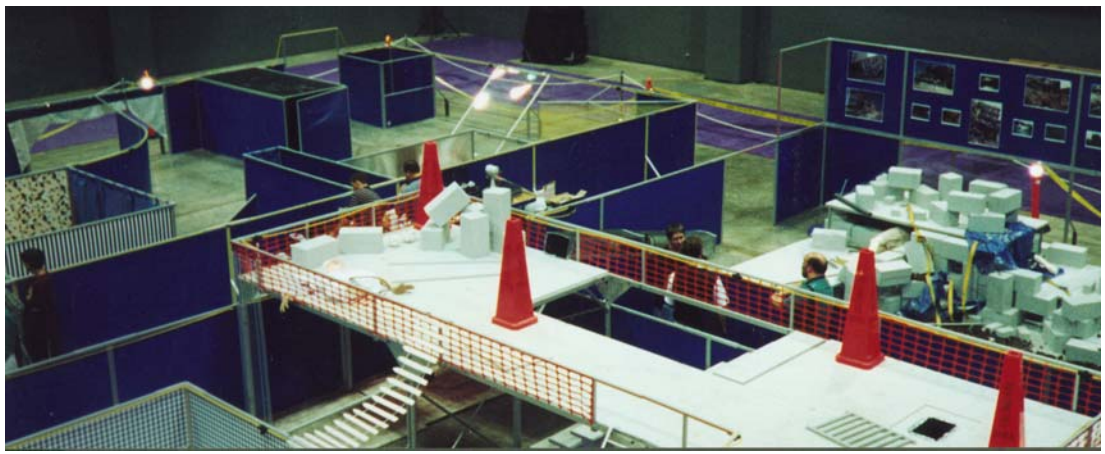
Test Arenas and Performance Metrics

for

Urban Search and Rescue Robots

Adam Jacoff, Brian A. Weiss, Elena Messina



Intelligent Systems Division
National Institute of Standards and Technology
United States Department of Commerce

100 Bureau Drive, MS 8230
Gaithersburg, MD 20899-8230

Email: adam.jacoff@nist.gov
Phone: 301.975.4235

PRESENTATION OVERVIEW

- Need and goal of reproducible measures and tests
- Reference Test Arenas for Urban Search and Rescue (USAR) Robots
- Performance Metric for USAR Robots
- Past Rescue Robot League Competitions (2002 & 2003)
  - RoboCupRescue
  - IJCAI/AAAI
- Future Rescue Robot League Competitions (2004)
  - American Open – RoboCupRescue
  - RoboCupRescue
  - AAAI
- Virtual Arenas
- Future Directions

NEED

QUESTION: Why Fabricate Reference Test Arenas for Mobile Robots?

"Teaching to the Test"

- Objectivity in evaluation of different robotic implementations
- Demonstrations representative of actual applications (non-idealized)
- Focus on specific abilities (relevant obstacle course)

"Comparing Apples to Apples"

- Isolate sensors, behaviors, capabilities (repeatability is critical)
- Standardized tests allow direct comparison of approaches

"Re-Creating the Wheel"

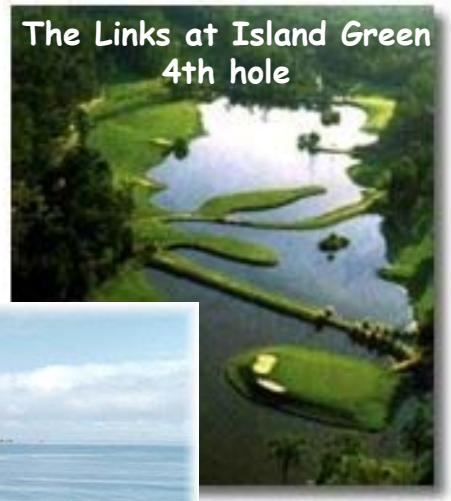
- Encourage transfer of designs and code by understanding capabilities
- Adopt and then augment "successful" implementations and algorithms

"Practice, Practice, Practice

- Representative environments to validate and challenge robots
- Robustness comes through repetition and testing outside perceived limits

GOLF COURSE ANALOGY

- Practice and play against the same (known) course
- Compare level of competence against others by score
- Handicap scores based on agility to allow direct competition
- Play different courses to improve/augment/test skills

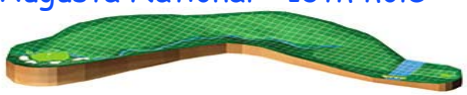


COMPUTER MODELS REAL COURSES

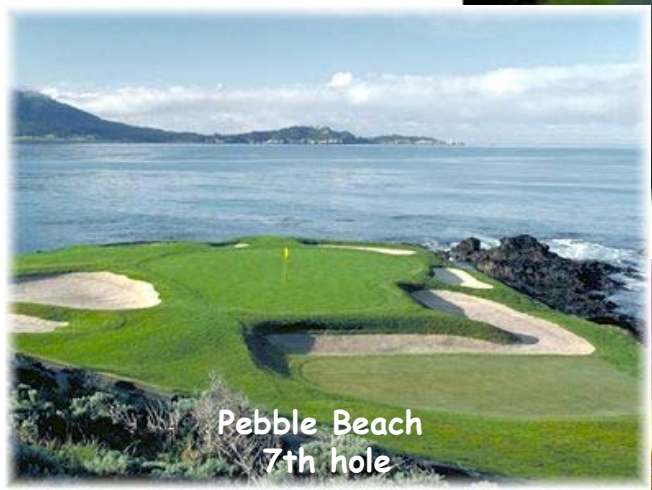
Augusta National - 6th hole

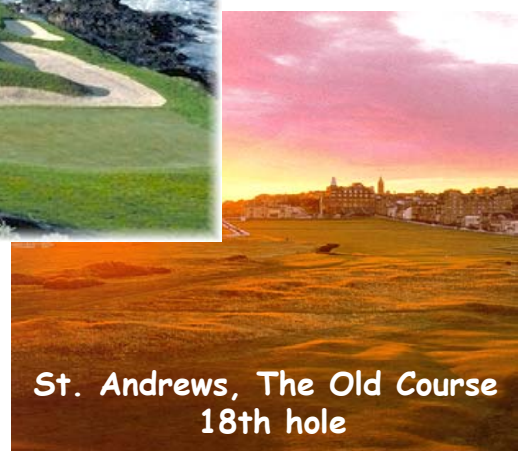
Augusta National - 12th hole

Augusta National - 13th hole



Augusta National - 18th hole





DO SKILLS TRANSFER?

GOAL and CUSTOMERS

GOAL:

Improve our ability to measure the capabilities of mobile robots.

CUSTOMERS:

Researchers

- Develop repeatable obstacles (sensory and physical) focused toward perception and intelligent behaviors
- Proliferate standard obstacles to test components and algorithms
- Compare implementations, support collaboration among development teams

Sponsors

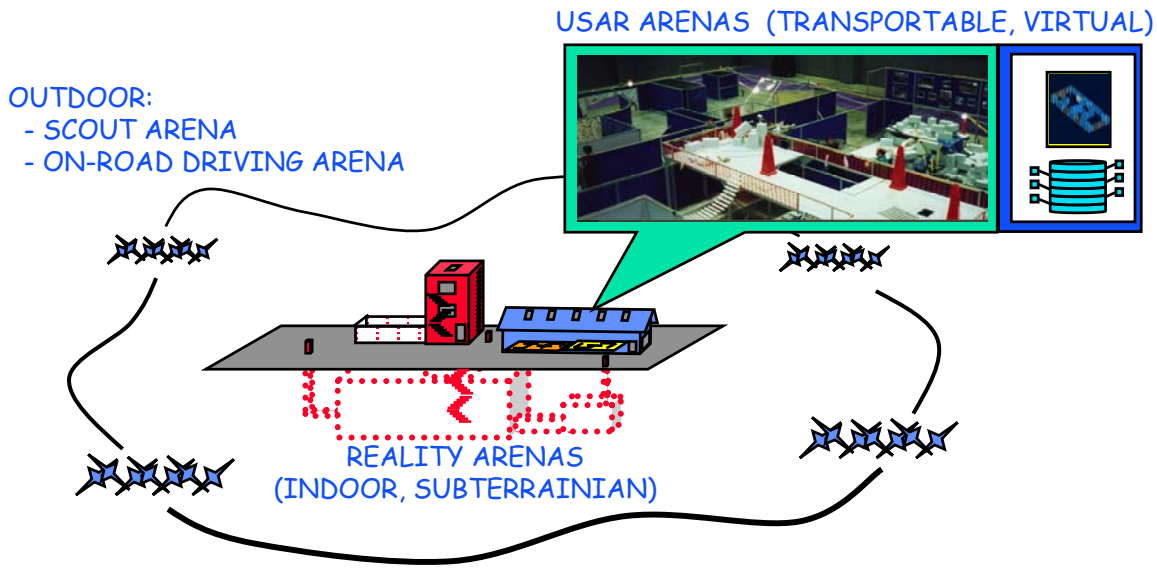
- Objectively evaluate robots in representative environments
- Identify strengths/weaknesses, compare cost effectiveness

Users

- Will benefit from performance metrics and standards for mobile robot capabilities

REFERENCE TEST ARENAS

Develop a facility that accelerates the advancement of mobile robot capabilities and provides a stepping stone from research to deployment



- *Objectively evaluate robotic components and methods*
- *Develop performance metrics and standards for mobile robots*
- *Foster collaboration among robotics researchers*

REPRODUCIBLE MEASURES and TESTS

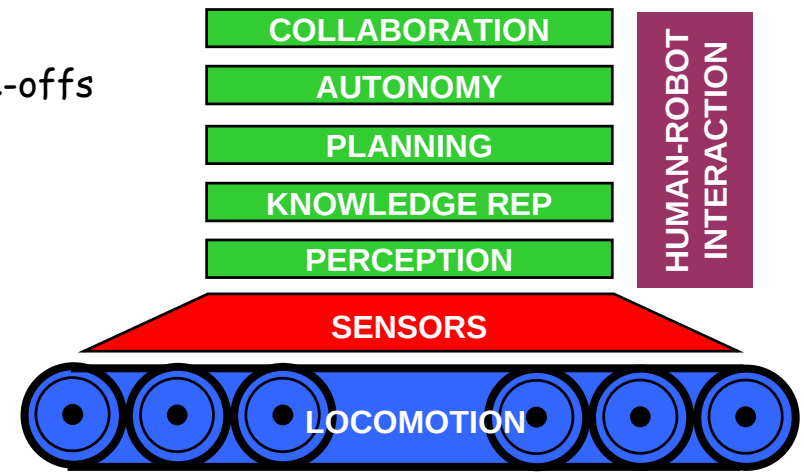
- **Collaboration**
  Maximize coverage, redundancy, efficiency among heterogeneous robot teams
  High level human/robot interactions

- **Autonomy**
  Mixed-initiative modes to limit human interactions, improve robot survivability

- **Planning**
  Negotiate obstacles, time-critical decisions, trade-offs

- **Knowledge Representation**
  A priori knowledge/skills (traversability)
  Gained information (3-D spatial maps)

- **Sensory Perception**
  Navigation, hazard detection, goal identification.
  Sensor fusion to provide robust performance



A CHALLENGING REAL-WORLD PROBLEM

Urban Search and Rescue (USAR) refers to rescue activities in collapsed buildings and structures

- **Application Goals**
  - Explore a structure, map significant features
  - Locate, assess, and map victims
  - Deliver emergency kits (radio, water, first aid…)
  - Transmit a human readable map
- **Hazardous task**
  - Lives saved by assisting human rescuers
  - Explore compromised structures, limited access areas
  - Robots are ultimately expendable
- **Time critical**
  - Great benefit from quickly locating victims
  - Requires careful path planning and strategy
- **Highly unstructured/unpredictable**
  - Requires adaptability, decision-making
  - Negotiation = Navigation + Influence

ROBOTS DEPLOYED AT WORLD TRADE CENTER

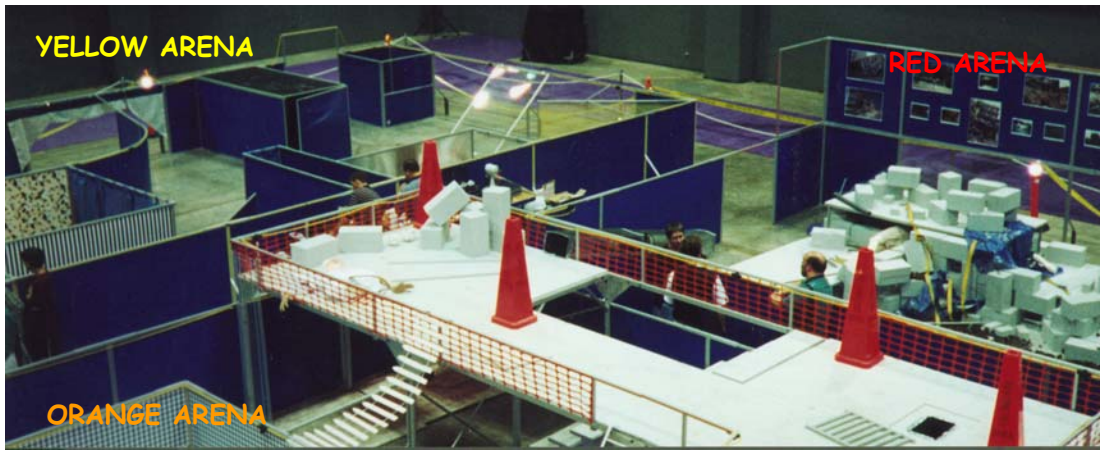


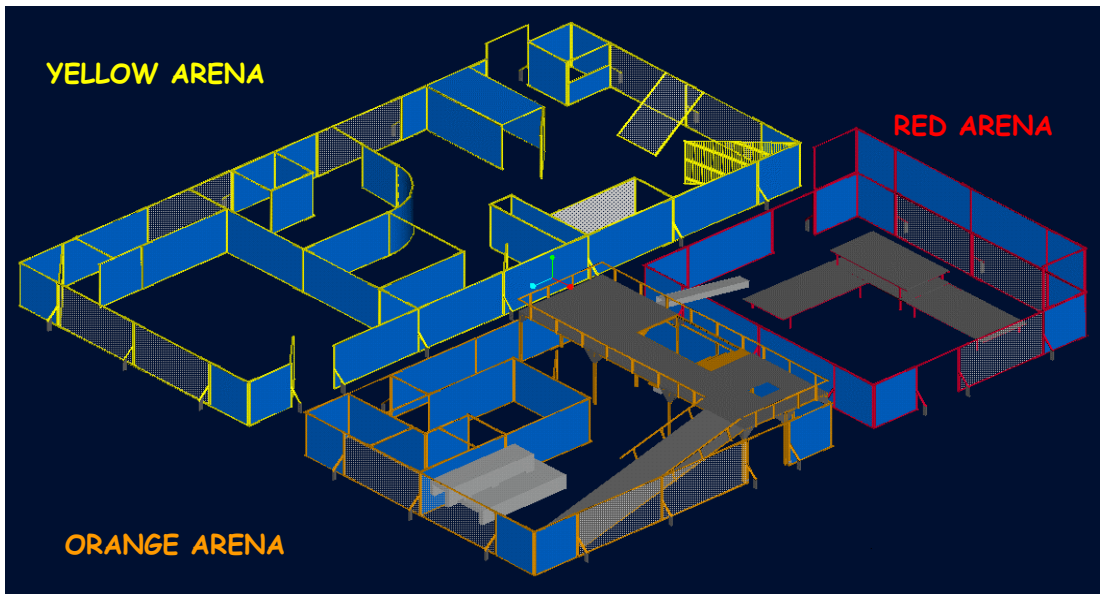




Photos courtesy of the Center for Robot-Assisted Search and Rescue (CRASAR)

REFERENCE TEST ARENAS for USAR ROBOTS

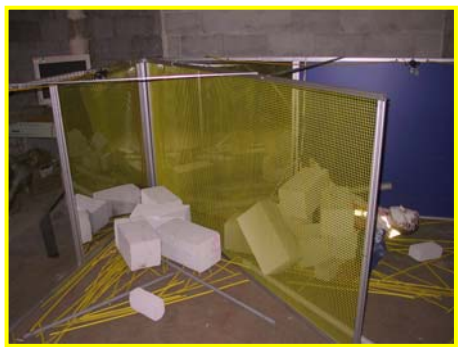




USAR TEST ARENA FEATURES

- Yellow Arena
  - No flooring issues
  - Planar (2-D) maze
  - Isolates sensors with obstacles/targets
  - Reconfigurable to test mapping/planning
- Orange Arena
  - Variable, but structured, flooring
  - Spatial (3-D) maze with stairs, ramp, holes
  - Semi-collapsed structures
- Red Arena
  - Unstructured, collapsed environment
  - Shifting floors, confined spaces
  - Problematic rubble: rebar, wiring, pipes…

YELLOW ARENA FEATURES







ORANGE ARENA FEATURES







RED ARENA FEATURES







SIMULATED VICTIMS

HUMAN FORM

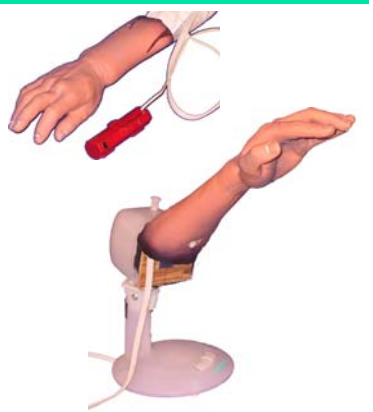
CLOTHING:
DUST COVERED
OR COLORFUL

REFLECTIVE TAPE

LOCATOR STROBE

VICTIM TAG

WAVING ARMS
MOVING FINGERS



TAPPING

LOCATOR
ALARM

VOICE

BODY HEAT

CO2 EMISSIONS

SIMULATED VICTIM SITUATIONS/STATES

SITUATIONS

- Surface
- Trapped
- Void
- Entombed

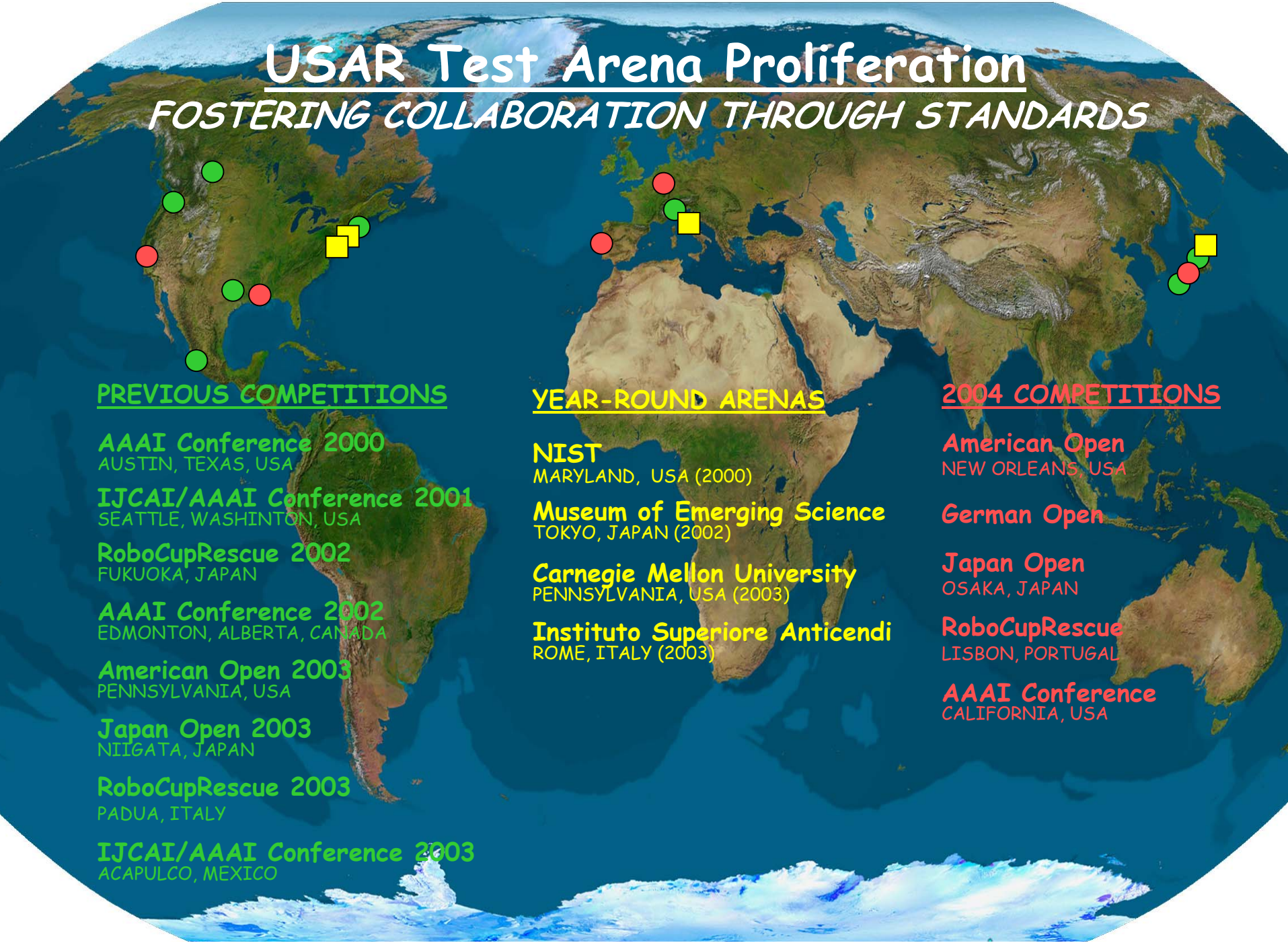
STATES

- Aware
- Semi-conscious
- Unconscious

Competitions and the Performance Metric

USAR Test Arena Proliferation

FOSTERING COLLABORATION THROUGH STANDARDS



PREVIOUS COMPETITIONS

AAAI Conference 2000
AUSTIN, TEXAS, USA

IJCAI/AAAI Conference 2001
SEATTLE, WASHINTON, USA

RoboCupRescue 2002
FUKUOKA, JAPAN

AAAI Conference 2002
EDMONTON, ALBERTA, CANADA

American Open 2003
PENNSYLVANIA, USA

Japan Open 2003
NIIGATA, JAPAN

RoboCupRescue 2003
PADUA, ITALY

IJCAI/AAAI Conference 2003
ACAPULCO, MEXICO

YEAR-ROUND ARENAS

NIST
MARYLAND, USA (2000)

Museum of Emerging Science
TOKYO, JAPAN (2002)

Carnegie Mellon University
PENNSYLVANIA, USA (2003)

Instituto Superiore Anticendi
ROME, ITALY (2003)

2004 COMPETITIONS

American Open
NEW ORLEANS, USA

German Open

Japan Open
OSAKA, JAPAN

RoboCupRescue
LISBON, PORTUGAL

AAAI Conference
CALIFORNIA, USA

RESCUE ROBOT LEAGUE VISION

When disaster happens, minimize risk to search and rescue personnel, while increasing victim survival rates, by fielding teams of collaborative robots which can:

- Autonomously negotiate compromised and collapsed structures
- Find victims and ascertain their conditions
- Produce practical maps of their locations
- Deliver sustenance and communications
- Identify hazards
- Emplace sensors (acoustic, thermal, hazmat, seismic, etc,…)
- Provide structural shoring

…allowing human rescuers to quickly locate and extract victims.

SEARCH AND RESCUE SCENARIO

A building has partially collapsed due to earthquake.

The Incident Commander in charge of rescue operations at the disaster site, fearing secondary collapses from aftershocks, has asked for teams of robots to immediately search the interior of the building for victims.

The mission for the robots and their operators is to find victims, determine their situation, state, and location, and then report back their findings in a map of the building and a victim data sheet.

The section near the building entrance appears relatively intact while the interior of the structure exhibits increasing degrees of collapse. Robots must negotiate the lightly damaged areas prior to encountering more challenging obstacles and rubble.

The robots are considered expendable in case of difficulty.

NEED FOR RULE/METRIC CHANGES

Deter parallel teleoperation in separate arenas

- Solution: Force robots to traverse arenas sequentially

Deter sequential teleoperation in separate arenas

- Solution: Remove "Number of Robots" in scoring formula

Deter false victim identifications

- Solution: Add penalties for errors in scoring formula

Promote use of multiple sensors

- Solution: Add incentives for multiple sensor identifications
- Solution: Add incentives for correctly identifying victim
  "Situation" (surface/trapped/void/entombed)
  "State" (aware/semi-conscious/unconscious)

PERFORMANCE METRIC FOR USAR ROBOTS

50 POINTS POSSIBLE PER VICTIM FOUND

PENALTIES PER EVENT

$$\text{ARENA WEIGHTING} \left(\frac{\text{MAP QUALITY} + \text{VICTIM LOCATION} + \text{VICTIM TAG} + \text{VICTIM SITUATION} + \text{VICTIM STATE} - \text{ARENA BUMPING} - \text{VICTIM BUMPING}}{\left[1 + \text{NUMBER OF OPERATORS} \right]^2} \right)$$

PERFORMANCE METRIC FOR USAR ROBOTS

$$\text{ARENA WEIGHTING} \left(\frac{\text{MAP QUALITY} + \text{VICTIM LOCATION} + \text{VICTIM TAG} + \text{VICTIM SITUATION} + \text{VICTIM STATE} - \text{ARENA BUMPING} - \text{VICTIM BUMPING}}{\left[1 + \text{NUMBER OF OPERATORS} \right]^2} \right)$$

ENCOURAGES VALIDATION OF LOCALIZATION
(EFFECTIVE ARENA MAPPING)

1.00/0.75/0.50

10 PTS 10 PTS
5 PTS 5 PTS
1 PTS 1 PTS

+ 10 PTS + 5 PTS
- 10 PTS

+ 15 PTS
- 10 PTS

-20 PTS -20 PTS
-5 PTS -5 PTS

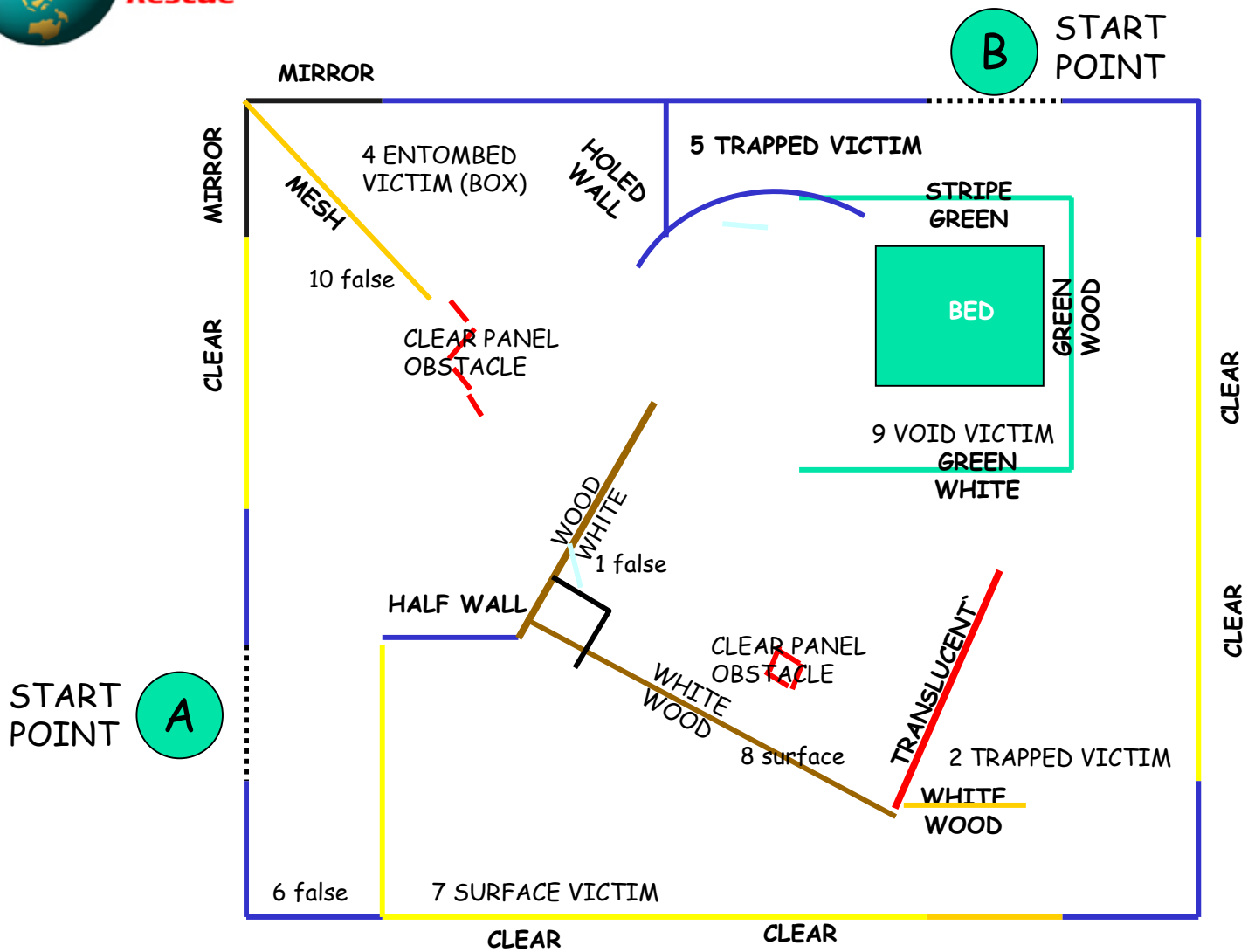
FORM +/- 1 PTS
MOTION +/- 1 PTS
HEAT +/- 3 PTS
SOUND +/- 2 PTS
CO2 +/- 3 PTS

STATE + 5 PTS
(need 3 correctly interpreted)

ENCOURAGES
ADVANCED MOBILITY

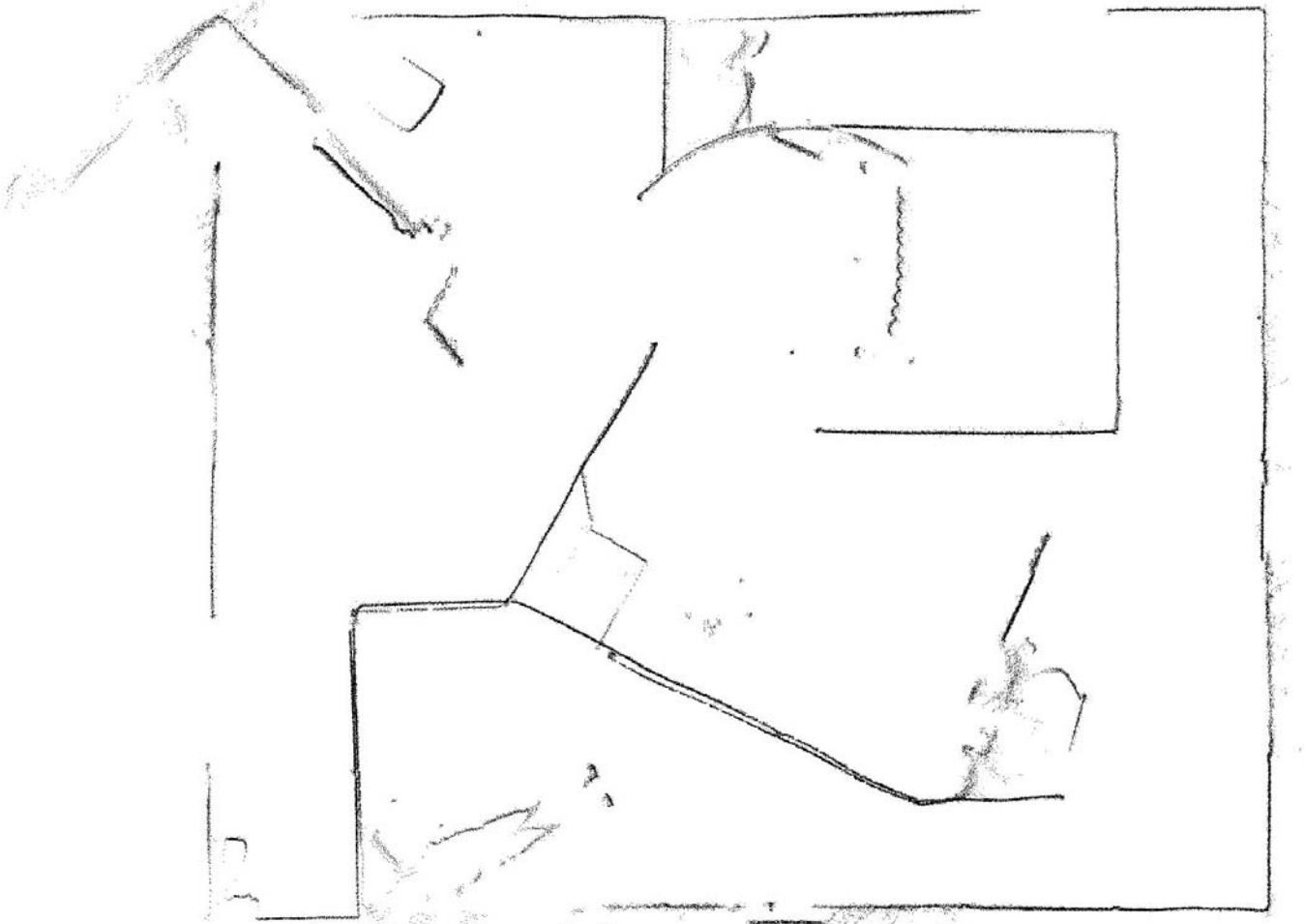
ENCOURAGES
SENSOR FUSION

EFFECTIVE 2-D MAPPING (Set-up Plan)



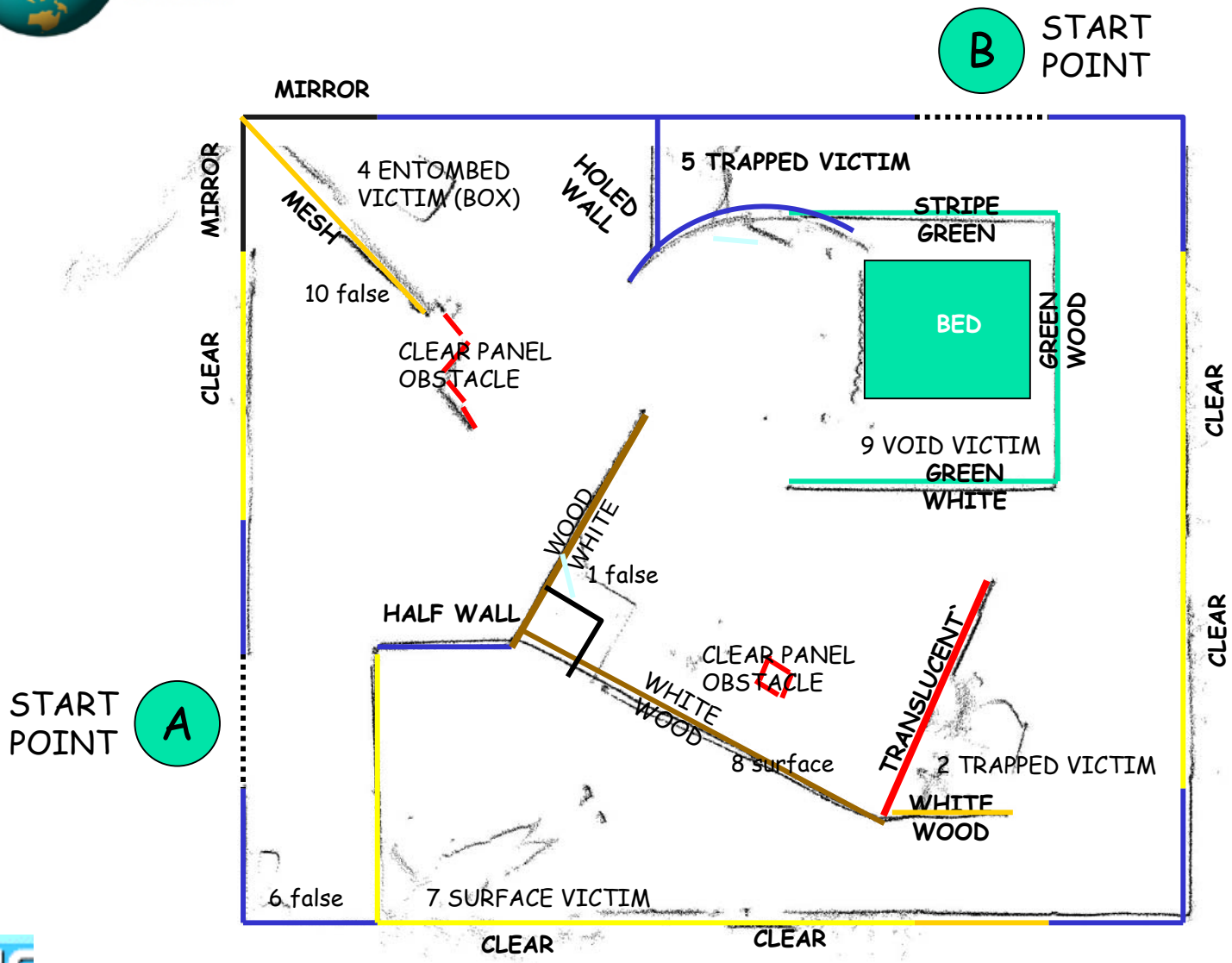
EFFECTIVE 2-D MAPPING (LADAR Map)

EXTREMELY GOOD AUTOMATIC MAPPING OF WALLS AND FEATURES, ADD VICTIM POSITIONS FOR MAXIMUM POSSIBLE SCORE



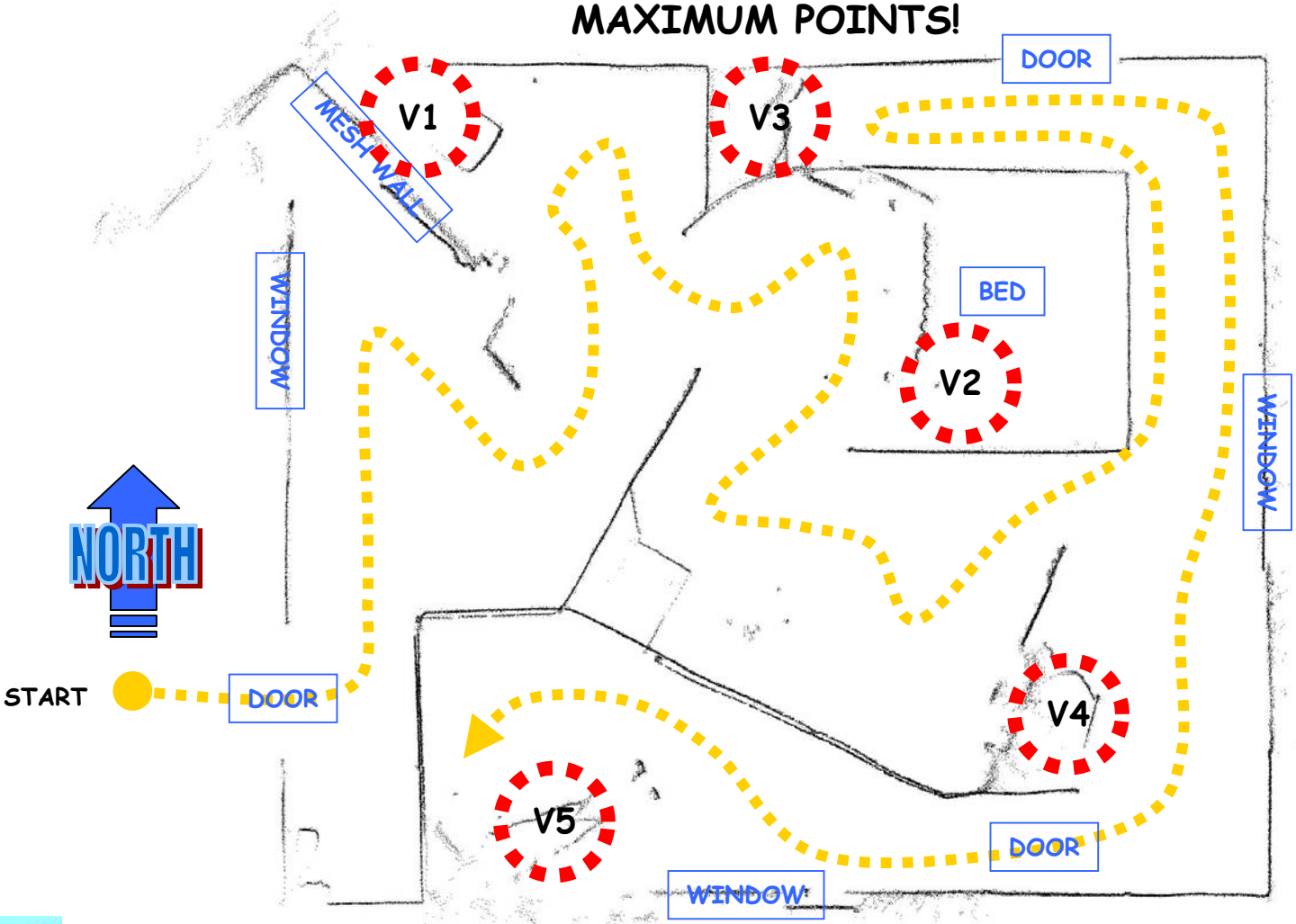
LADAR map generated by ActivMedia, Inc.
www.activmedia.com

EFFECTIVE 2-D MAPPING (Plan and Map)



EFFECTIVE 2-D MAPPING (Example)

MAP, AUTOMATICALLY GENERATED, WOULD SCORE MAXIMUM POINTS!



V1:
SITUATION: ENTOMBED
STATE: CONSCIOUS
TAG#: 4

V2:
SITUATION: VOID
STATE: SEMI-CONSCIOUS
TAG#: 9

V3:
SITUATION: TRAPPED
STATE: CONSCIOUS
TAG#: 5

V4:
SITUATION: TRAPPED
STATE: UNCONSCIOUS
TAG#: 2

V5:
SITUATION: SURFACE
STATE: UNCONSCIOUS
TAG#: 7

LADAR map generated by ActivMedia, Inc.
www.activmedia.com

RoboCup Rescue VICTIM INFO

TEAM | RD/MSN | TOTAL

TAG (+/- 10 of 50 pts per victim)

❑ YELLOW ❑ ORANGE ❑ RED

V - TAG# [+10] [-10]

SCORE

MAPPING (+20 of 50 pts per victim)

❑	LADAR	MAP QUALITY
❑	SONAR	[+1][+5][+10]
❑	DRECKON	LOCATION
❑	TELEOP	[+1][+5][+10]
❑	OTHER	

SCORE

STATE (+15/-5 of 50 pts per victim)

	SENSOR	INDICATOR		
❑	FORM	_____	[+1]	[-1]
❑	MOTION	_____	[+1]	[-1]
❑	HEAT	_____	[+3]	[-3]
❑	SOUND	_____	[+2]	[-2]
❑	CO_2	_____	[+3]	[-3]

IF YOU HAVE (3) OF THE ABOVE INDIACTORS CHOOSE:

VICTIM STATE:

❑	AWARE:	*WAVING, YELLING*	[+5]
❑	SEMI:	*TWITCHING, MOANING*	[+5]
❑	UNCONCIOUS:	*NO MOTION, BEACON*	[+5]
❑	UNKNOWN		[0]

SCORE

SITUATION (+/-5 of 50 pts per victim)

	SIUATION	INDICATOR	(CIRCLE ONE)
❑	SURFACE (*Entirely visible*)		[+5]
	FULL BODY UPPERBODY LEGS ARM BABY		[+5]
❑	TRAPPED (*Partially visible under rubble*)		
	FULL BODY UPPERBODY LEGS ARM BABY		[+5]
❑	VOID (*Minimally visible in void*)		
	FULL BODY UPPERBODY LEGS ARM BABY		[+5]
❑	ENTOMBED (*Visible only with probing*)		
	FULL BODY UPPERBODY LEGS ARM BABY		[0]
❑	UNKNOWN		

SCORE

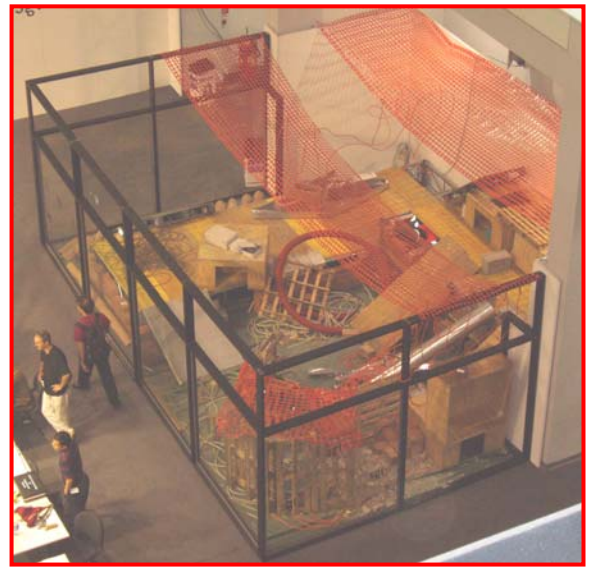
RoboCup – Padua, Italy (July 2003)

ROBOCUP2003 ARENAS (ITALY)

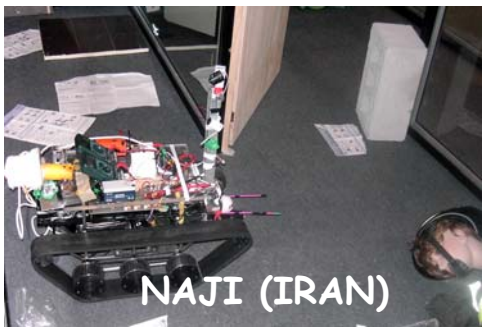
YELLOW ARENA

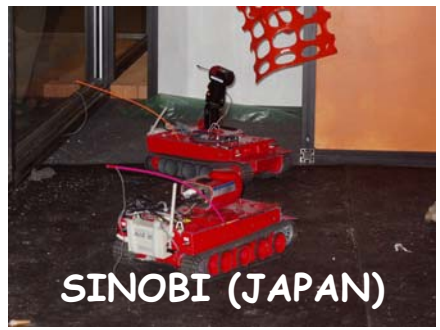
ORANGE ARENA

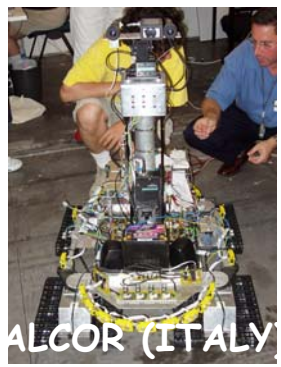
RED ARENA



ROBOCUP2003 ROBOTS (ITALY)







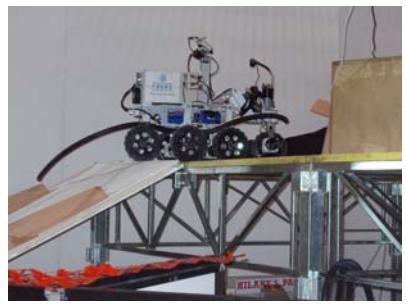
ROBOCUP2003 INSPIRING IMPLEMENTATIONS

ROBRNO (Czech Republic)

- Simple, Robust Design
- Heads-Up Display w/Tracking
- Great Situational Awareness
- Dexterous Control

CEDRA (Iran)

- Custom Mobility Platform
- Articulated Body Design



IUB (Germany)

- Visual, Audio, and FLIR for Victim Detection
- LADAR and Sonar Mapping

IJCAI/AAAI – Acapulco, Mexico (August 2003)

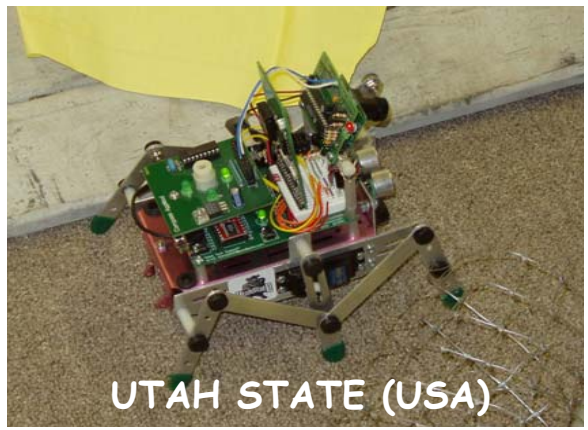
IJCAI/AAAI2003 ARENAS (MEXICO)

YELLOW ARENA

ORANGE ARENA

RED ARENA

IJCAI/AAAI2003 ROBOTS (MEXICO)



IJCAI/AAAI2003 INSPIRING IMPLEMENTATIONS

INEEL (Idaho, USA)

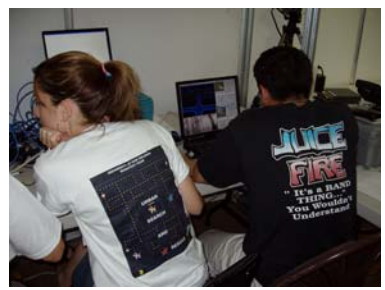
- Adjustable Autonomy
- Sensor/Vehicle Status-Laden User Interface
- Visual and Thermal for Victim Detection
- LADAR and Sonar Mapping/Navigation

Swarthmore (Pennsylvania, USA)

- Web-Based Victim ID Display
- Sonar Mapping

New Orleans (Louisiana, USA)

- UnReal Game Engine-Based World Modeling
- Collaborative Mapping

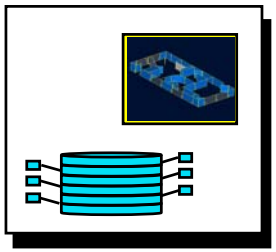


2003 COMPETITION STATISTICS

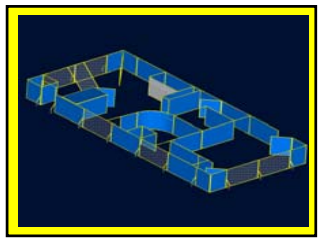
2003 Statistics	No. of Missions	High Score	Average Score	Operators (Avg.)	Resets (Avg.)	Victims Found (Avg.)			Penalties (Avg.)			Missions > 0 (%)
						Yellow	Orange	Red	Yellow	Orange	Red	
RoboCupRescue (Padua, Italy, July 2003)												
Team A	7	23.8	15.1	1.0	0.0	1.1	3.0	1.3	0.4	0.3	0.3	100%
Team B	7	12.5	7.6	1.0	0.0	1.3	2.1	1.1	0.4	0.0	0.1	100%
Team C	7	7.3	3.0	1.0	0.0	2.1	1.1	0.0	1.4	0.9	0.0	86%
Team D	7	5.9	2.4	1.0	0.1	1.0	0.3	0.0	0.1	0.0	0.0	71%
Team E	5	13.2	5.0	1.6	0.6	3.6	2.7	0.0	0.8	1.2	0.0	80%
Team F	5	5.6	2.1	1.0	0.4	0.6	1.7	0.0	0.0	0.2	0.0	40%
Team G	3	1.8	0.7	1.3	0.7	1.7	0.0	0.0	1.0	0.0	0.0	67%
Team H	3	1.5	0.5	1.0	0.7	0.7	0.0	0.0	0.7	0.0	0.0	67%
Team I	3	0.8	0.3	1.0	0.0	0.7	0.0	0.0	1.3	0.0	0.0	67%
Team J	3	0.0	0.0	1.0	0.3	0.0	0.0	0.0	1.0	0.0	0.0	0%
Team K	3	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
Team L	3	Technical Difficulties - Did not compete										----------
SITE AVGS.	**4.8**	**6.6**	**3.3**	**1.2**	**0.3**	**1.2**	**1.0**	**0.2**	**0.7**	**0.2**	**0.0**	**61.6%**
IJCAI/AAAI (Acapulco, Mexico, August 2003)												
Team M	5	27.6	9.2	1.0	0.0	1.8	1.6	0.0	1.0	2.6	0.0	100%
Team N	5	12.5	6.1	1.0	0.2	2.4	0.0	0.0	0.4	0.0	0.0	60%
Team O	5	2.9	1.6	2.4	0.0	2.2	0.4	0.0	0.0	0.0	0.0	100%
Team P	5	4.0	1.5	1.2	0.2	1.8	0.0	0.0	2.6	0.0	0.0	40%
Team Q	3	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.3	0.0	0.0	0%
Team R	3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0%
SITE AVGS.	**4.3**	**7.8**	**3.1**	**0.9**	**0.5**	**1.4**	**0.3**	**0.0**	**0.7**	**0.4**	**0.0**	**50.0%**

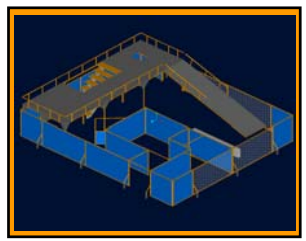
SPECTRUM OF TEST ARENAS

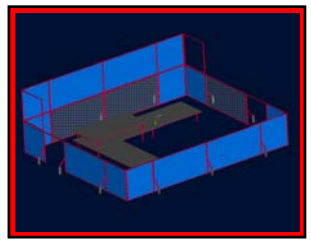
ACTIVE ARENAS



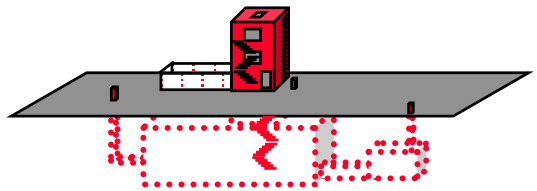
"VIRTUAL"





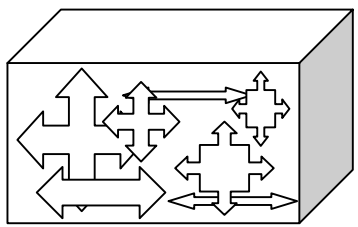


"USAR"



"REALITY"

VIRTUAL — INDOOR — OUTDOOR

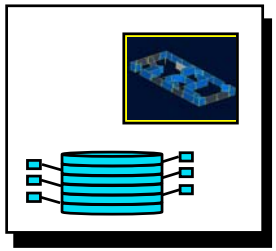


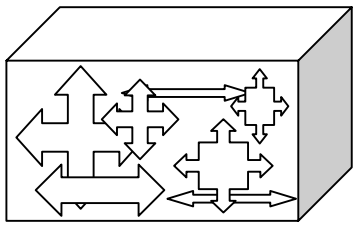
"CONFINED SPACE MANEUVER"

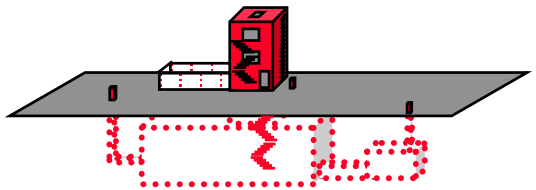
"SCOUT"

PROPOSED ARENAS

SPECTRUM TEST ARENAS

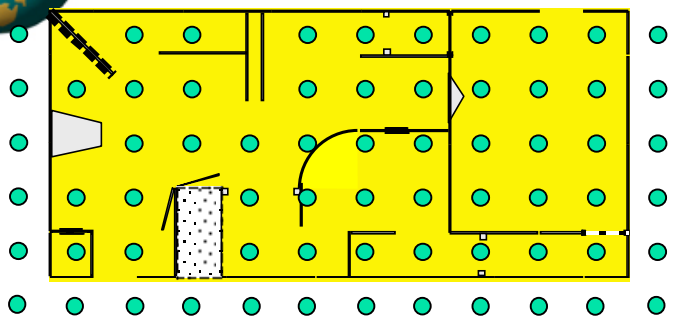


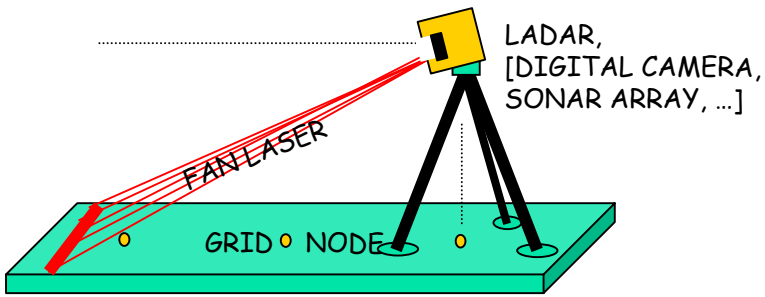


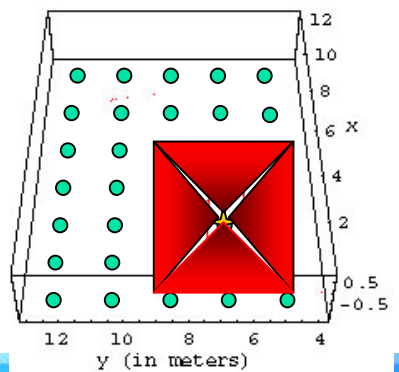


- **Virtual Arena**
  - Captured sensor data with ground truth (and noise)
  - Simulated environment for robot software testing
  - Faster algorithm development (hardware independent)
  - Test successful algorithms in actual arena
- **Confined Space Maneuver Arena**
  - Test shape shifting robotic implementations
  - Evaluate situational awareness, improved access, shoring
  - Environment Negotiation = Navigation + Influence
- **Reality Arena**
  - Realistic, safe, controlled and repeatable
  - Above and below ground barrier penetrations
  - Indoor situational awareness, communications dropouts
- **Scout Arena**
  - Outdoor sensory obstacles (ditches, tall grass, water,…)
  - Test transition recognition (i.e. woods to clearing)
  - For lightweight UGVs (< 500 lbs)

VIRTUAL ARENA I – SENSOR DATA SETS







GOAL:

Enable research into robotic perception, navigation, mapping, and planning *without robot hardware*

FOCUS:

Provide a variety of real sensor data sets captured from known points within the actual arena (ground truth data with noise)

BENEFITS:

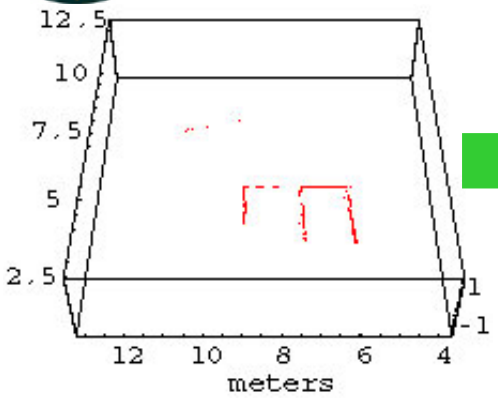
- Promote robust sensor fusion algorithms
- Allow quick iterations toward solution
- Test successful algorithms in actual arenas, on actual robots

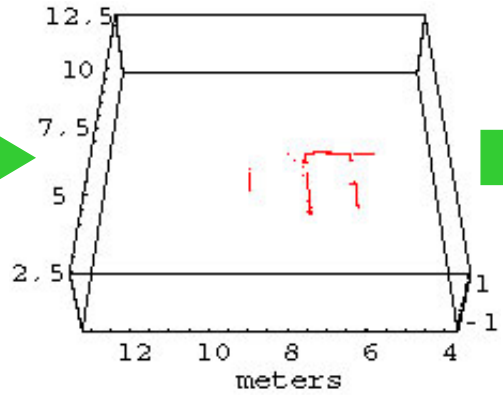
VIRTUAL ARENA I – SENSOR DATA SETS

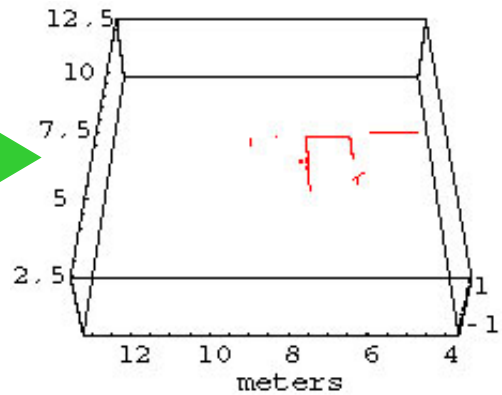
REFLECTION ARTIFACTS

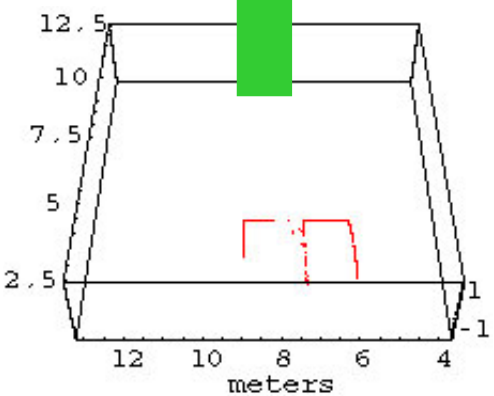
LASER RANGE IMAGING DATA OVERLAID ON PHOTOGRAPH

VIRTUAL ARENA I – SENSOR DATA SETS

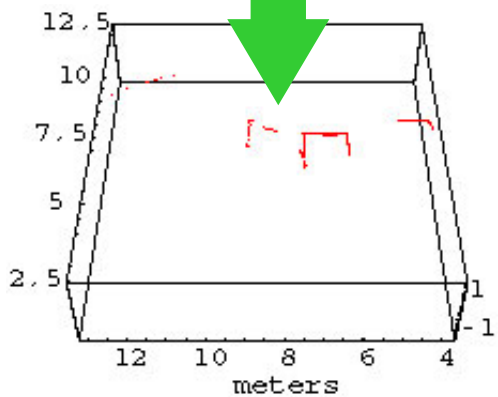








LASER RANGE
IMAGING DATASETS
Moving down a hallway



START

END

VIRTUAL ARENA II – SIMULATED ENVIRON.

Developed by
University of Pittsburgh
and
Carnegie Mellon University

GOAL:

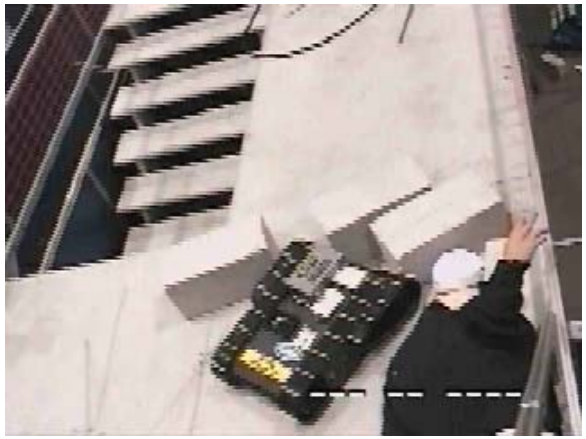
Enable research into robotic perception, navigation, mapping, and planning without robot hardware

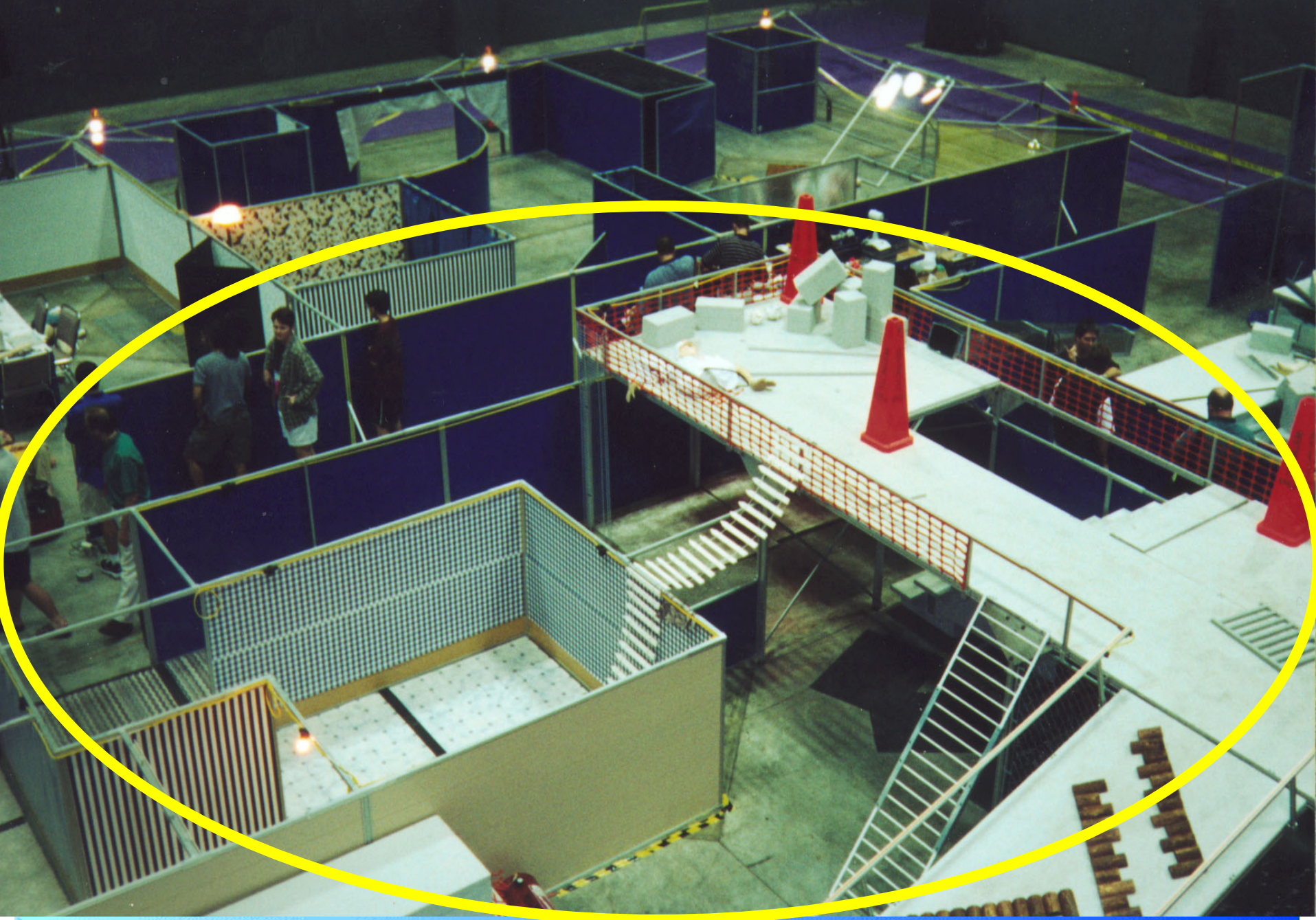
FOCUS:

Provide arena simulation that allows users to model their robots, sensor types and sensor positions based on UnReal Game Engine

BENEFITS:

- Supports greater diversity in robot design and sensor placement
- Allow quick iterations toward solution
- Test successful algorithms in actual arenas, on actual robots
- Photo-realistic representation of the NIST Orange Arena
- Physics are modeled (e.g. gravity, collisions)






DM-USAR_orange.RemoteBot (800)
DM-USAR_orange.Remote
DM-USAR_orange.RemoteBot (8

FUTURE DIRECTIONS & DISCUSSIONS

Arena Features

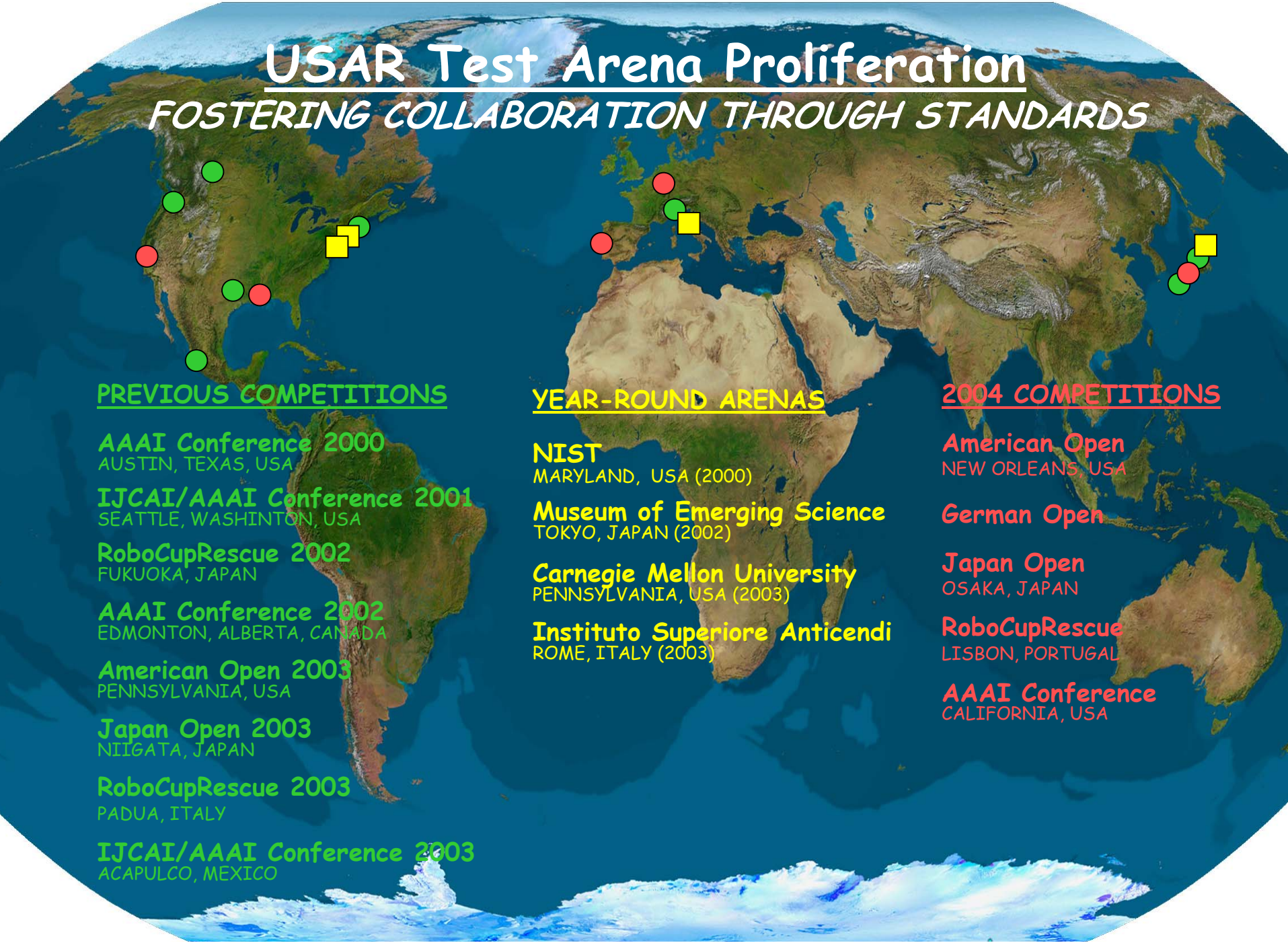
- Add sensory features: target signatures (chemical, EOD), stairs
- Add physical features: confined space obstacles
- Maintain arenas as stepping stone from research to deployment

Objective Evaluations

- HRI and robot video captured for analysis (RoboCup and AAAI)
- New **robot tracking system** (ultra wideband system) being installed

USAR Test Arena Proliferation

FOSTERING COLLABORATION THROUGH STANDARDS



PREVIOUS COMPETITIONS

AAAI Conference 2000
AUSTIN, TEXAS, USA

IJCAI/AAAI Conference 2001
SEATTLE, WASHINTON, USA

RoboCupRescue 2002
FUKUOKA, JAPAN

AAAI Conference 2002
EDMONTON, ALBERTA, CANADA

American Open 2003
PENNSYLVANIA, USA

Japan Open 2003
NIIGATA, JAPAN

RoboCupRescue 2003
PADUA, ITALY

IJCAI/AAAI Conference 2003
ACAPULCO, MEXICO

YEAR-ROUND ARENAS

NIST
MARYLAND, USA (2000)

Museum of Emerging Science
TOKYO, JAPAN (2002)

Carnegie Mellon University
PENNSYLVANIA, USA (2003)

Instituto Superiore Anticendi
ROME, ITALY (2003)

2004 COMPETITIONS

American Open
NEW ORLEANS, USA

German Open

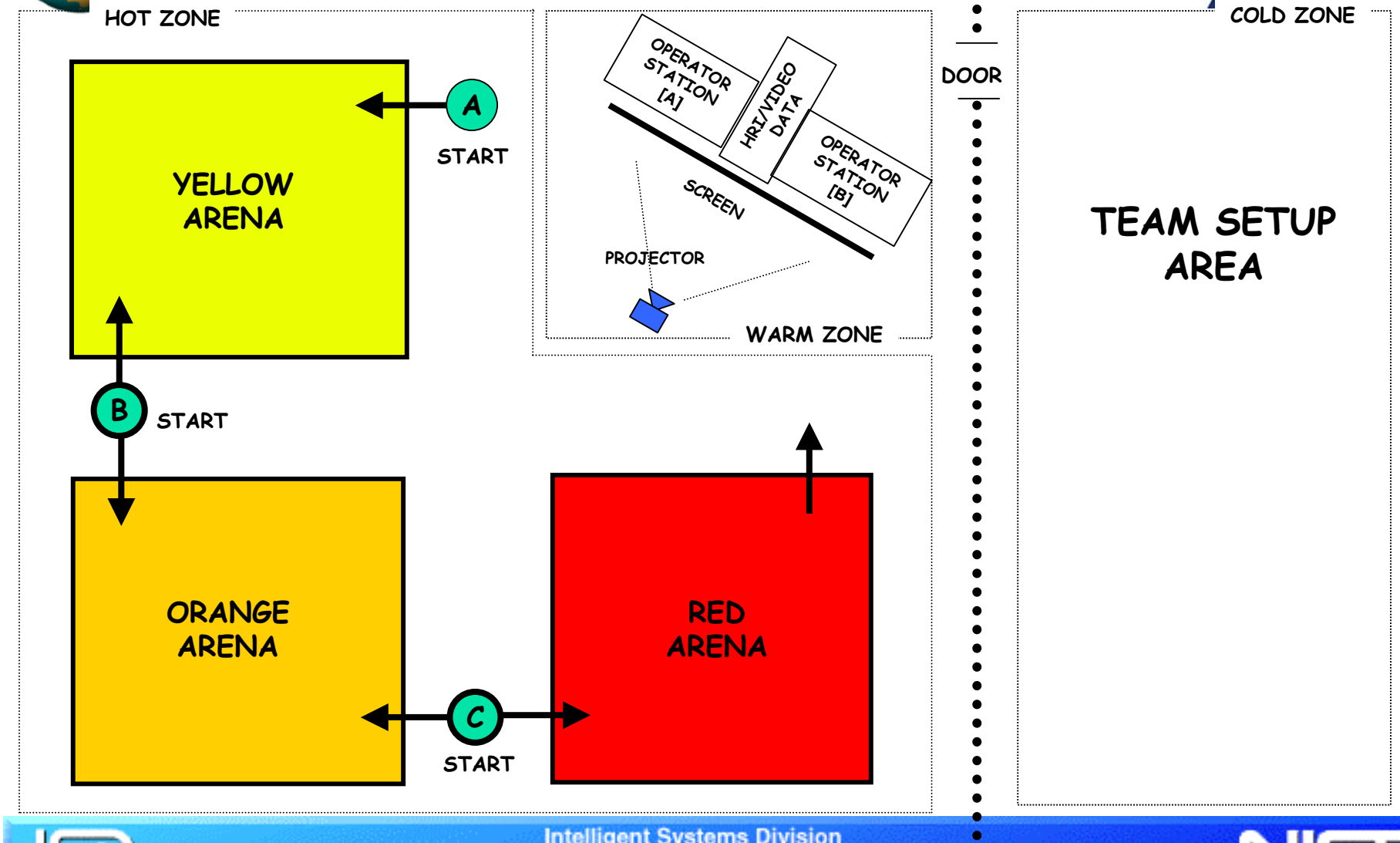
Japan Open
OSAKA, JAPAN

RoboCupRescue
LISBON, PORTUGAL

AAAI Conference
CALIFORNIA, USA

ADDITIONAL SLIDES

ARENA LAYOUT and START POINTS



PERFORMANCE METRIC FOR USAR ROBOTS

Encourage desirable robot capabilities

Discourage unhelpful team strategies

Award points per victim found (50 possible)...

- **(20) points for Mapping**
- **(15) points for Sensing**
- **(15) points for Mobility**

Subtract penalties per event...

- **(-5,-20) points for Arena penalties**
- **(-5,-20) points for Victim penalties**

Divide by number of operators required...

- **$(1 + \text{Operators})^2$ [always > 0, exponential deterrent]**

Multiply by weightings to account for arena difficulty...

- **(1.00) Red Arena, (0.75) Orange Arena, (0.50) Yellow Arena**

MISSION START POINTS

To similarly test mapping and planning capabilities, while allowing robots better access to their intended arenas, each round of competition will proceed as follows:

- **First mission of every round:** Teams must begin at START POINT [A] and must negotiate the Yellow arena.
- **Middle mission of every round (if any):** Teams must begin at START POINT [B], between the Yellow and Orange arenas. Teams may enter either arena.
- **Last mission of every round:** Teams may choose their start point, START POINT [A], [B], or [C], but may not repeat their previous start point.

NOTE: After starting, all teams must follow the rule of Advancing & Retreating (next page).

ADVANCING and RETREATING

To promote collaboration between robots, and deter parallel teleoperation in separate arenas, the following rules apply:

Advancing to more difficult arenas:

- Robots are always free to advance to the next most difficult arena, but they must earn it by leaving the simpler arena through the door on the far side of the arena from their start point.
- Robots may always advance without the entire team of robots

Retreating to simpler arenas:

- Robots are always free to retreat to a simpler arena already negotiated during the current mission
- Retreating to a simpler arena not successfully negotiated during the current mission must be done as a team (all robots gather at the mission start point before entering the simpler arena). Teams may need to use "RESETs" if necessary to retrieve robots stuck in the more difficult arena. Once retreating, robots may retreat as far as they can without the entire team of robots.

PERFORMANCE METRIC – USED IN 2002

RescueRobotScore =

(VictimsPoints (NumberOfRobots / (1+ NumberOfOperators)^3) AverageAccuracy

VictimsPoints = **(YellowVictimsFound - YellowPenalties) * (*YellowVictimWeighting*)**
+ (OrangeVictimsFound - OrangePenalties) * (*OrangeVictimWeight)*
+ (RedVictimsFound - RedPenalties) * (*RedVictimWeighting*)

[*YellowVictimWeighting* = *0.50*]
[*OrangeVictimWeighting* = *0.75*]
[*RedVictimWeighting* = *1.00*]

NumberOfRobots = *Number of robots that find a unique victim*
NumberOfOperators = *Number of operators having touched the robot or are in the hot zone*
AverageAccuracy = *(positional accuracy + map quality) / Total victims found*

PERFORMANCE METRIC FOR USAR ROBOTS

50 POINTS POSSIBLE PER VICTIM FOUND

PENALTIES PER EVENT

$$\text{ARENA WEIGHTING} \left(\frac{\text{MAP QUALITY} + \text{VICTIM LOCATION} + \text{VICTIM TAG} + \text{VICTIM SITUATION} + \text{VICTIM STATE} - \text{ARENA BUMPING} - \text{VICTIM BUMPING}}{\left[1 + \text{NUMBER OF OPERATORS} \right]^2} \right)$$

ARENA WEIGHTING	MAP QUALITY	VICTIM LOCATION	VICTIM TAG	VICTIM SITUATION	VICTIM STATE	ARENA BUMPING	VICTIM BUMPING
1.00/0.75/0.50	10 PTS 5 PTS 1 PTS	10 PTS 5 PTS 1 PTS	+ 10 PTS - 10 PTS	+ 5 PTS	+ 15 PTS - 10 PTS	-20 PTS -5 PTS	-20 PTS -5 PTS

ENCOURAGES ADVANCED MOBILITY

ENCOURAGES SENSOR FUSION

FORM	+/- 1 PTS
MOTION	+/- 1 PTS
HEAT	+/- 3 PTS
SOUND	+/- 2 PTS
CO2	+/- 3 PTS
STATE	+ 5 PTS

(need 3 correctly interpreted)

RoboCup – Fukuoka, Japan (July 2002)

ROBOCUP2002 ARENAS (JAPAN)

YELLOW ARENA

ORANGE ARENA

RED ARENA