
	323.986	48	366.007	45	51.133	7

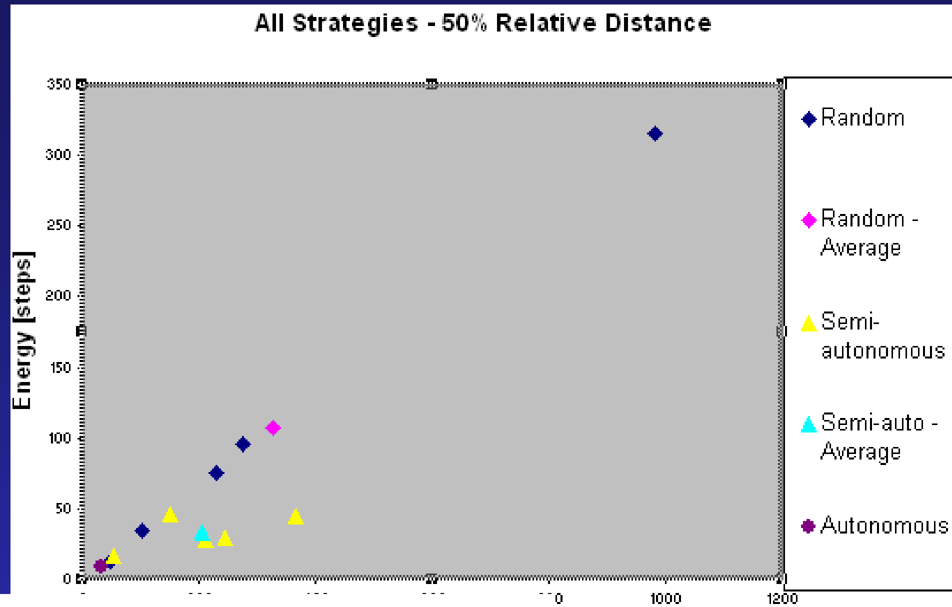
Data Analysis I

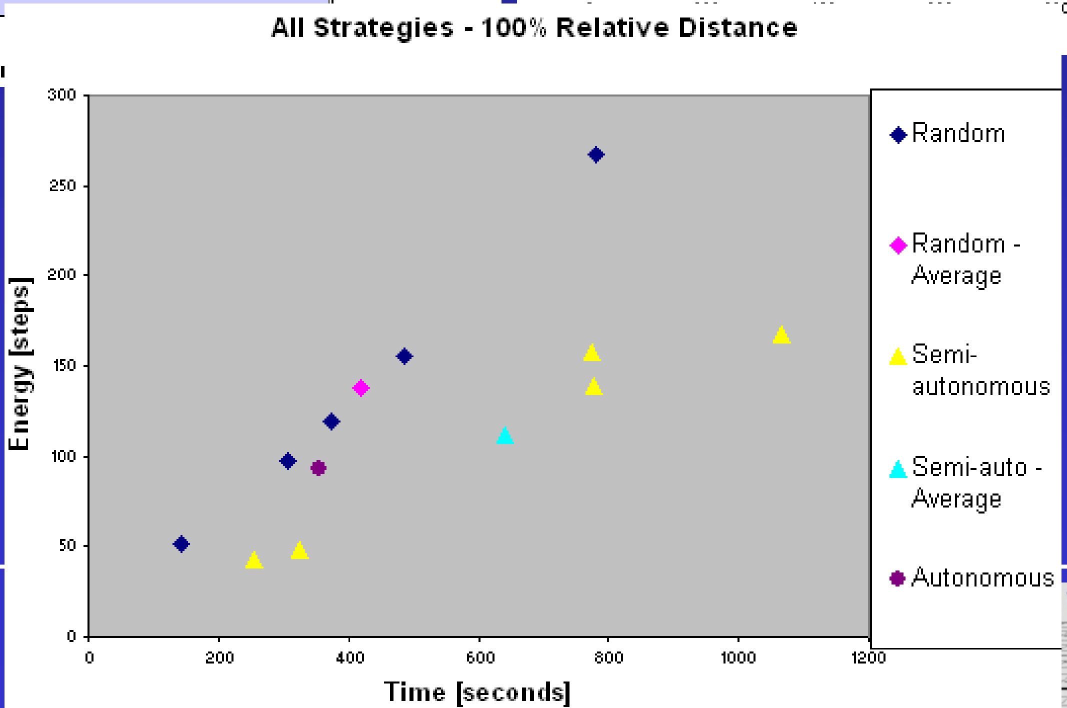


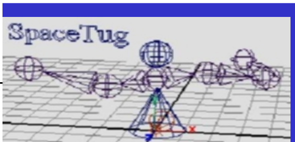


Data Analysis II: The Distance Factor

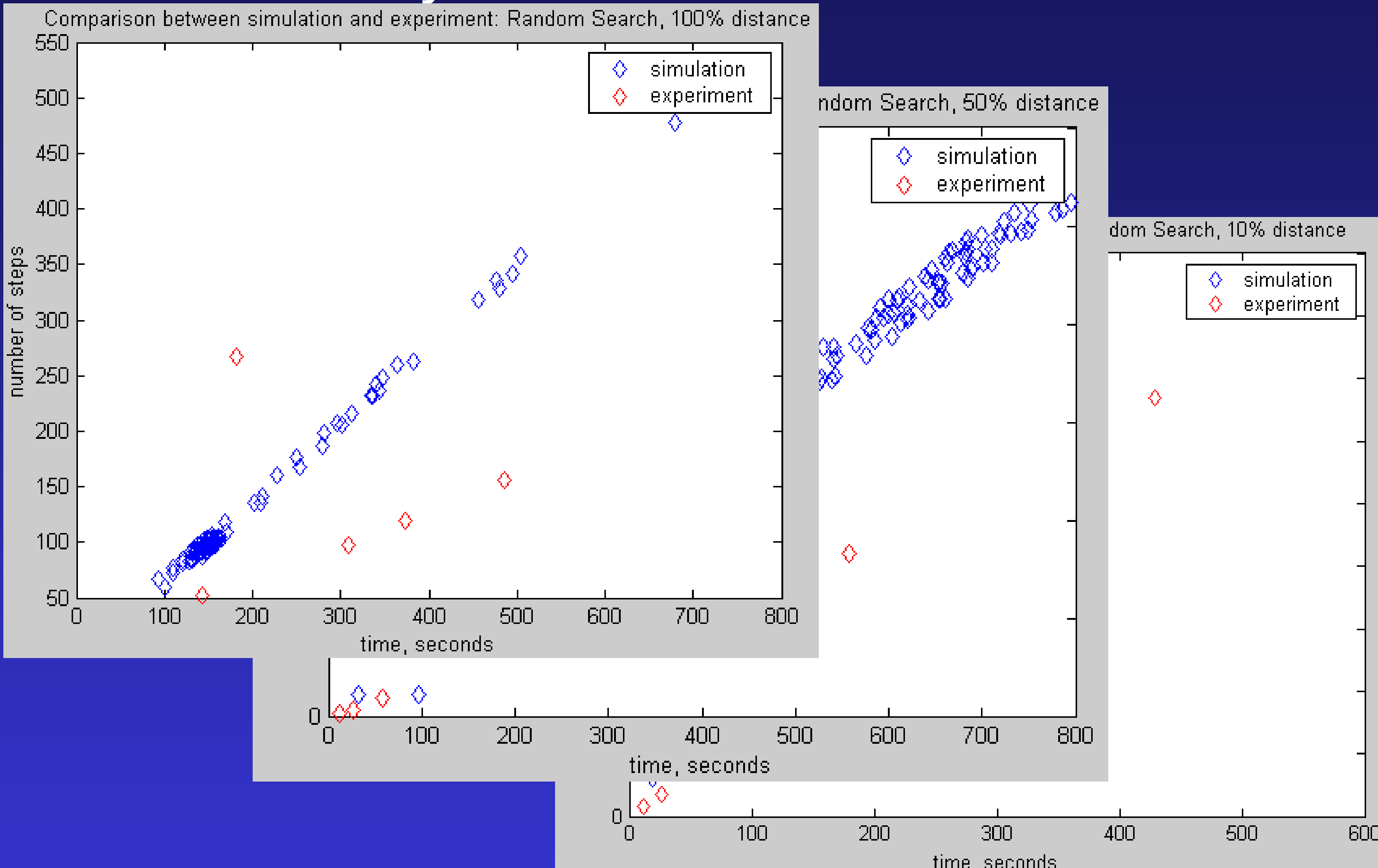




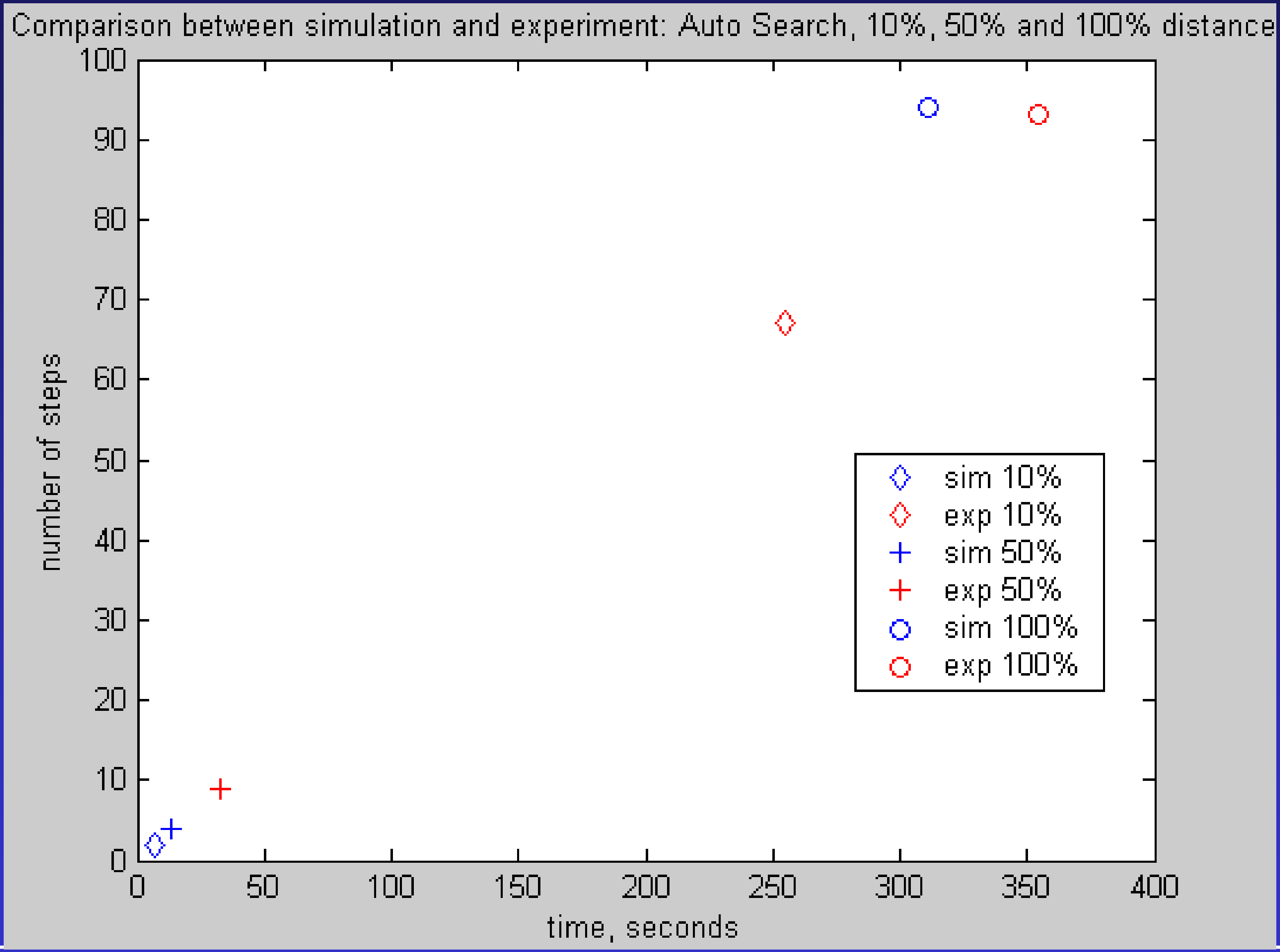




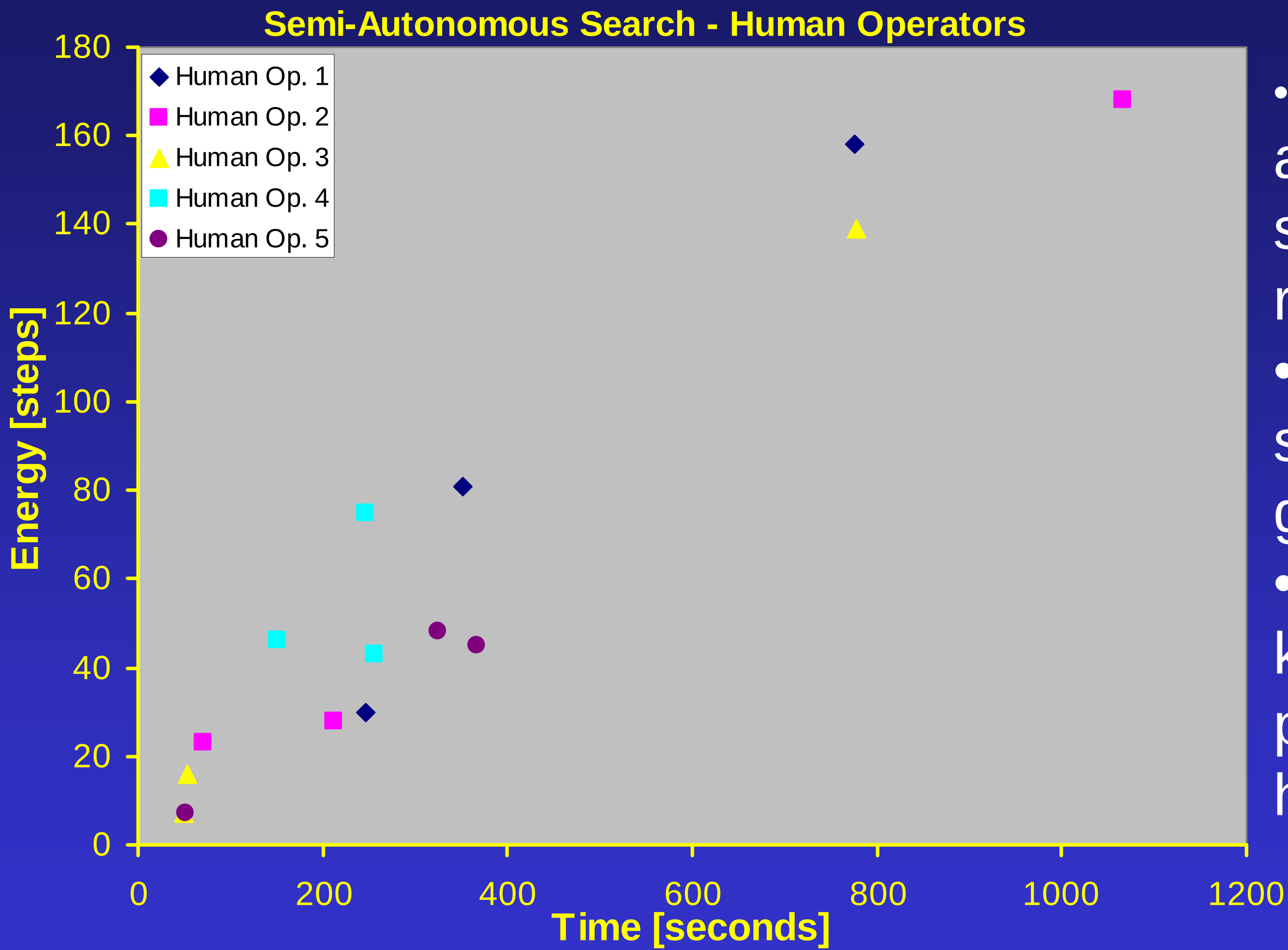
Data Analysis III: The Random Search



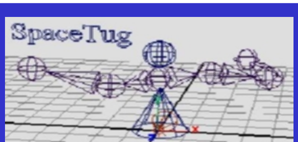
Data Analysis III: Autonomous



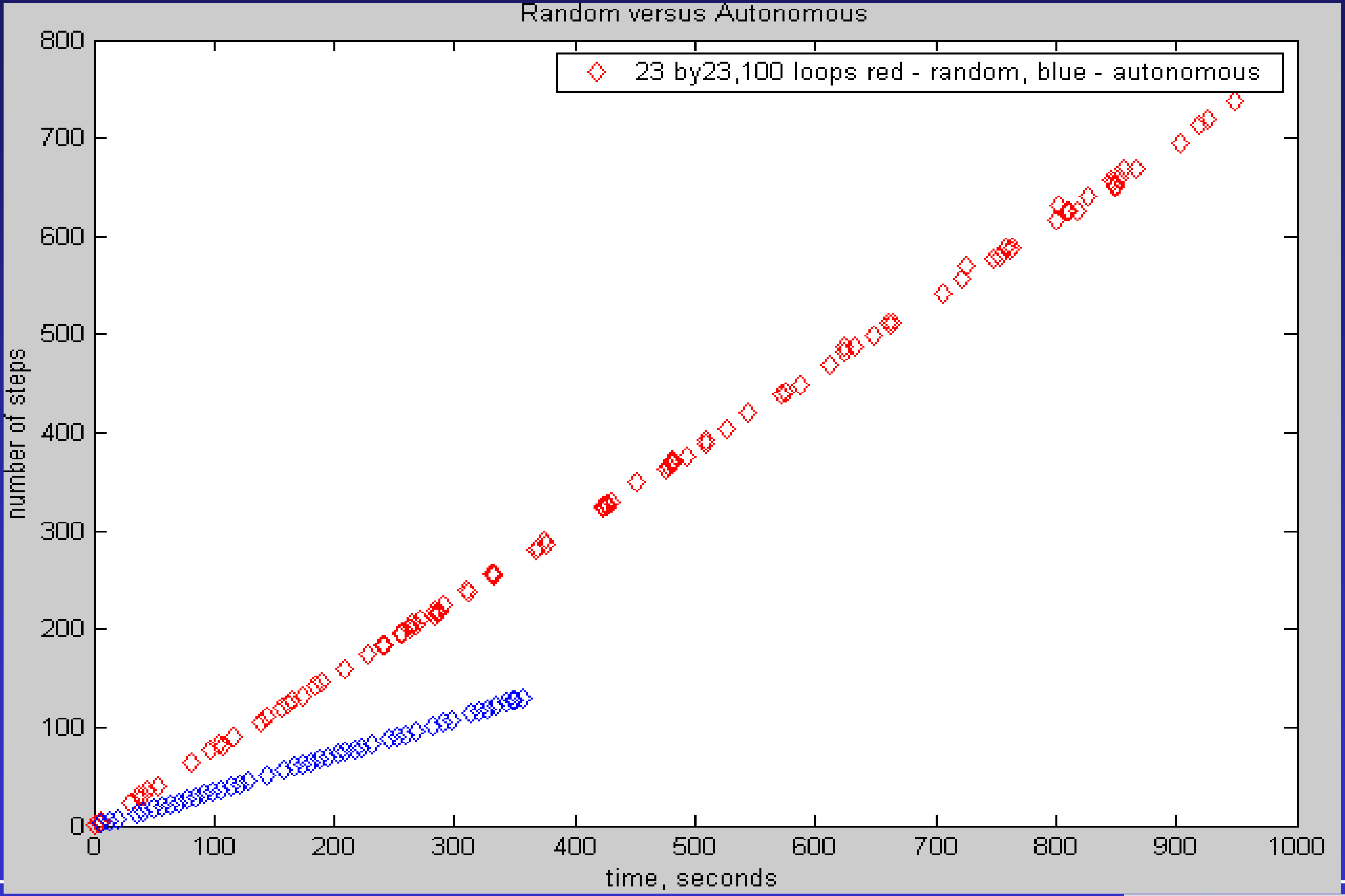
Data Analysis III: Semi-Autonomous

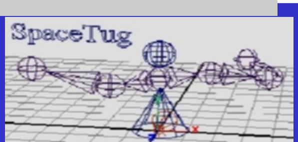


- Some people are systematic, some choose randomly
- Even the good strategists can get unlucky
- No prior knowledge of the problem might help!

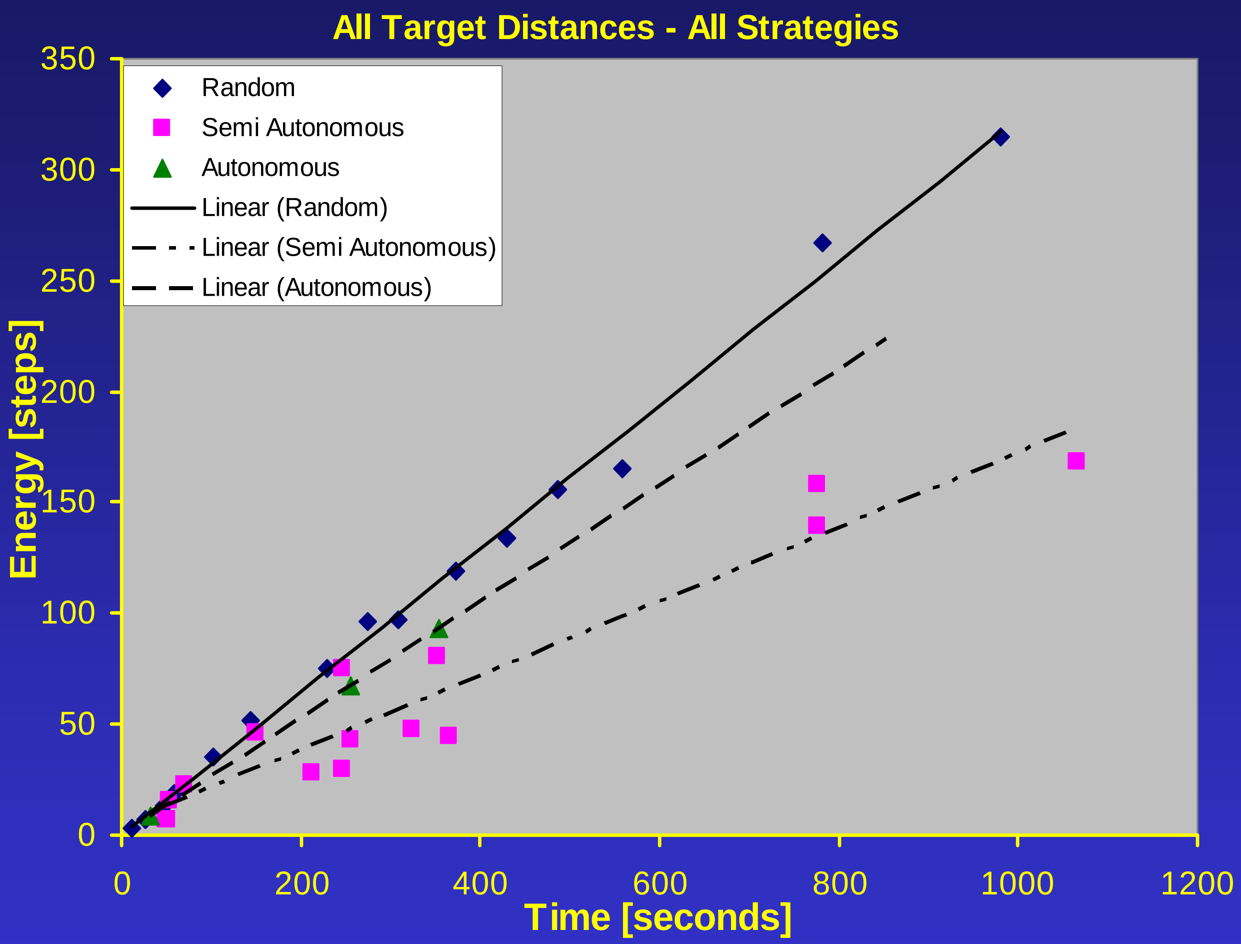


Simulation Trends

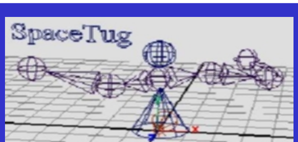




Back to Data Analysis I



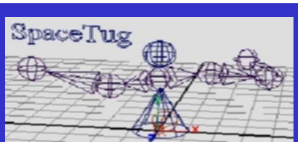
- Semi – autonomous requires least amount of energy!
- Random search is overall fastest
- Autonomous for space?



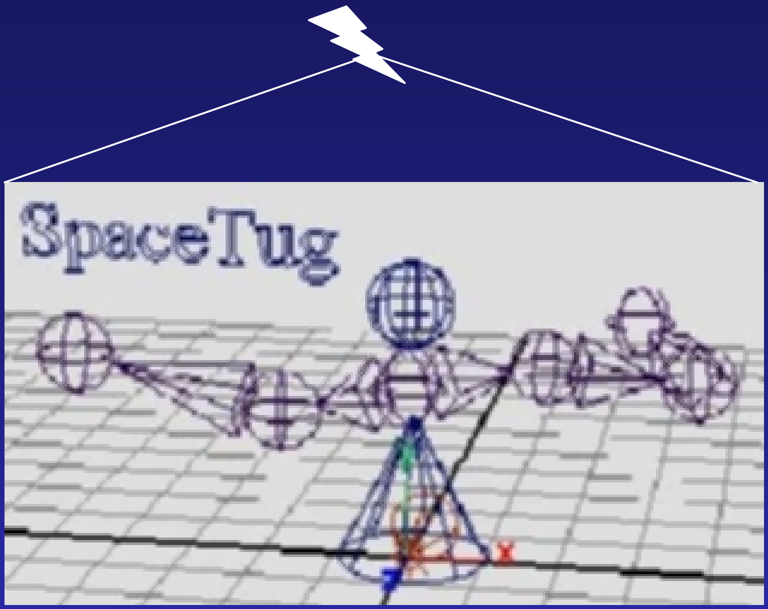
Conclusions: The Space Problem

- The hypothesis is disproved but…
  - Semi-autonomous expends the least energy (fuel in space)
  - But communication takes much longer (even worse in space)
  - Conclusion: the semi-autonomous search is great for conserving energy, but maybe not the most efficient in space
  - Hybrid search (semi-auto + autonomous) would be better depending on time and energy mission requirements

- The search strategies show strong trends (quasi-linear behavior)
- The 3-D problem is extendable due to additional knowledge of orbital dynamics (problem reducible to special 2D cases)



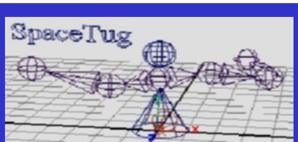
Perspectives



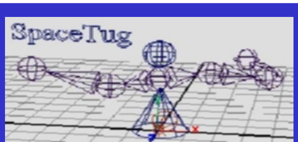
- Model a target moving in a circle around the robot (the Hill's frame)
- Randomize the target location
- Include metrology to close the control loop
- Develop a human factors experiment from the semi-autonomous strategy
- Build a higher-fidelity simulation

Budget

Item	Acquire from	Cost
Lego MindStorms © Computer + parts	Lego	$ 200
Ultrasonic Range Sensor	HiTechnic	$ 80
Infrared Proximity Sensor	HiTechnic	$ 40
Touch Sensor Multiplexor	HiTechnic	$ 19
Search space building materials	Home Depot	$ 50
Batteries	RadioShack	$ 100
Video Tape	*RadioShack*	*$ 6*
	Total	$ 495



A Random Walk

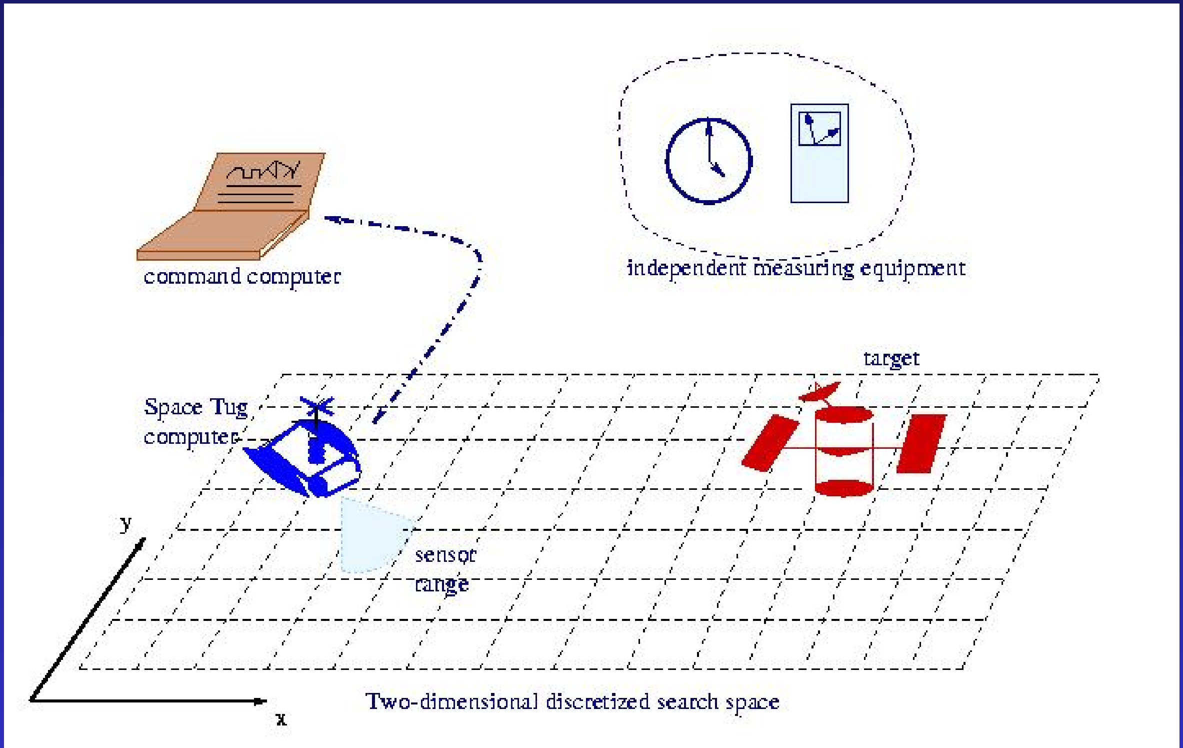


Backup Slide 1: Experimental Overview

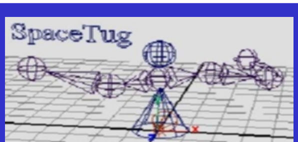
- Area dimensions for search space based on actual size ratios

- Using sensors, the Tug computer searches for the target

- Command computer used to transmit orders to the Tug

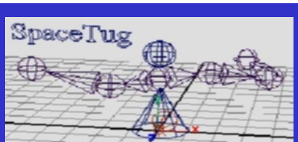


- Time and energy are measured for each search strategy

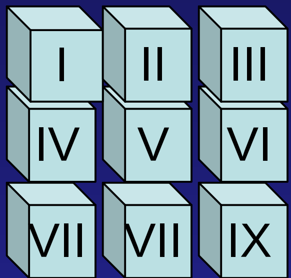


Backup Slide 2: Experimental Variables

- Variables measured by the human operator
  - Time elapsed for the entire mission: t_{total}
  - Energy expended for the mission: E_{total}
- Variables measured by the robot
  - Target relative position: $X_r(t)$
  - Target relative velocity: Vr(t) (Hill's frame case)
- Independent Variables
  - Initial target relative position (input): $X_r(0)$
  - Type of search strategy (input)
- Dependent Variables
  - Time and Energy for the mission: t_{total}, E_{total}

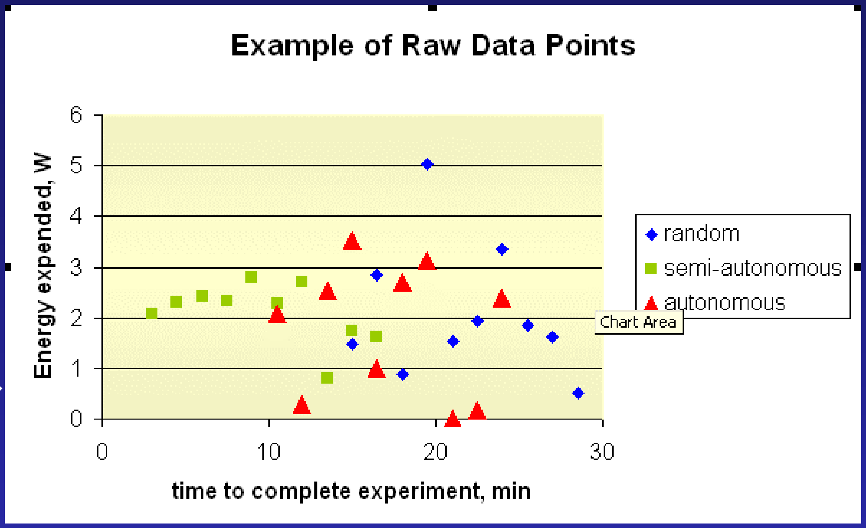


Backup Slide 3: Measurement, Errors and data analysis



TESTS

- Time Measurement:
  - Very accurate
  - Computer Internal Clock
- Energy Measurement
  - Accuracy depends on device



PLOTS

Receive & Process Data

Conclusion

In semi-autonomous search the human operator cannot know which test is being run

→ Avoid bias in decision making

Backup Slide 4: Schedule

Task	Start	End
Building Tug and target	2/3/03	2/14/03
Coding	2/3/03	3/7/03
Random	2/3/03	2/11/03
Semi-autonomous	2/11/03	2/19/03
Autonomous algorithm	2/20/03	2/28/03
Debugging and testing	2/10/03	3/7/03
Progress review 1	2/11/03	2/11/03
Experiment	2/24/03	4/18/03
Random	2/24/03	3/13/03
Semi-autonomous	3/14/03	4/3/03
Autonomous	4/4/03	4/18/03
Oral progress report	3/4/03	3/4/03
Progress review 2	4/1/03	4/1/03
Analysis & presentation	4/18/03	5/13/03
Data analysis	4/16/03	4/30/03
Written report	4/30/03	5/13/03
Final oral report	5/1/03	5/1/03
Last day to take data	4/18/03	4/18/03