Cooperative Robotics at Jacobs University:

Mapping and Navigation

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htttp://robotics.jacobs-university.de

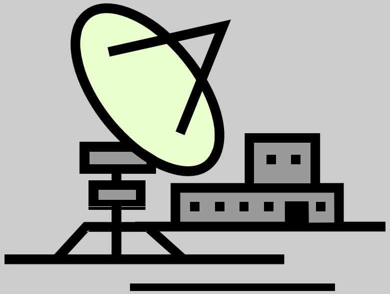
Institutional Name Change

Please note the name-change of our institution.

The Swiss Jacobs Foundation invests 200 Million Euro in ***International University Bremen (IUB)***. To date this is the largest donation ever given in Europe by a private foundation to a science institution. In appreciation of the benefactors and to further promote the university's unique profile in higher education and research, the boards of IUB have decided to change the university's name to ***Jacobs University Bremen***.

Overview

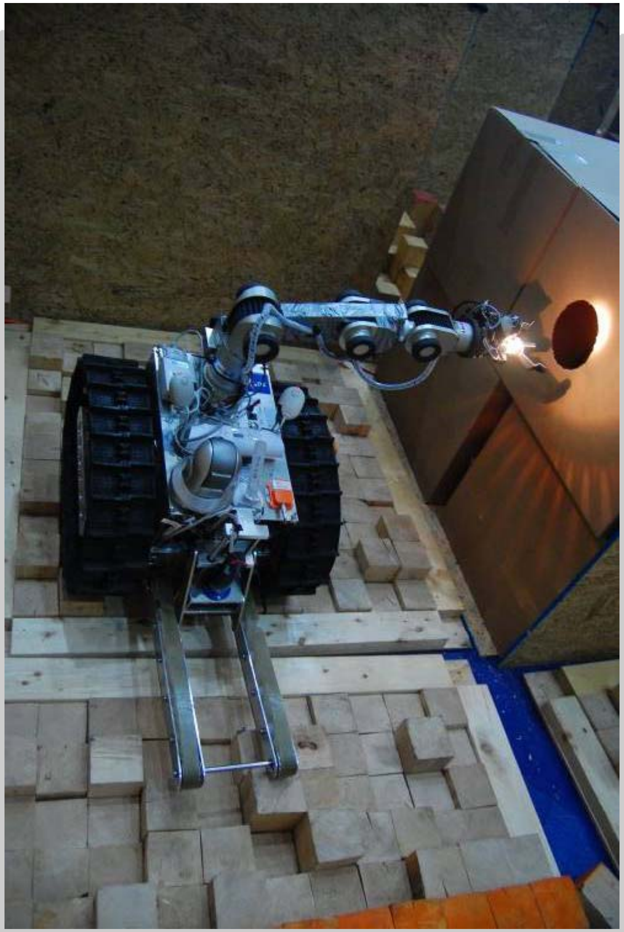
- Facilities and hardware at Jacobs
- Rescue robotics for real robots
- Current research in the group with mapping
  - Sensor Modeling
  - 3D Mapping using Planar Feature Extraction
- Multiple robot research (virtual robots)
  - Mapping and frontier exploration
  - Exploration under wireless networking constraints
  - Map merging from multiple robots
  - Beginning transfer to physical robots

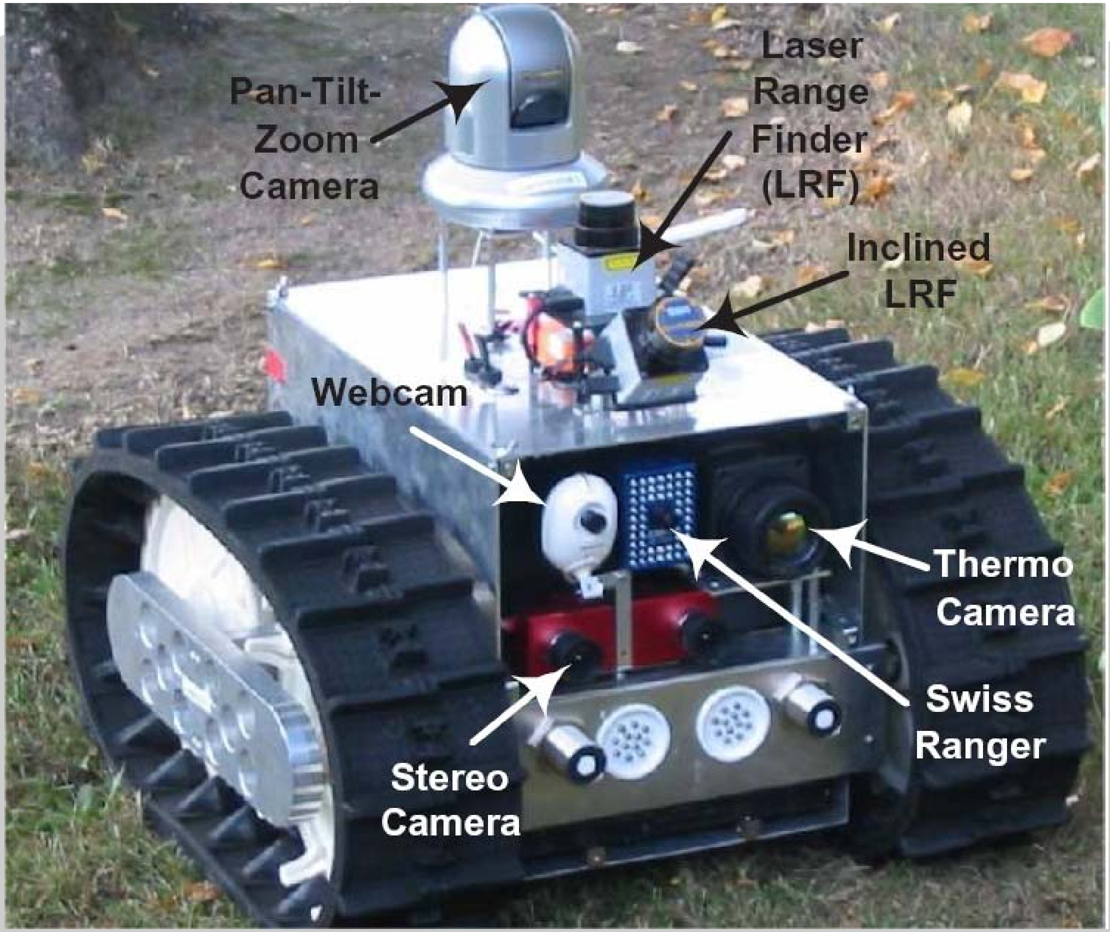


Facilities and Available Hardware at Jacobs University

Facilities and Hardware

Main Platform

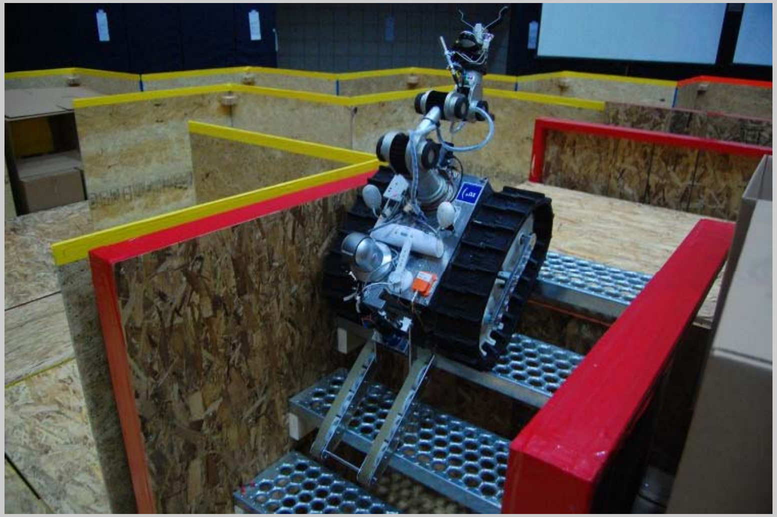




The ***Rugbot*** Search and Rescue Platform

Facilities and Hardware
Testing Facilities

- Arena based on the specs of N.I.S.T.,USA.
- Similar to the arena used in *Robocup* rescue league



Real Robot League in Robocup Rescue

Teleoperation and Autonomy

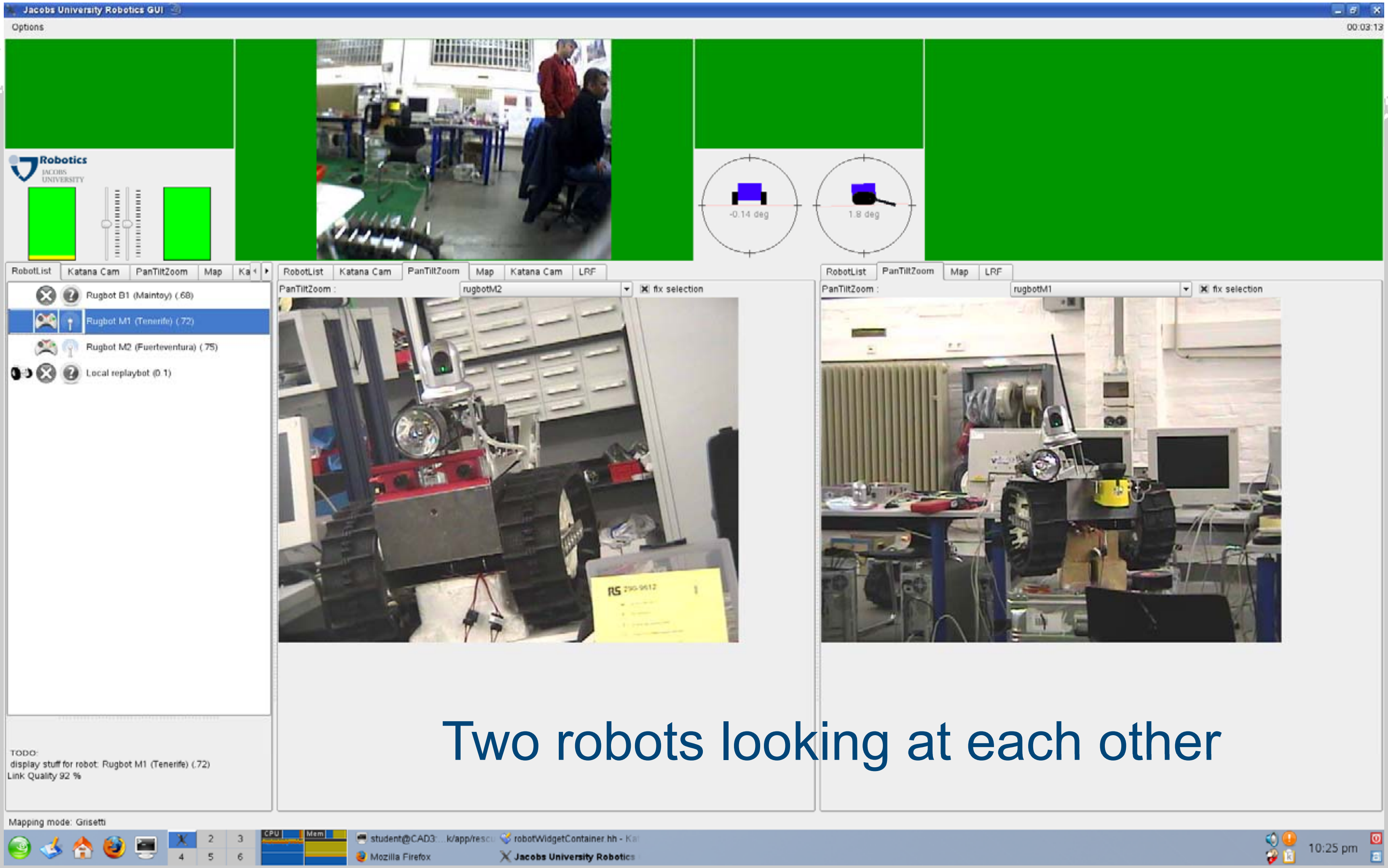
The IUB Rescue Robot Team
RoboCup German Open 2007 at Hannover Fair

Multi-robot Systems

“*In theory, there is no difference between theory and practice ... but in practice, there is* !” (Prof. Pedro Lima’s email footer)

There is a large gap between virtual (simulation based) capabilities and the those implemented and demonstrated on real (physical) robots.

Multi-robot Systems:
Real robots



Rugbot B1 (Maintoy) (.68)
Rugbot M1 (Tenerife) (.72)
Rugbot M2 (Fuerteventura) (.75)
Local replaybot (0.1)

PanTiltZoom : rugbotM2

PanTiltZoom : rugbotM1

TODO:
display stuff for robot: Rugbot M1 (Tenerife) (.72)
Link Quality 92 %

Mapping mode: Grisetti

student@CAD3:...k/app/rescu
robotWidgetContainer.hh - Ka
Mozilla Firefox
Jacobs University Robotics

Two robots looking at each other

Very recent– our new multi-robot capable GUI for real robots

Multi-robot systems
Cooperative Exploration (2D/Virtual)

Exploration requires data exchange
→ need for communication

- Typical approaches
  - assumption of perfect communication throughout the environment
  - or exchange data only when in communication range
- Communicative Exploration (CE)
  - multiple robots
  - population of possible moves
  - heuristic utility function to
    - maintain communication all the time
    - plus attraction to frontiers (frontier based exploration)

Martijn N. Rooker and Andreas Birk
Multi-robot exploration under the constraints of wireless networking
Control Engineering Practise, 15 (4), pp. 435-445
Elsevier Science, 2007

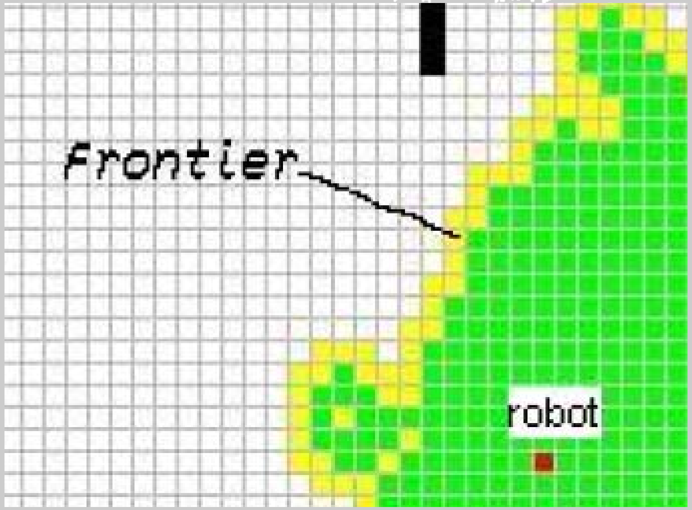
Martijn Rooker and Andreas Birk,
Combining Exploration and Ad-Hoc Networking in RoboCup Rescue
RoboCup 2004: Robot Soccer World Cup VIII, D. Nardi . M. Riedmiller and C. Sammut (Eds.), LNAI 3276, Springer, 2005

Martijn Rooker and Andreas Birk,
Communicative Exploration with Robot Packs
RoboCup 2005: Robot WorldCup IX, I. Noda, A. Jacoff, A. Bredenfeld, Y. Takahashi (Eds.) LNAI, Springer, 2006

Explanation of the Utility Function

n robots

- Each robot, at each step can stay in its grid cell, or move to any of the 8-neighboring cells.
- 9^n options. Randomly sample this space– k samples.

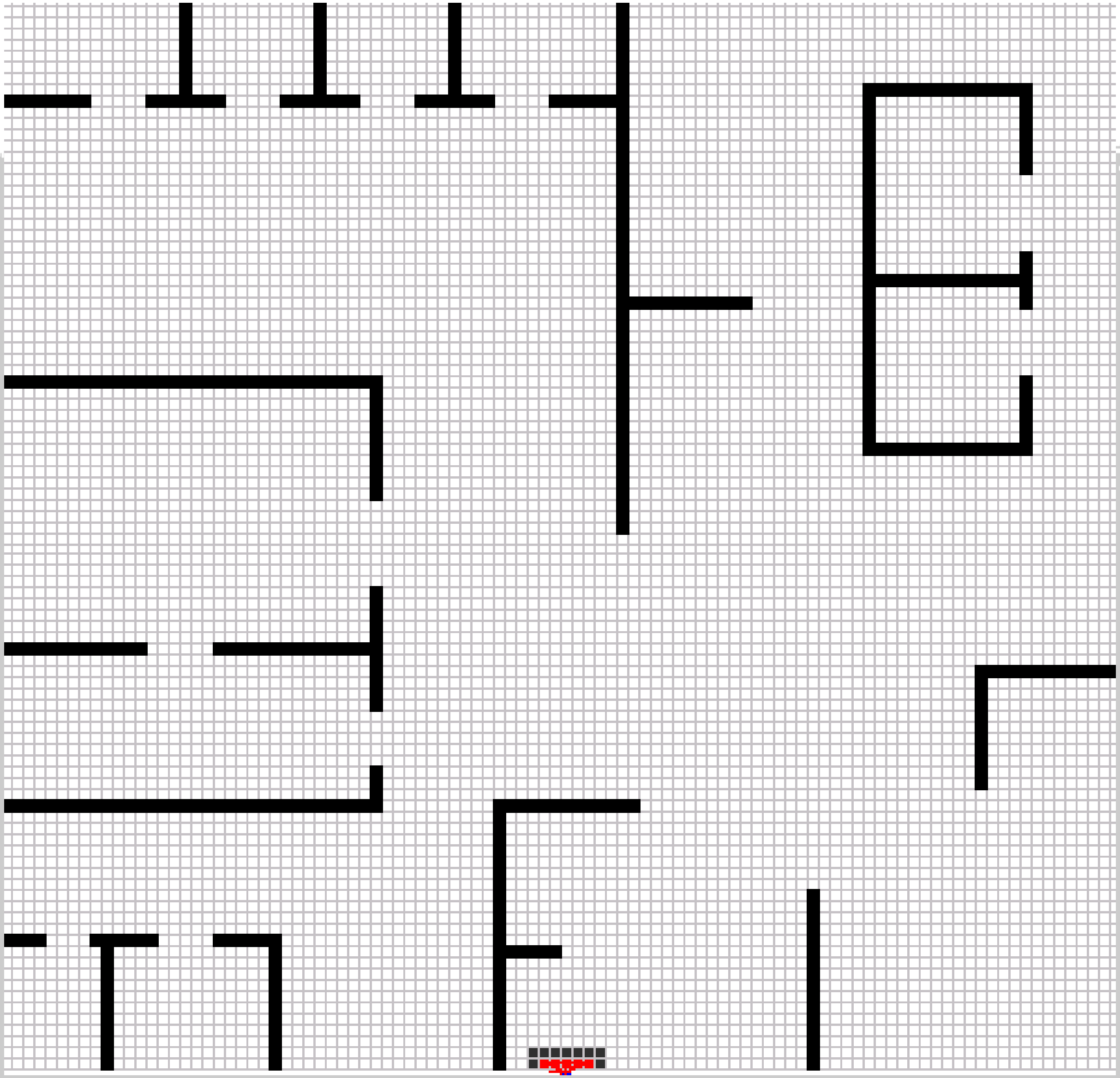


$$U_{CE}(P^i_{t+1}) = \begin{cases} -3 & \text{if impossible position} \\ -3 & \text{if loss of communication} \\ -md(P^i_{t+1}) & \text{otherwise} \end{cases}$$

$$U_{CE}(cfg\_c^i_t) = \sum_{j=1}^{n} U_{CE}(P^j_{t+1})$$

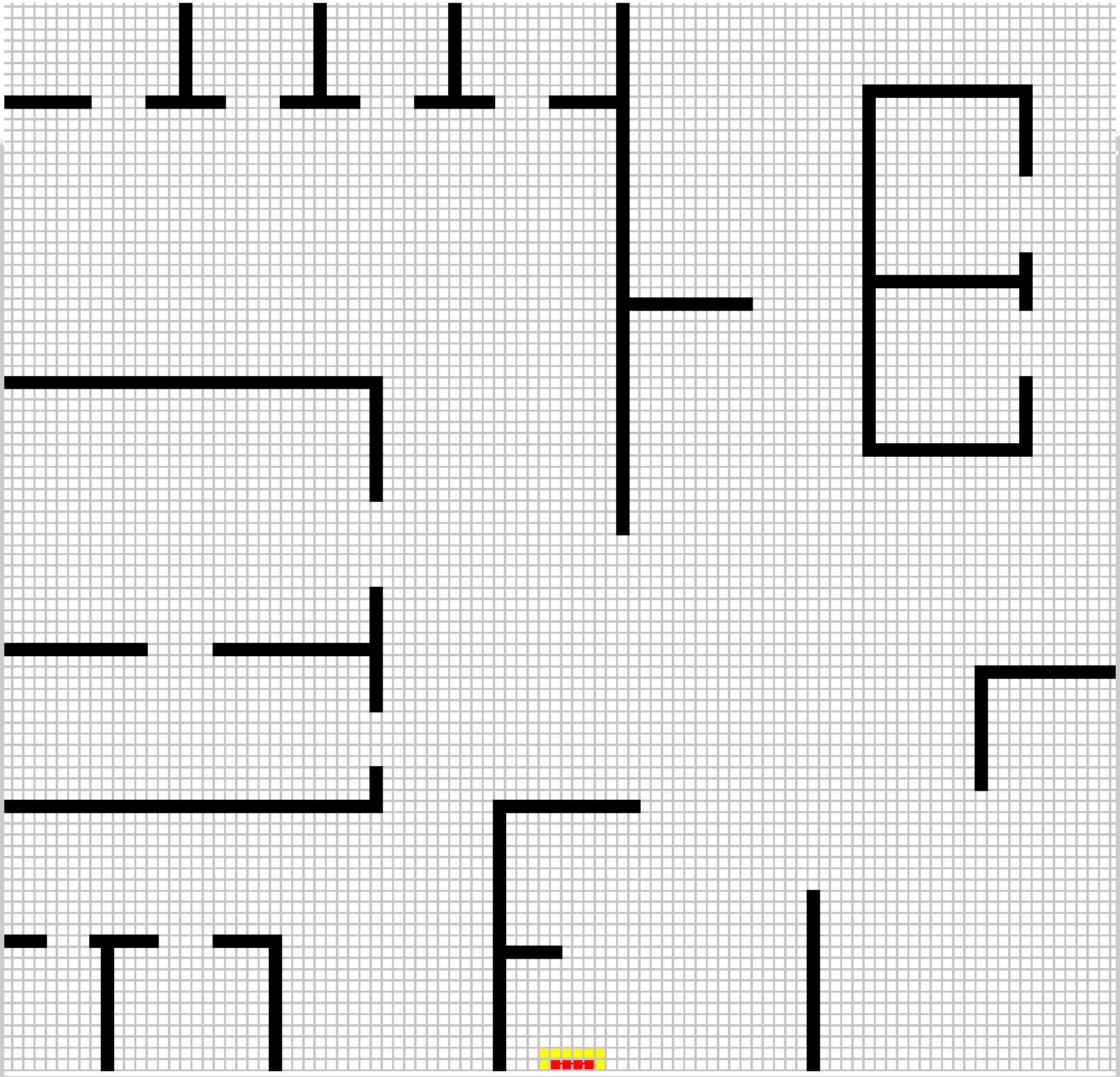
Change in Manhattan distance to the nearest frontier from the new position

Example with fixed base station



- Greedy population based
- optimization of simple heuristic
- penalties for comm. loss & collisions
- rewards for movements to frontier
- proper planning would be NP complete in every single step

Example with robot packs



- Additional role switches to escape local minima
- robots detect “being stuck”
- role switch to move to meeting point moving through **known space** but **without communication constraint**
- then continue exploration

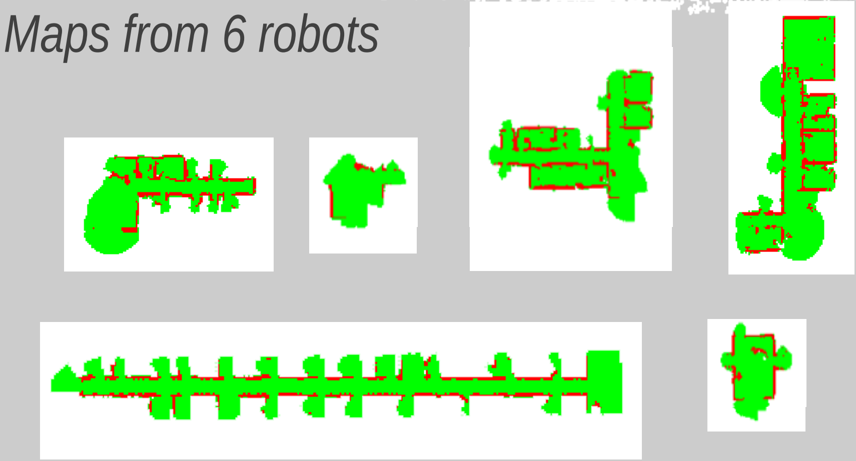
Map Merging

- Independent exploration followed by batch merging
- Online merging and exploration

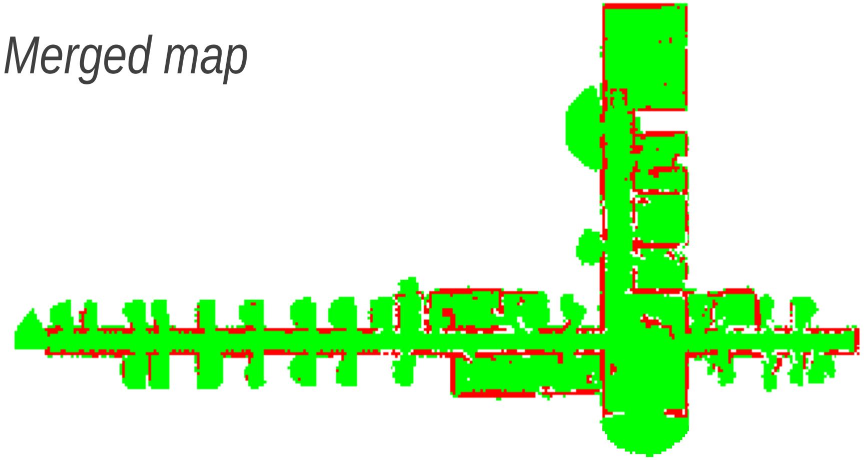
Decentralized Independent Mapping
Map Merging

- *n* robots build maps *independently*
- no global reference frame
- approach similar to image stitching
  - translate & rotate maps
  - measure similarity
  - try to "lock" identical regions

Maps from 6 robots



Merged map



Andreas Birk and Stefano Carpin
Merging occupancy grid maps from multiple robots
Proceedings of the IEEE, special issue on Multi-Robot Systems
94 (7), pp.1384-1397, IEEE Press, 2006

Stefano Carpin, Andreas Birk and Viktoras Jucikas
On Map Merging
Robotics and Autonomous Systems, 53 (1), pp. 1-14,
Elsevier Science, 2005

Map Merging Explained

Similarity Metric Ψ (Birk)

$$\psi(m_1, m_2) = \sum_{c \in \mathcal{C}} d(m_1, m_2, c) + d(m_2, m_1, c)$$

color (*free, occupied, ~~unknown~~*)

with

$$d(m_1, m_2, c) = \frac{\sum_{m_1[p_1]=c} \min\{md(p_1, p_2) | m_2[p_2] = c\}}{\#_c(m_1)}$$

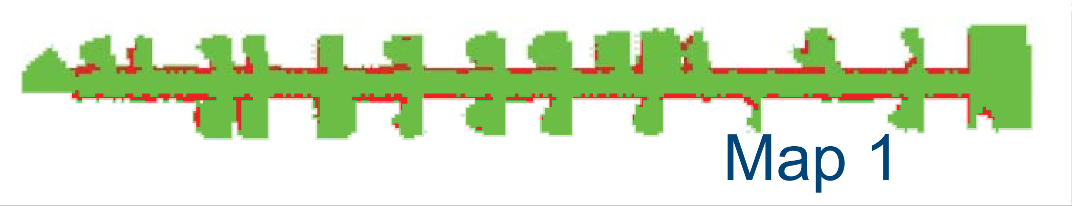
Ψ supplemented by locking function

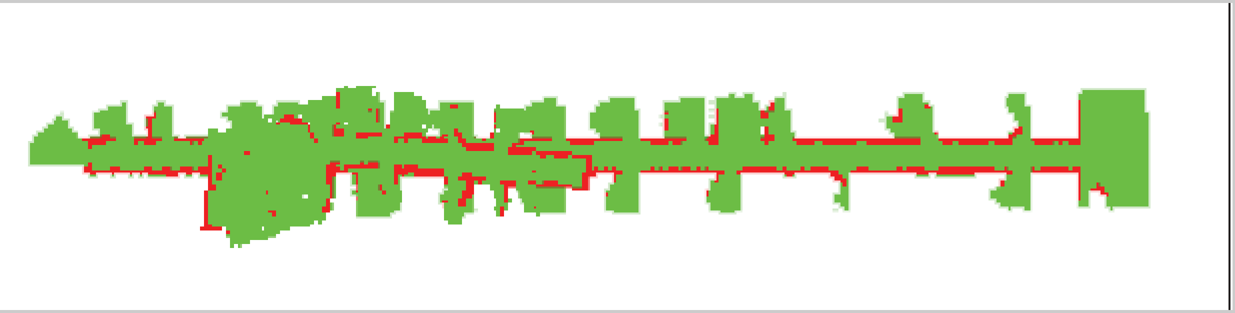
$$\begin{aligned}\Delta(m_1, m_2) \quad = \quad & \psi(m_1, m_2) + \\ & c_{lock} \cdot (dis(m_1, m_2) - agr(m_1, m_2))\end{aligned}$$

disagreement *agreement*

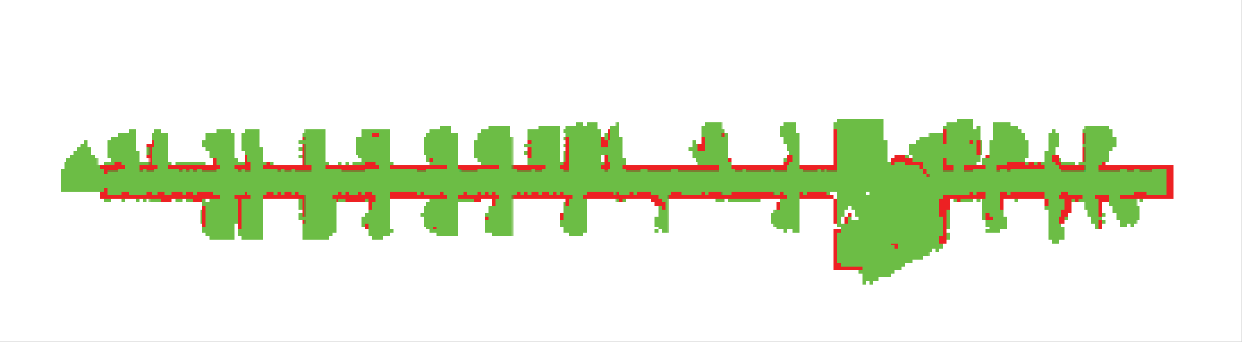
Samples in transformation-space (x, y, ɵ) generated by *adaptive random walk* (Carpin).

Example of map-merging





Over-fit by Ψ alone

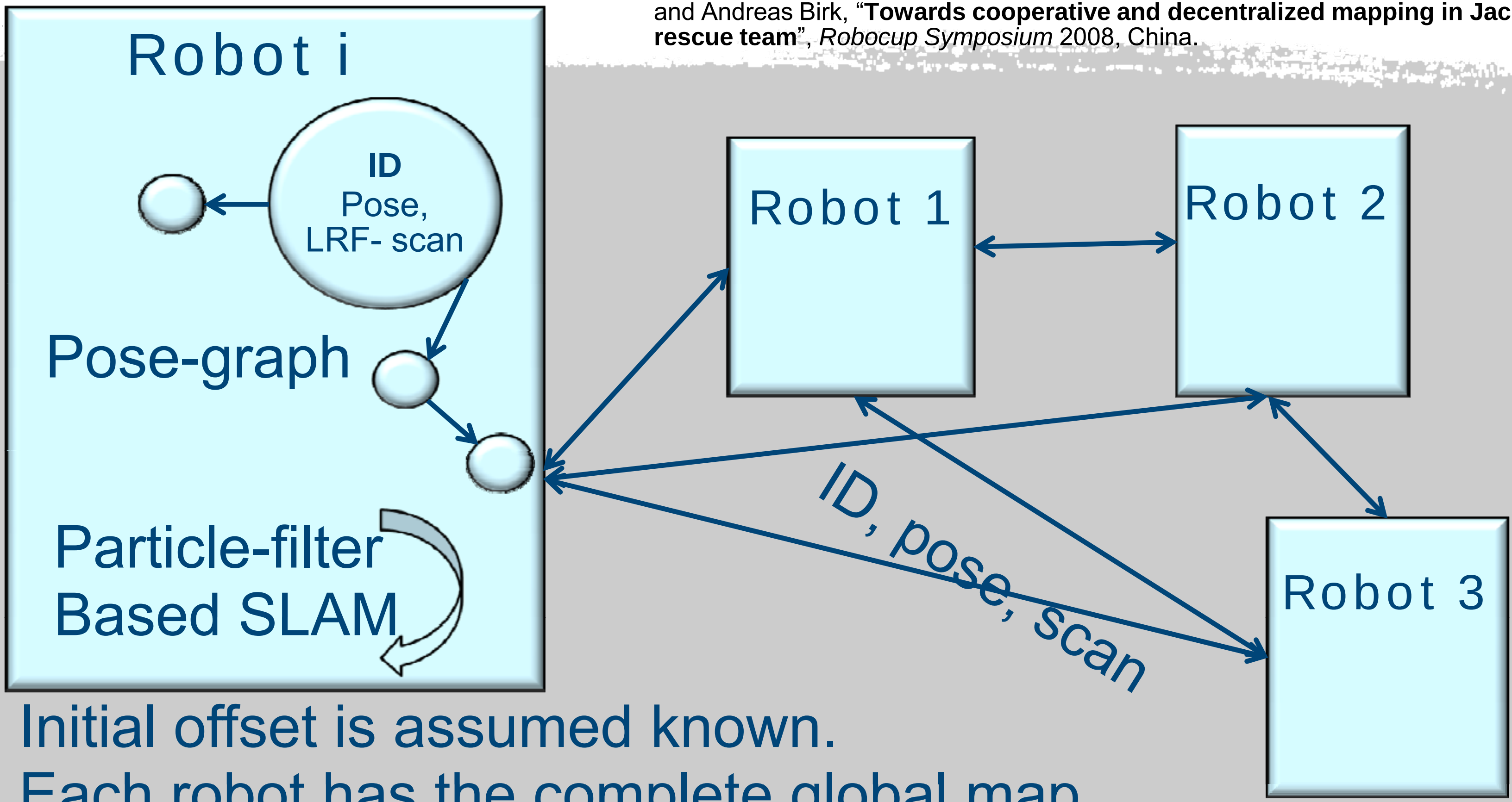


Ψ + locking term

Cooperative Mapping

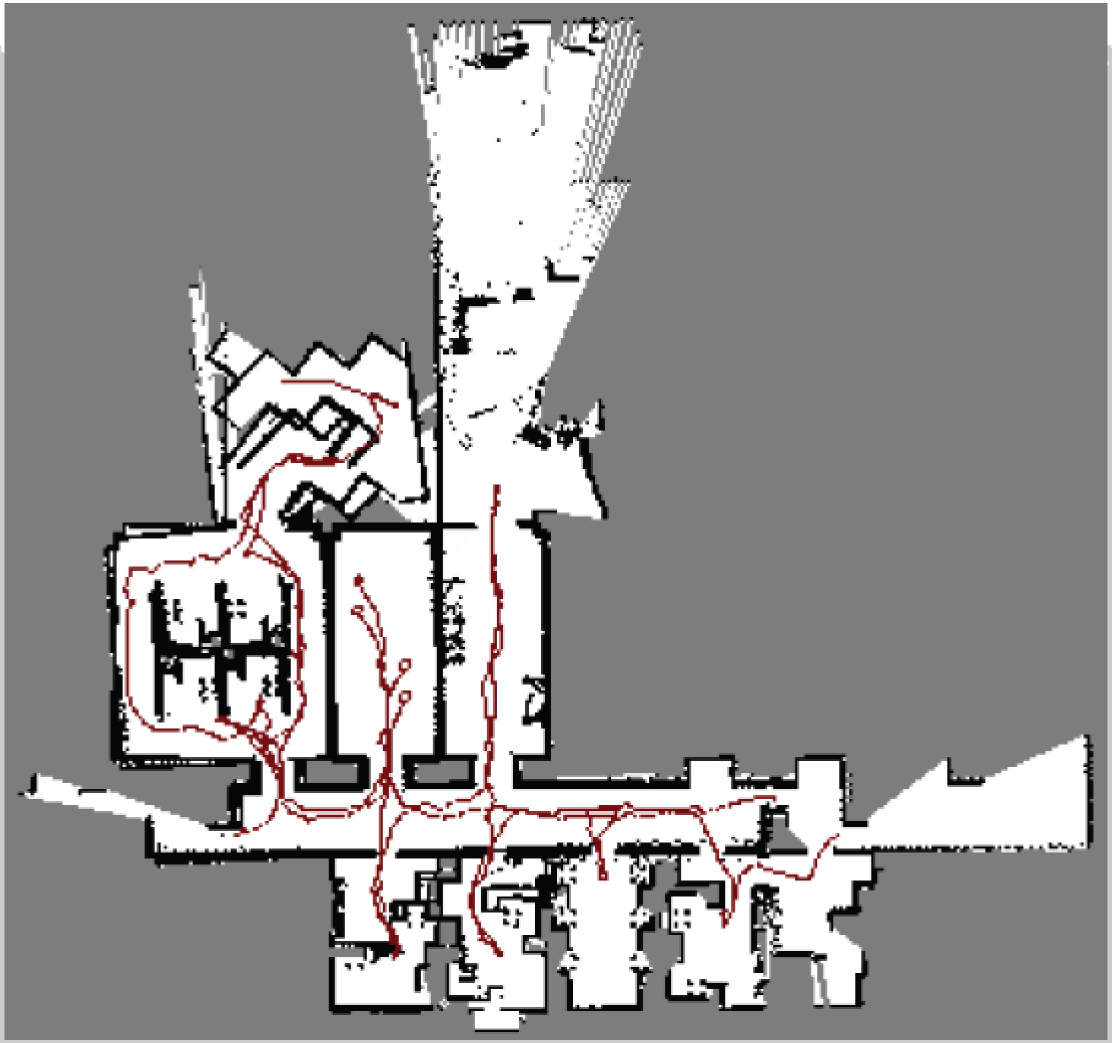
Pose-graph based mapping

Max Pfingsthorn, Yashodhan Nevatia, Todor Stoyanov, Ravi Rathnam, Stefan Markov, and Andreas Birk, "**Towards cooperative and decentralized mapping in Jacobs virtual rescue team**", *Robocup Symposium* 2008, China.



- Initial offset is assumed known.
- Each robot has the complete global map.
- Frontiers are selected and broadcast to others
- Lazy rendering of occupancy grid saves transmission time

Example of approach



Simulation
Rescue league

Map generated by
a team of four robots
at Robocup 2007
in Bremen

New Project Starting Early 2009
Cooperative Cognitive Control for AUVs (Co^{3}AUVs)

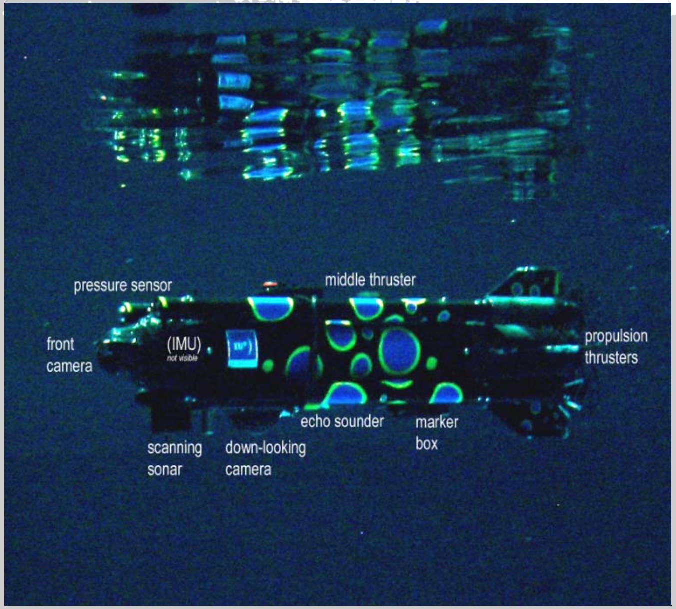
- Jacobs Robotics (coordinator), Germany
- Interuniversity Centre of Integrated Systems for the Marine Environment, Italy
- Dynamical Systems and Ocean Robotics (DSOR) group of the Institute for Systems and Robotics (ISR) at IST, Portugal
- Graaltech, SME, Italy

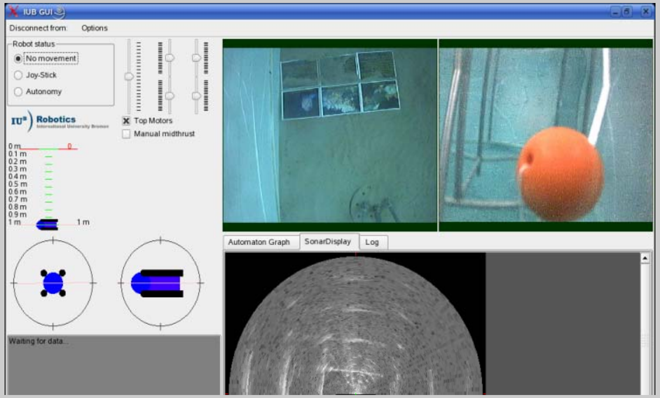
Objectives

- Best practices and procedures for underwater monitoring, exploration and intervention
- Improving underwater perception and modeling as basis for cognition
- Improvement in underwater communications and cooperative navigation and motion control under communications constraints
- Coordination control strategies for multi AUVs
- Non-conventional geophysical-based navigation

Co^{3}AUVs
Project specific expertise

- Perception and world modelling
  - 2D mapping (land/aerial/ underwater)
  - 3D mapping (land)
  - semantic annotations of models (2D)
  - sensor fusion and 3D object recognition
- Cooperative systems
  - cooperative versions of 2D mapping (map merging)
  - team based control (exploration, mission planning)
  - multi robot operator interface (adjustable autonomy)





Robot status
● No movement
○ Joy-Stick
○ Autonomy

☒ Top Motors
☐ Manual midthrust

Waiting for data...

Conclusions

- There is a need for theoretically rigorous techniques for multiple robots to avoid a proliferation of heuristics.
- Simulated techniques need to be implemented and verified on real robots to see the effect of noise and unmodeled dynamics.