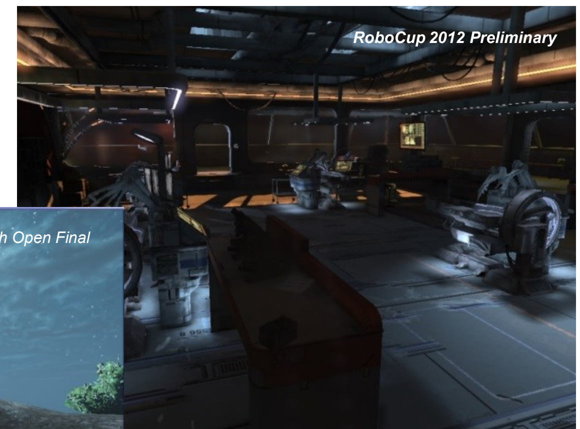
Success Stories of USARSim



Arnoud Visser

Universiteit van Amsterdam

Future of Rescue Robot Simulation workshop,
Leiden, February 29, 2016

Urban Search & Rescue (USAR)

- Research in USAR robotics is a vigorous research area
- Offers unique challenges that are difficult to create in a lab environment

Image from RoboCamp 2006 Tutorial

Applications of rescue robots

- After the Oklahoma City bombing (1995),
  J. Blitch took notes as to how robots might have been applied.
- The trigger for the RoboCup Rescue initiative was the Hanshi-Awaji earthquake which hit Kobe City on the same year.
- Rescue robots were first used at the WTC 9/11 (2001).
  M. Micire analyzed the operations and identified
  seven research topics for the robotics community.
- After 2001, rescue robots were applied in several occasions:
  - Aerial robots were used after hurricane Katrina and Rita
  - Boat robots after hurricane Wilma
  - Snake robots after Bonn’s city archive collapse
  - iRobot, BobCat and Talon at Fukushima Nuclear Power Plant

Analysis the USAR operations

Figure 8. CRASAR operator extended over void acting as a tether manager for robot.

[1] M. Micire, "Analysis of the Robotic-Assisted Search and Rescue Response to the World Trade Center Disaster," Masters Thesis, University of South Florida, July 2002.

Analysis the USAR operations

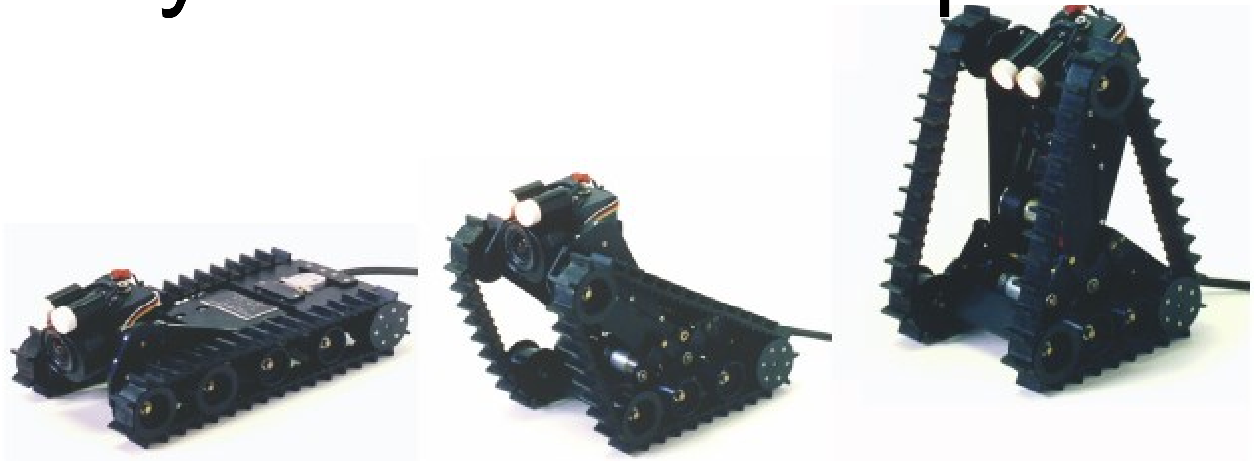
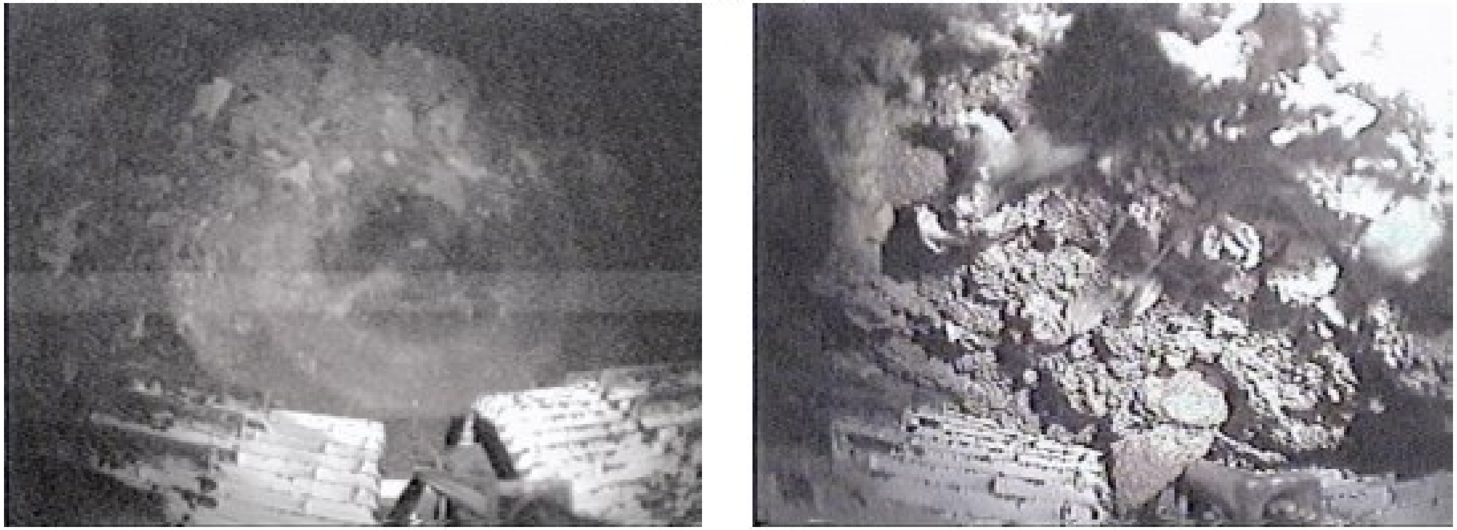


Figure 10. VGTV in lowered, obstructed view (left), and higher non-obstructed view (right).

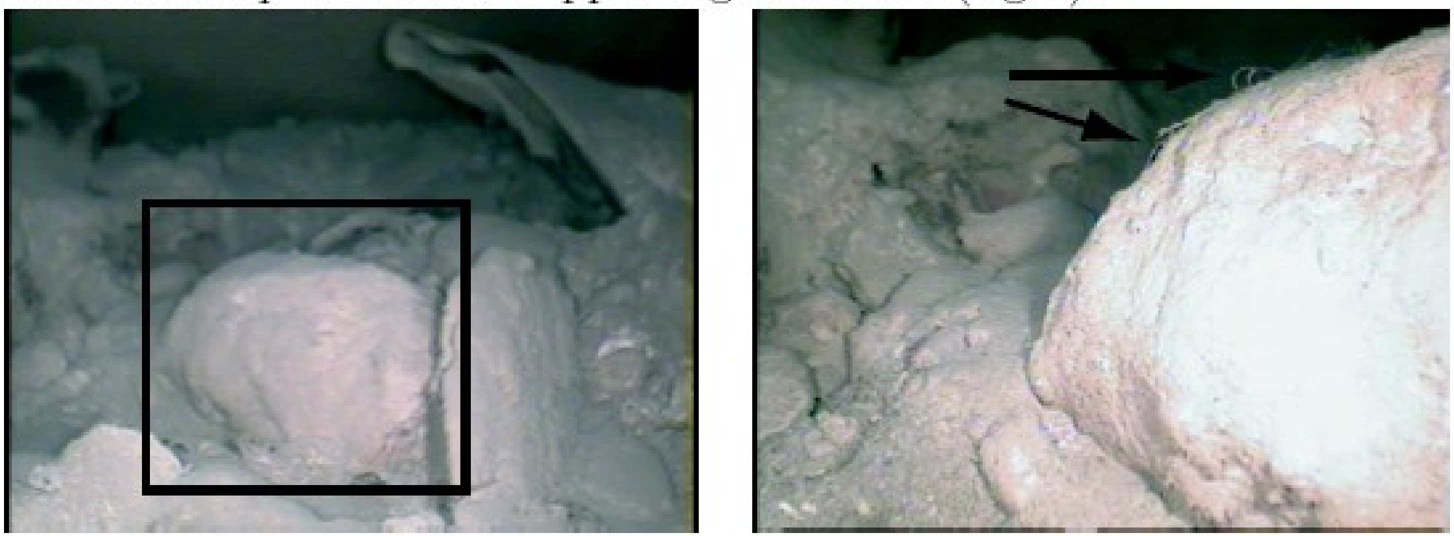
Analysis the USAR operations

Figure 11. View from SOLEM when the robot flipped over into a third void opening and could no longer provide useful information about the environment.



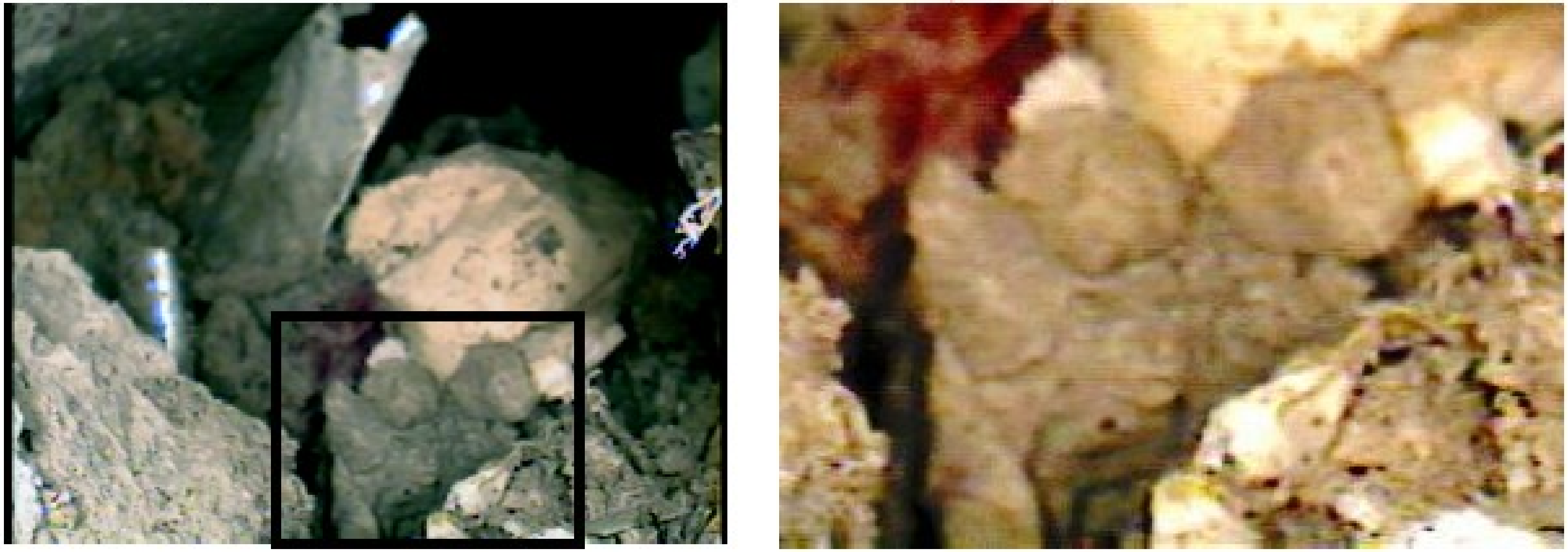
Analysis the USAR operations

Figure 12. View from VGTV showing a pile of debris with a human head in the center (left) and a closeup of the hair supporting this claim (right).



Analysis the USAR operations

Figure 7. The remains of a hand in the lower part of the photo (left) are enhance using histogram equalization to enhance contrast (right).



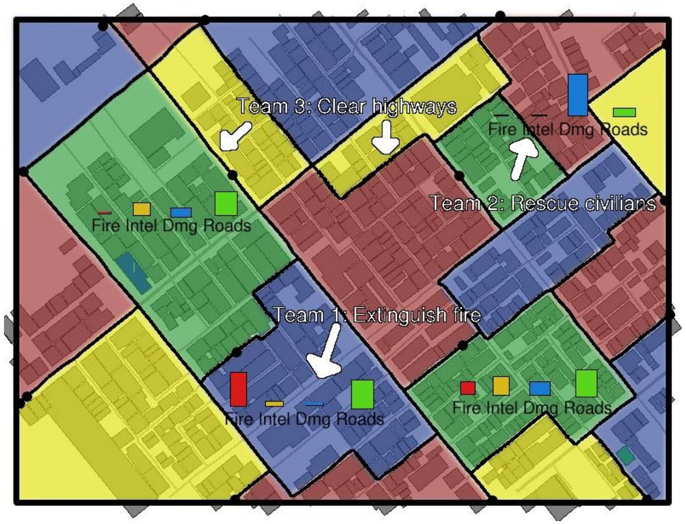
Recommendations [1]

1. Research in image processing is needed for fast and accurate victim detection.
2. Automated tether management is needed for robot mobility assistance.
3. Methodologies to increase the quality of wireless communication is required for robots traveling deep into void structures.
4. Research must continue for small robots that can adaptively optimize their shape in difficult void structures.
5. Localization and mapping must be expanded to include highly unstructured domains.
6. Operator assistance through size and depth estimation techniques should be researched.
7. Assisted navigation techniques in highly irregular confined spaces must be explored to limit the number of pose and robot state errors.

[1] M. Micire, "Analysis of the Robotic-Assisted Search and Rescue Response to the World Trade Center Disaster," Masters Thesis, University of South Florida, July 2002.

RoboCup Rescue Competitions

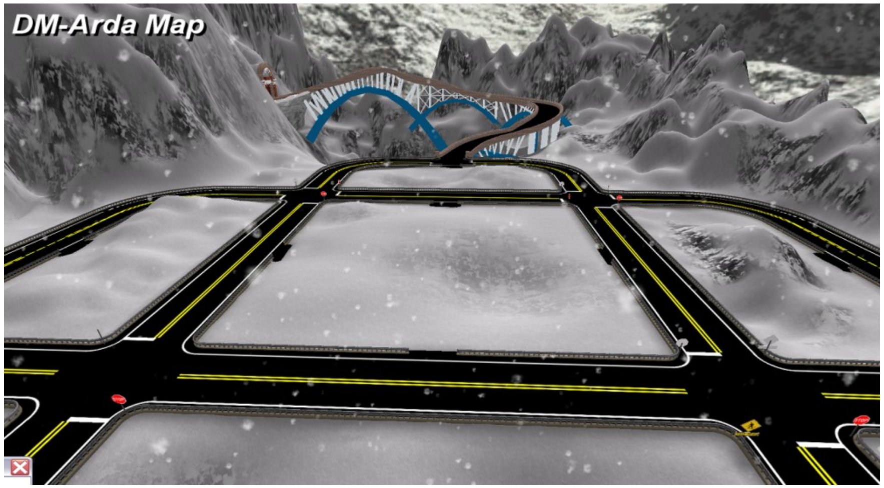
- Rescue Agent simulation
  - Distributed decision making
  - Cooperation
  - Simulations of:
    - Building collapses
    - Road Blockages
    - Spreading fire
    - Traffic
- Real Robots
  - Single collapsed structure
  - Autonomous navigation
  - Victim location and assessment

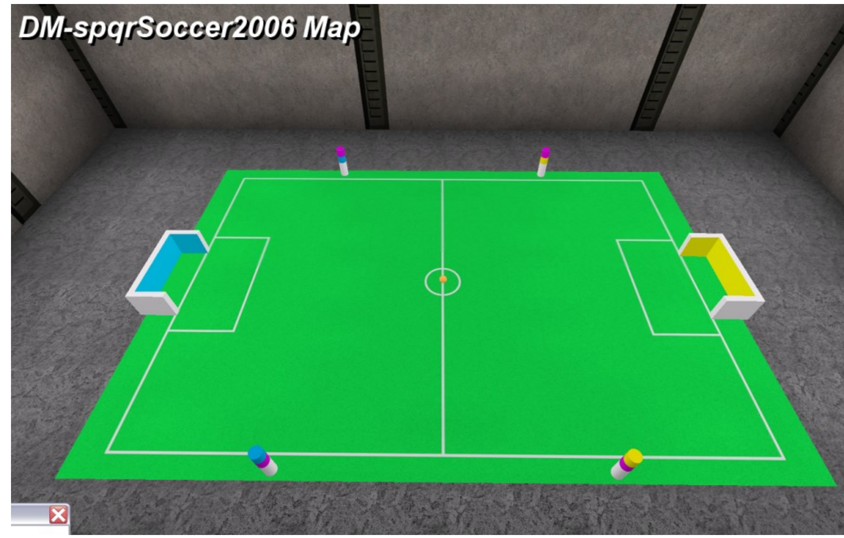


Virtual Robot Competition

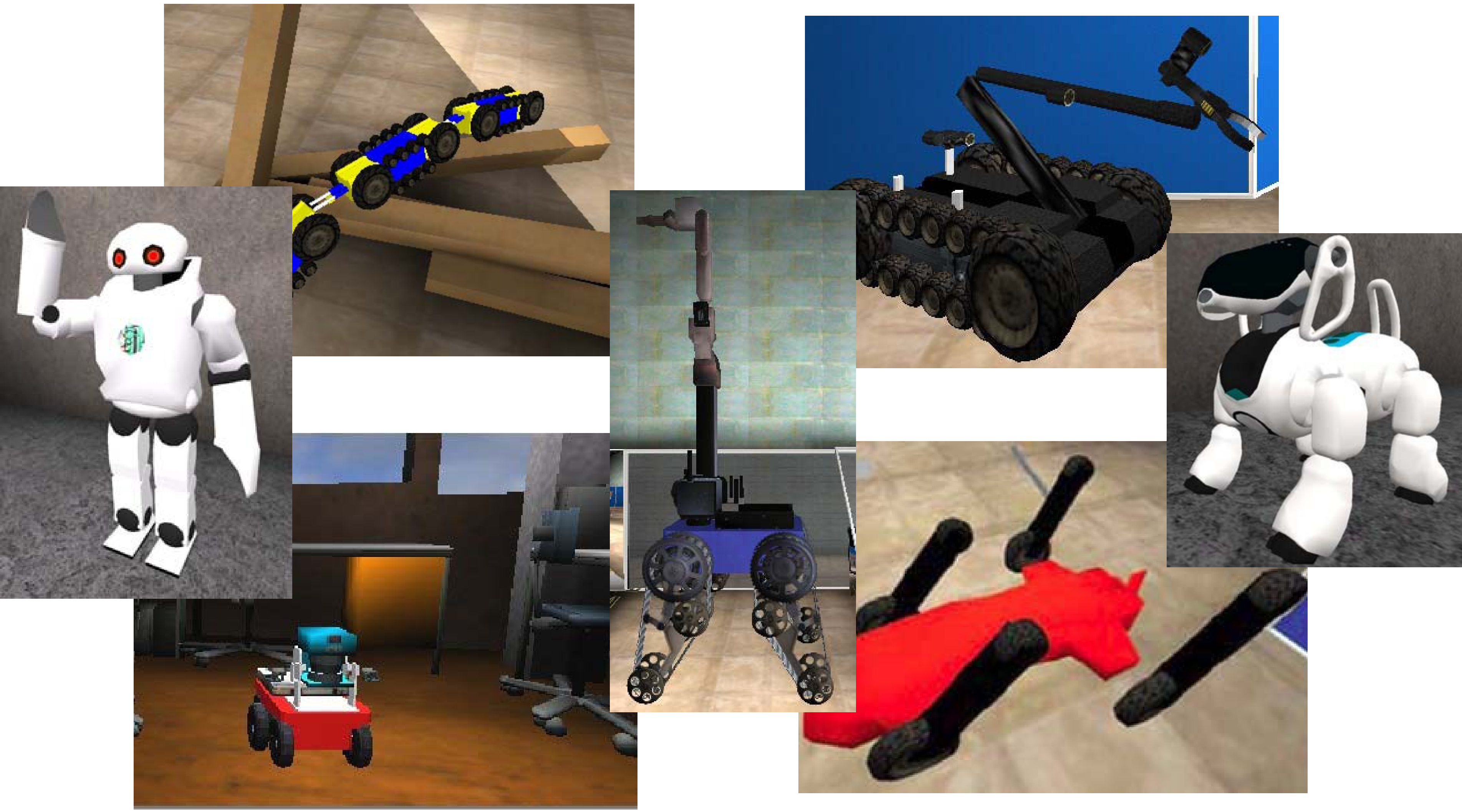
- Autonomous multi-robot control
- Human, multi-robot interfaces
- 3D mapping and exploration by fusing information from multiple robots
- Development of novel mobility modes and sensor processing skills
- Lower entry barriers for developers
- Competition based upon a realistic simulation

USARSim: A wide variety of worlds

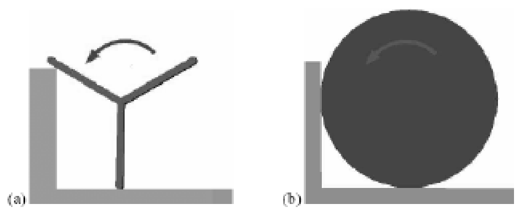


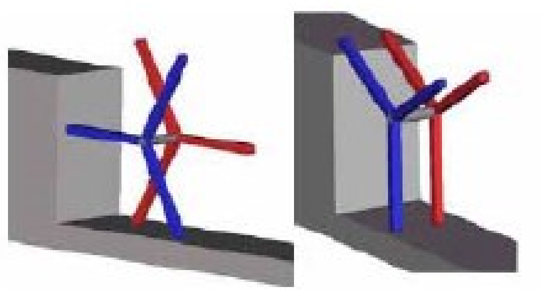


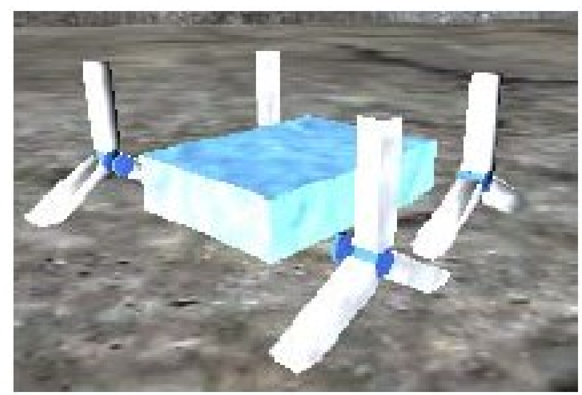
USARSim: A wide variety of Robots



Wheg based robot

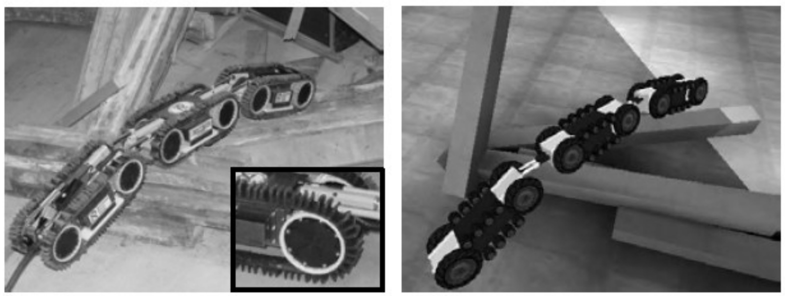


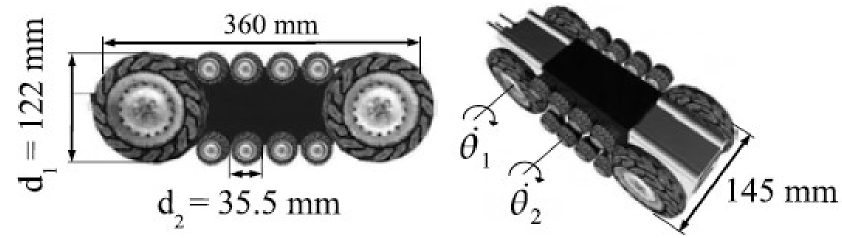


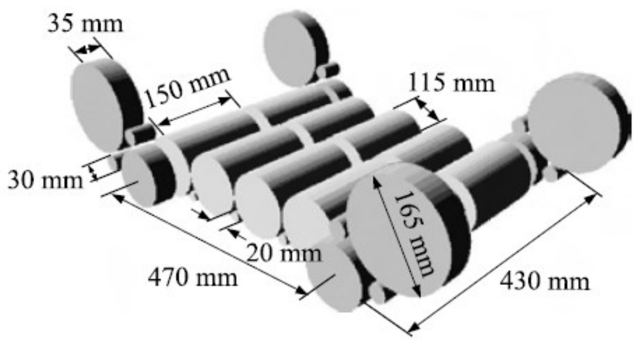


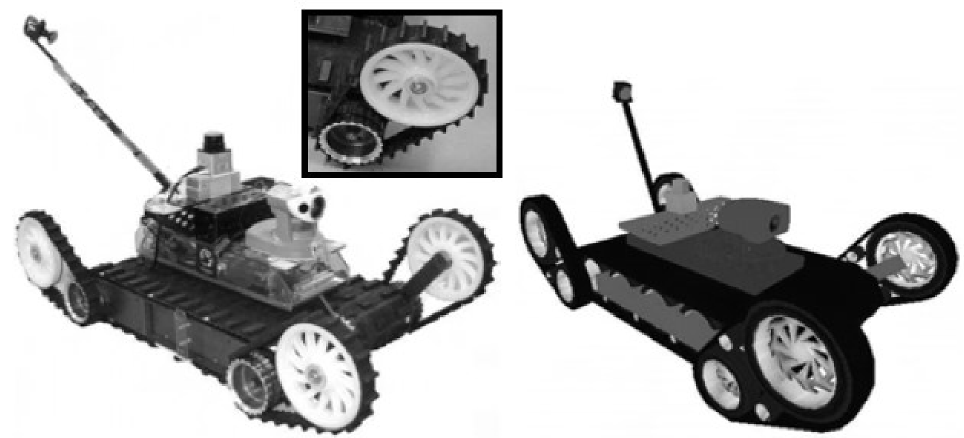
[2] Taylor, B. K., et al. "Design and validation of a Whegs robot in USARSim." Proceedings of the 2007 Workshop on Performance Metrics for Intelligent Systems. ACM, 2007.

Soryu and Kenaf robot



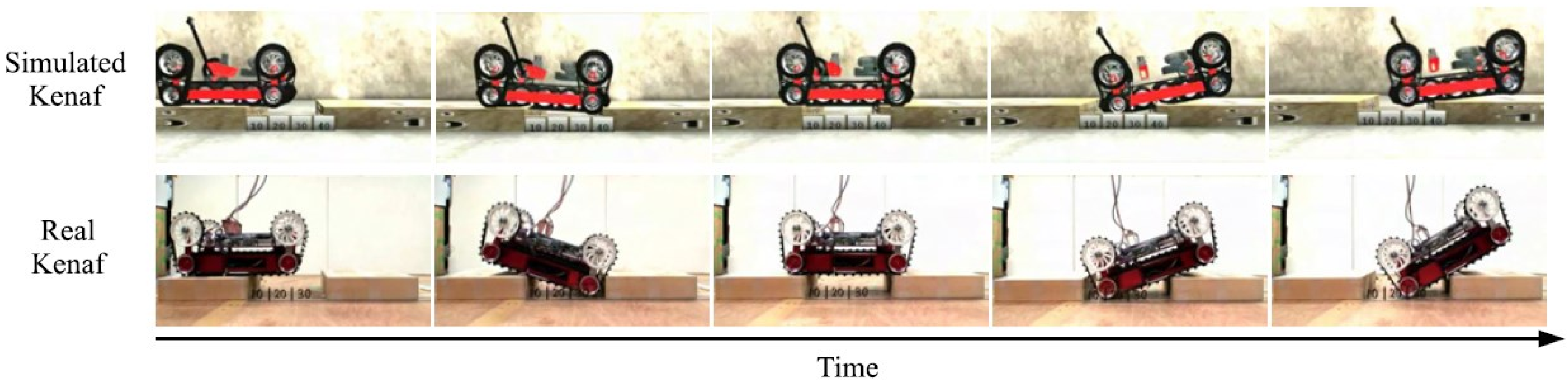






[3] Okamoto, Shogo, et al. "Validation of simulated robots with realistically modeled dimensions and mass in usarsim." *Safety, Security and Rescue Robotics, 2008. SSRR 2008. IEEE International Workshop on*. IEEE, 2008.

Validation of Kenaf robot



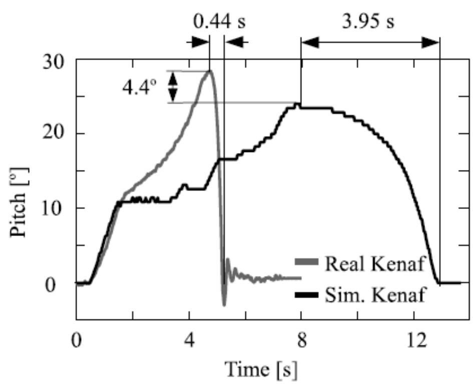


Fig. 12. Transition in pitch angles of real and simulated Kenaf during ascension of a-100-mm-high step

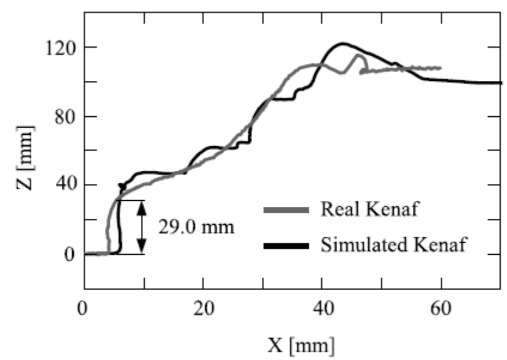
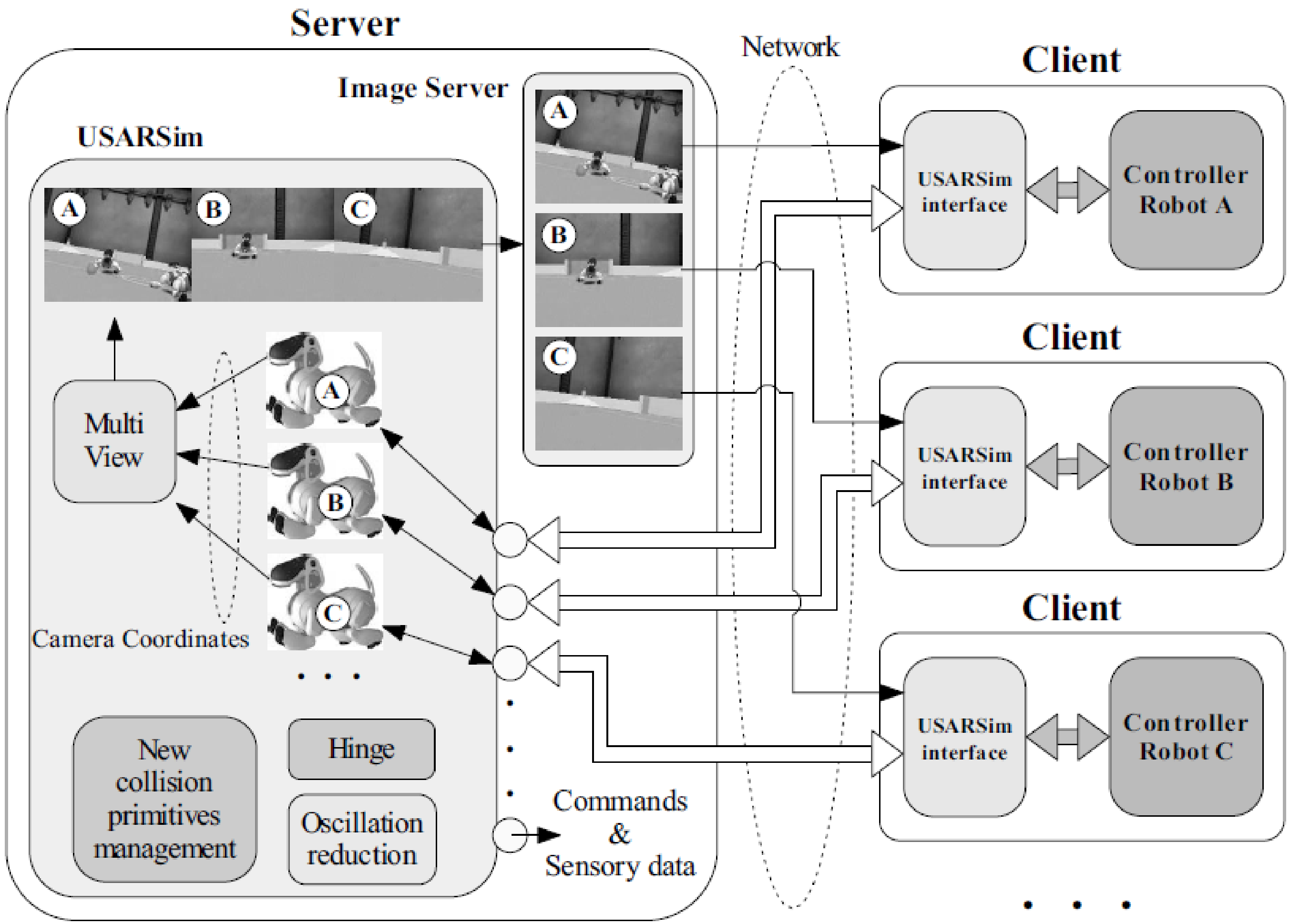


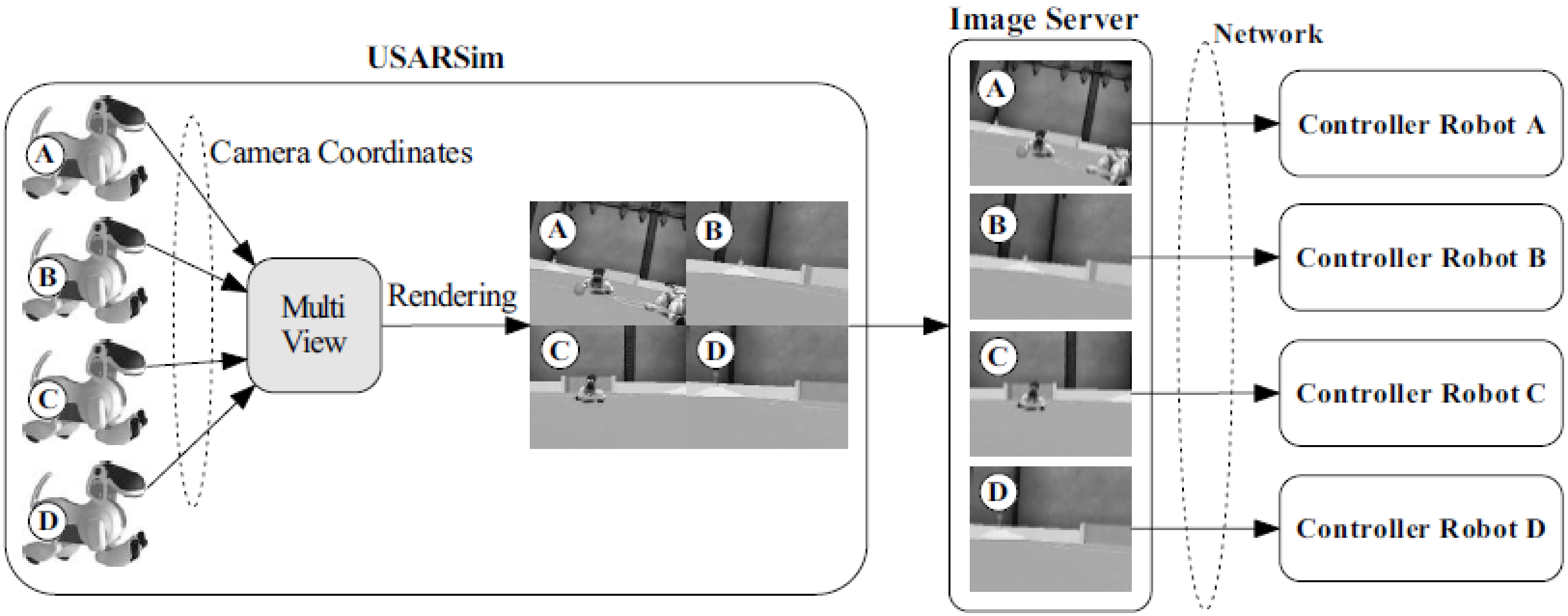
Fig. 13. Trajectory of the centers of mass of the real and simulated Kenaf robots on the x-z plane during ascension of a 100-mm-high step

4 Legged League



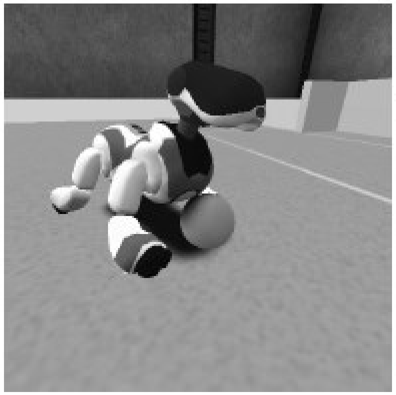
[4] Marco Zaratti, Marco Fratarcangeli, and Luca Iocchi. "A 3D simulator of multiple legged robots based on USARSim." Robocup 2006: Robot Soccer World Cup X. Springer Berlin Heidelberg, 2006. 13-24.

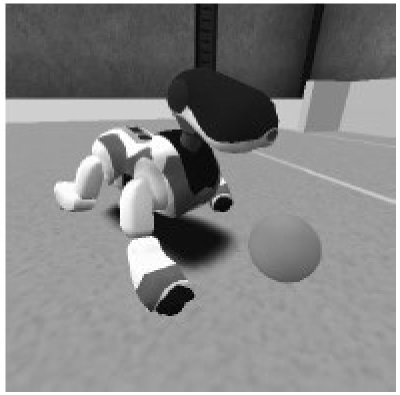
Multiview

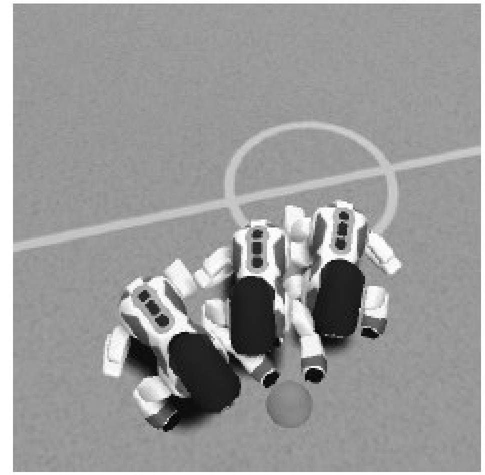


USARSim
A
B
C
D
Camera Coordinates
Multi View
Rendering
A
B
C
D
Image Server
A
B
C
D
Network
Controller Robot A
Controller Robot B
Controller Robot C
Controller Robot D

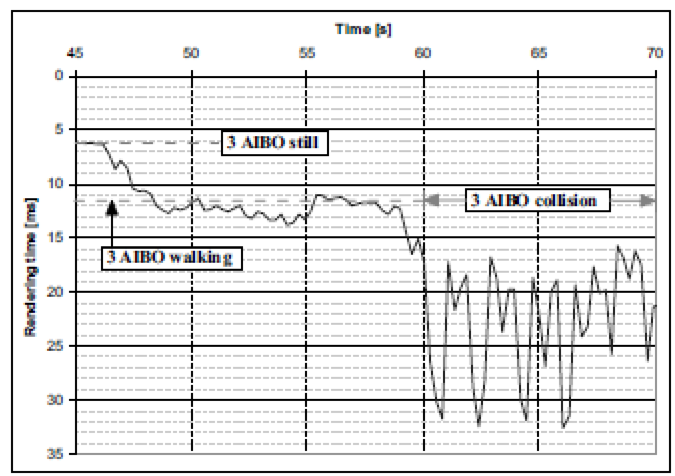
Robot Teams



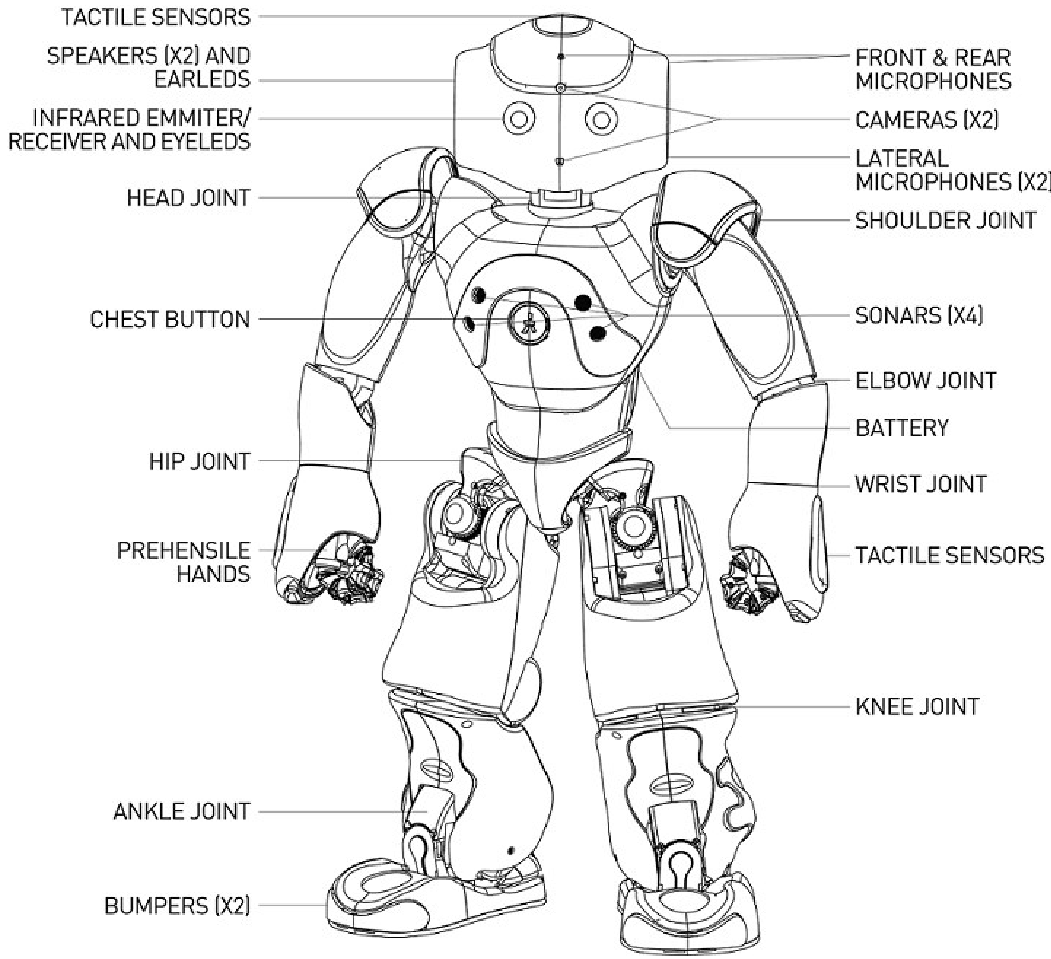





Unreal Tournament 2004
iRobot
ATRV-JR

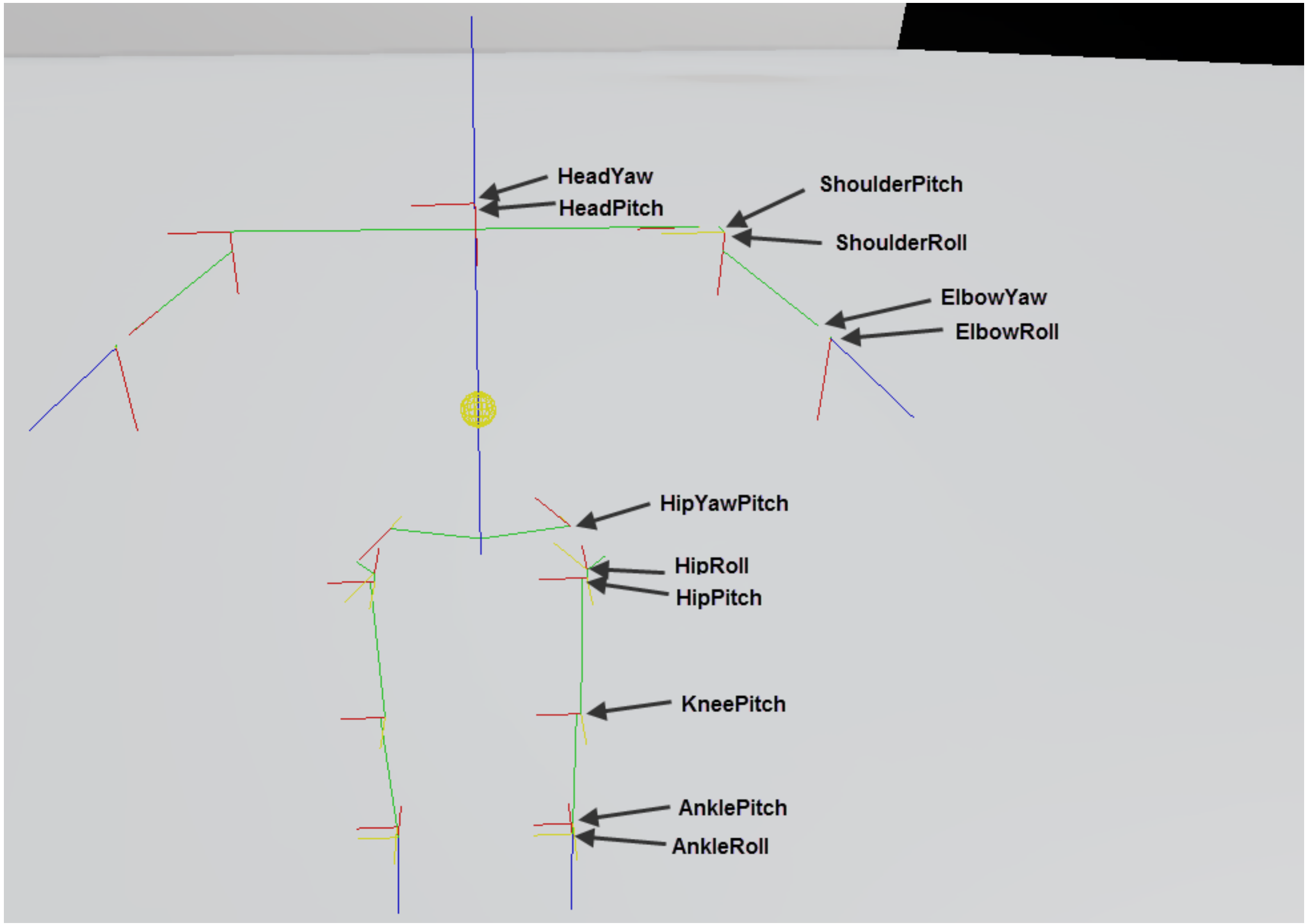

Time [s]
45
50
55
60
65
70
0
5
10
15
20
25
30
35
Rendering time [ms]
3 AIBO still
3 AIBO walking
3 AIBO collision

Humanoid robot NAO



Aldebaran Robotics, France

Constrained Kinematic Chains



5 Kinematic chains; 21 Degrees of Freedom.

Denavit Hartenberg representation

- Offset and range of each joint

$$LHipYawPitch = \begin{bmatrix} \cos\theta_1 & -\frac{1}{4}\pi\sin\theta_1 & \frac{1}{4}\pi\sin\theta_1 & 0.0461\cos\theta_1 \\ \sin\theta_1 & \frac{1}{4}\pi\cos\theta_1 & -\frac{1}{4}\pi\cos\theta_1 & 0.0461\cos\theta_1 \\ 0 & \frac{1}{4}\pi & \frac{1}{4}\pi & 0.07 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$LShoulderPitch = \begin{bmatrix} \cos\theta_1 & 0 & \sin\theta_1 & 0.0900\cos\theta_1 \\ \sin\theta_1 & 0 & -\cos\theta_1 & 0.0900\cos\theta_1 \\ 0 & 1 & 0 & 0.08 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$LShoulderRoll = \begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 & 0.0100\cos\theta_2 \\ \sin\theta_2 & 0 & -\cos\theta_2 & 0.0100\cos\theta_2 \\ 0 & 1 & 0 & 0.01 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$LElbowYaw = \begin{bmatrix} \cos\theta_3 & 0 & \sin\theta_3 & 0.1097\cos\theta_3 \\ \sin\theta_3 & 0 & -\cos\theta_3 & 0.1097\cos\theta_3 \\ 0 & 1 & 0 & 0.01 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$LElbowRoll = \begin{bmatrix} \cos\theta_4 & 0 & \sin\theta_4 & 0 \\ \sin\theta_4 & 0 & -\cos\theta_4 & 0 \\ 0 & 1 & 0 & 0.00 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$LHipRoll = \begin{bmatrix} \cos\theta_2 & 0 & \sin\theta_2 & 0.0134\cos\theta_2 \\ \sin\theta_2 & 0 & -\cos\theta_2 & 0.0134\cos\theta_2 \\ 0 & 1 & 0 & 0.03 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

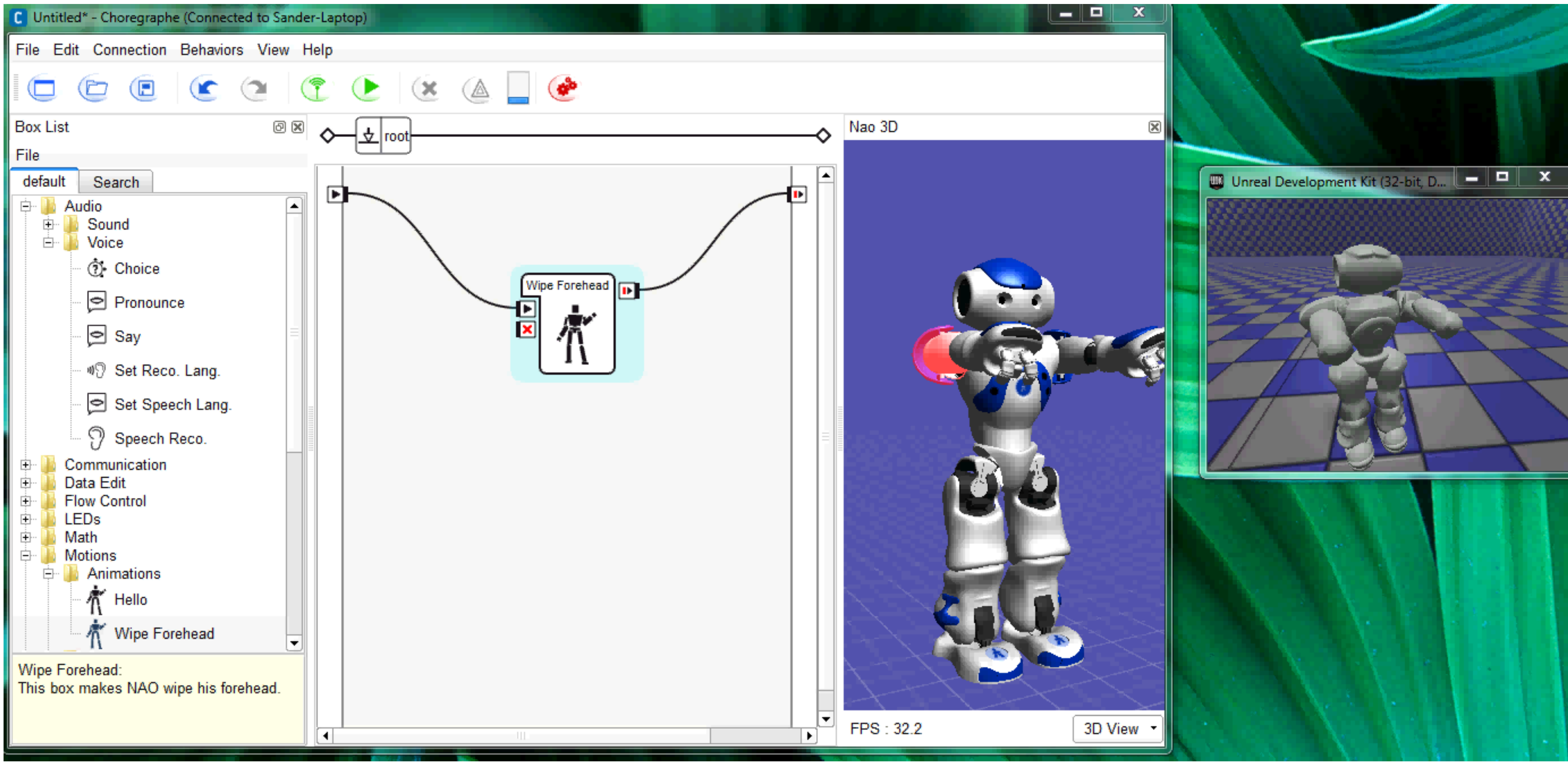
$$LHipPitch = \begin{bmatrix} \cos\theta_3 & 0 & \sin\theta_3 & 0.0050\cos\theta_3 \\ \sin\theta_3 & 0 & -\cos\theta_3 & 0.0050\cos\theta_3 \\ 0 & 1 & 0 & 0.00 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$LKneePitch = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & 0.0880\cos\theta_4 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0.0880\cos\theta_4 \\ 0 & 0 & 1 & 0.00 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

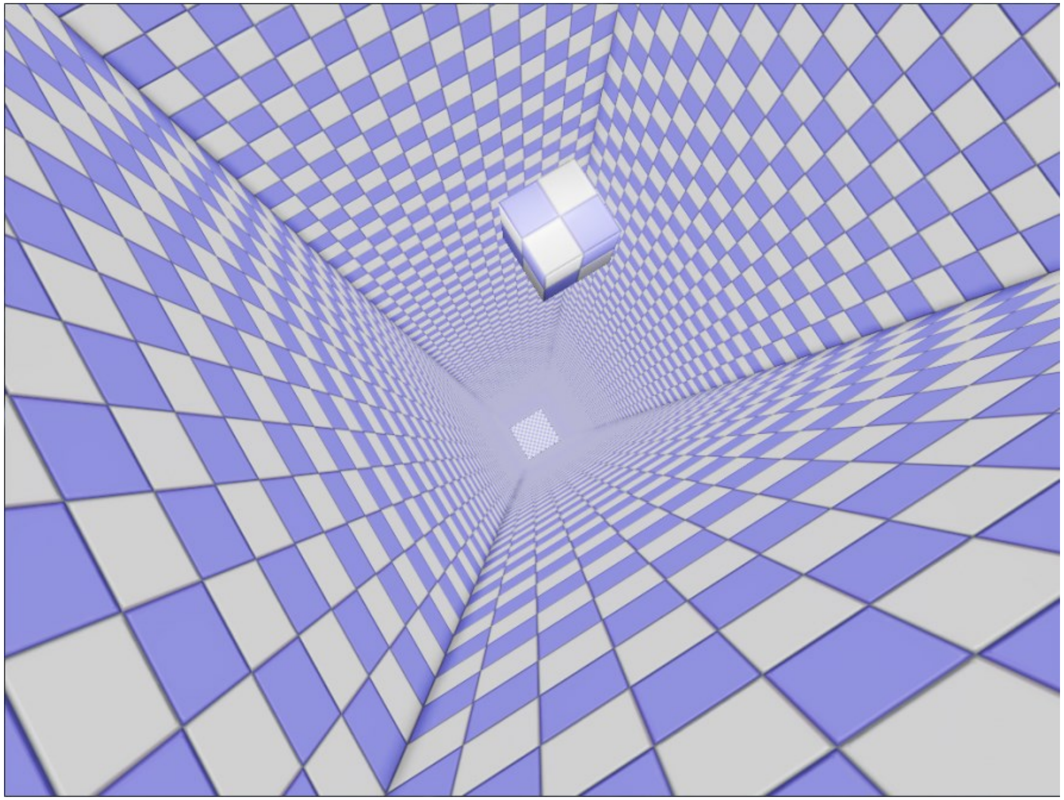
$$LAnklePitch = \begin{bmatrix} \cos\theta_5 & -\sin\theta_5 & 0 & 0.1001\cos\theta_5 \\ \sin\theta_5 & \cos\theta_5 & 0 & 0.1001\cos\theta_5 \\ 0 & 0 & 1 & 0.00 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$LAnkleRoll = \begin{bmatrix} \cos\theta_6 & 0 & \sin\theta_6 & 0.0100\cos\theta_6 \\ \sin\theta_6 & 0 & -\cos\theta_6 & 0.0100\cos\theta_6 \\ 0 & 1 & 0 & 0.00 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Constrained movement of joints



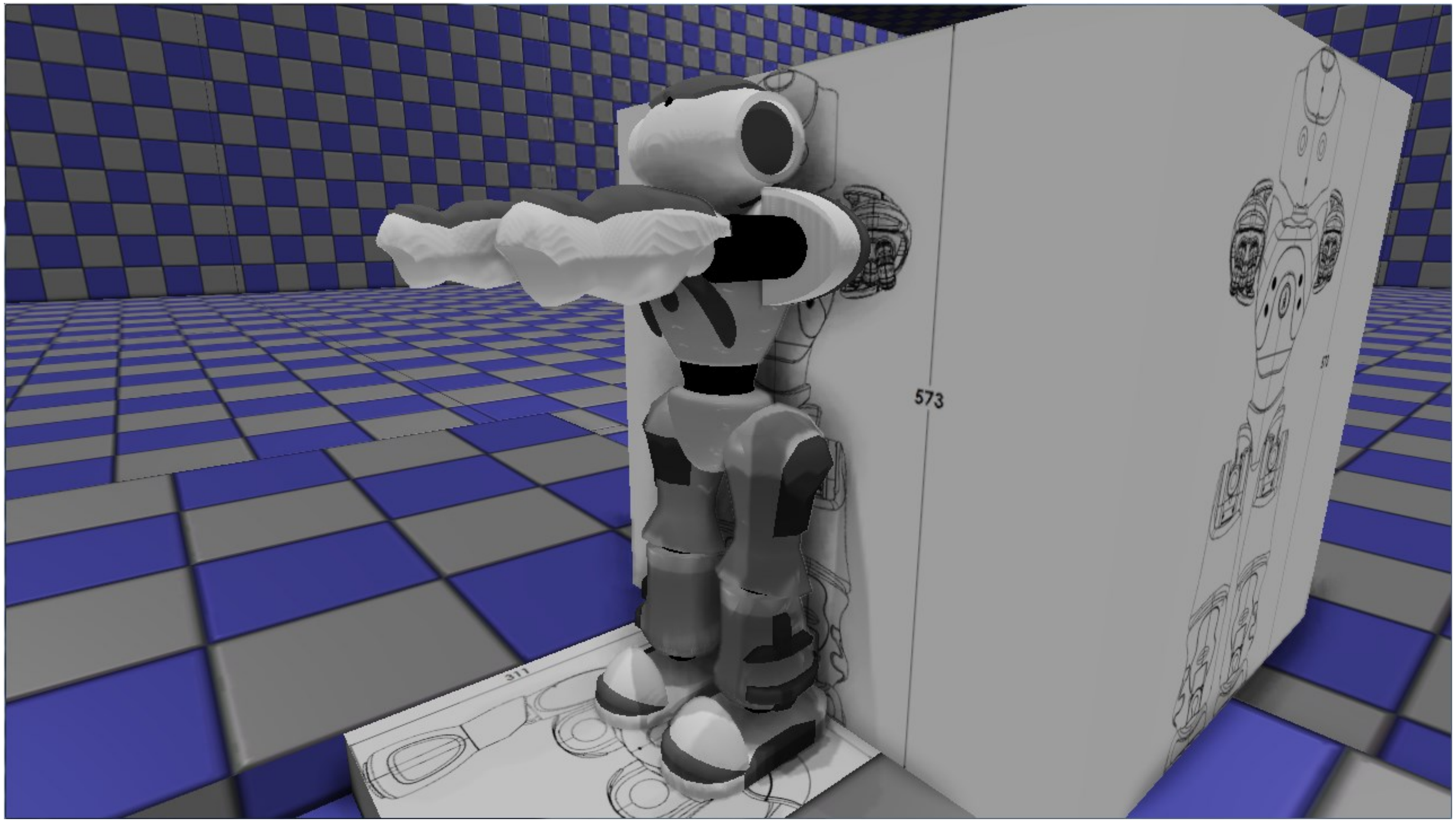
Gravity



Default values for the Unreal Engine had to be corrected with a factor

G (uu/s) / Dist (uu)	1024	2048	4096	8192	16384	32768
-2452.5uu (rbs 1, ld 0.1)	1.06	1.06	1.08	1.1	1.13	1.19
-2452.5uu (rbs 1, ld 0.0)	1.03	1.02	1.01	1.01	1.01	1.00

Advanced experiments



Three full body movements:

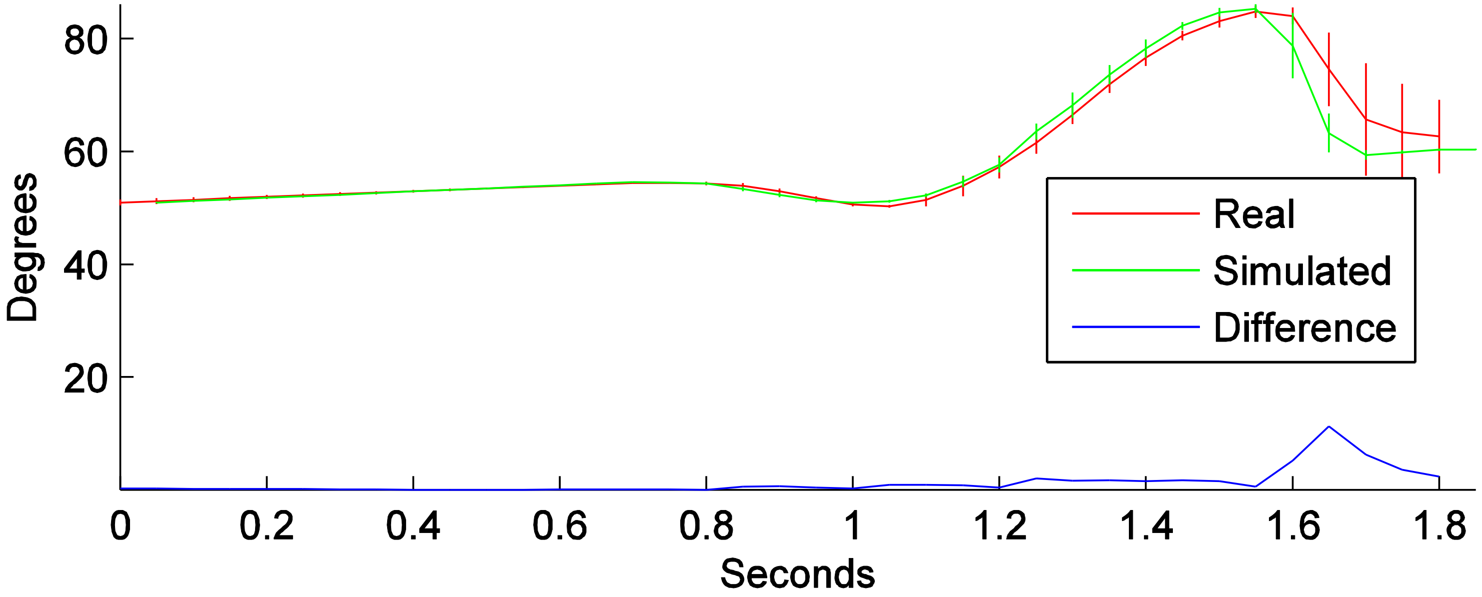
- **A kick**
- **Balance act (Tai Chi Chuan)**
- **Single step**

Balance act

Diagnostic movement: Tai Chi Chuan

- **Real robot: all motors and joints still functional**
- **Simulated robot: weight correctly distributed over body**

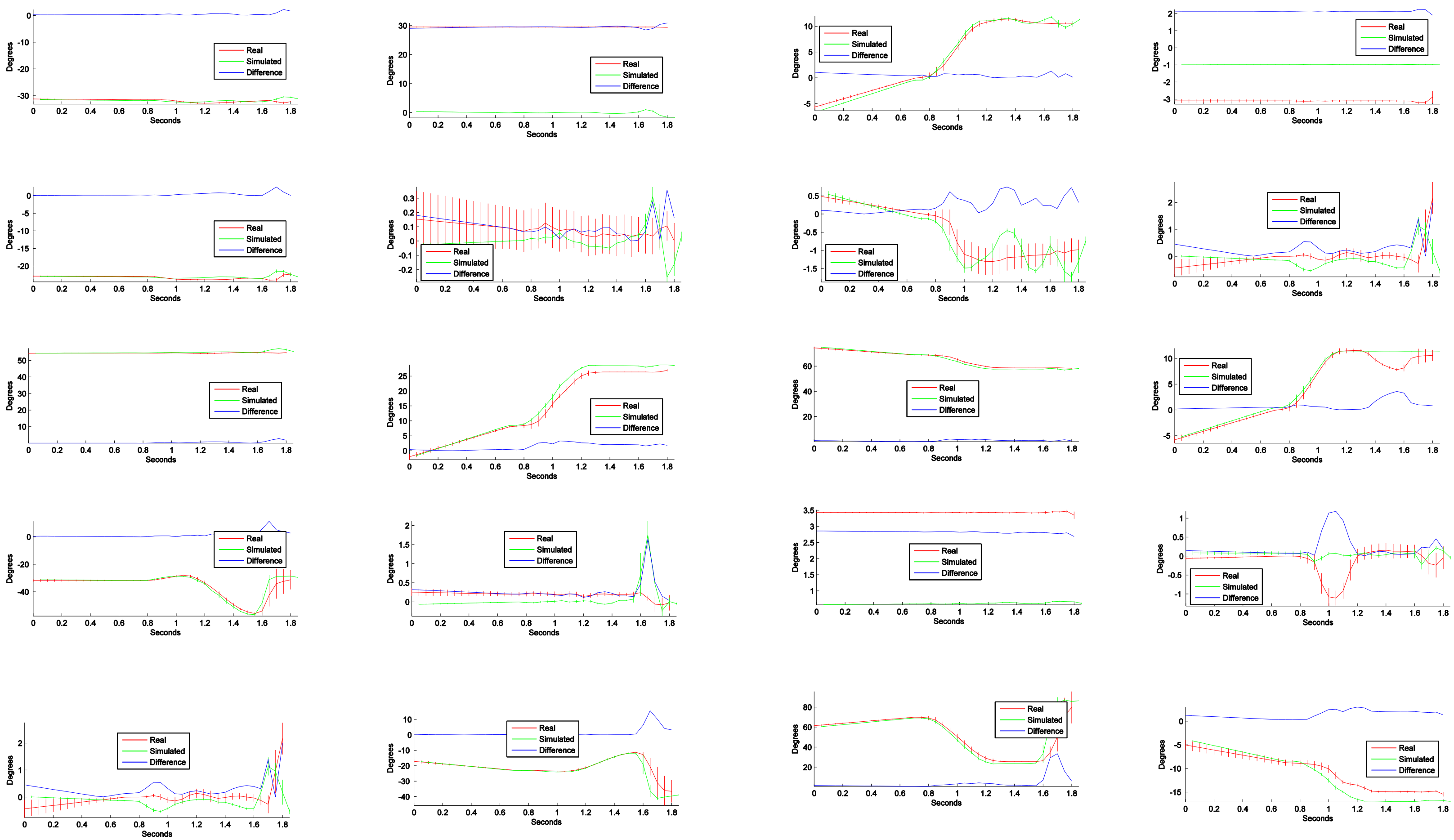
A kick



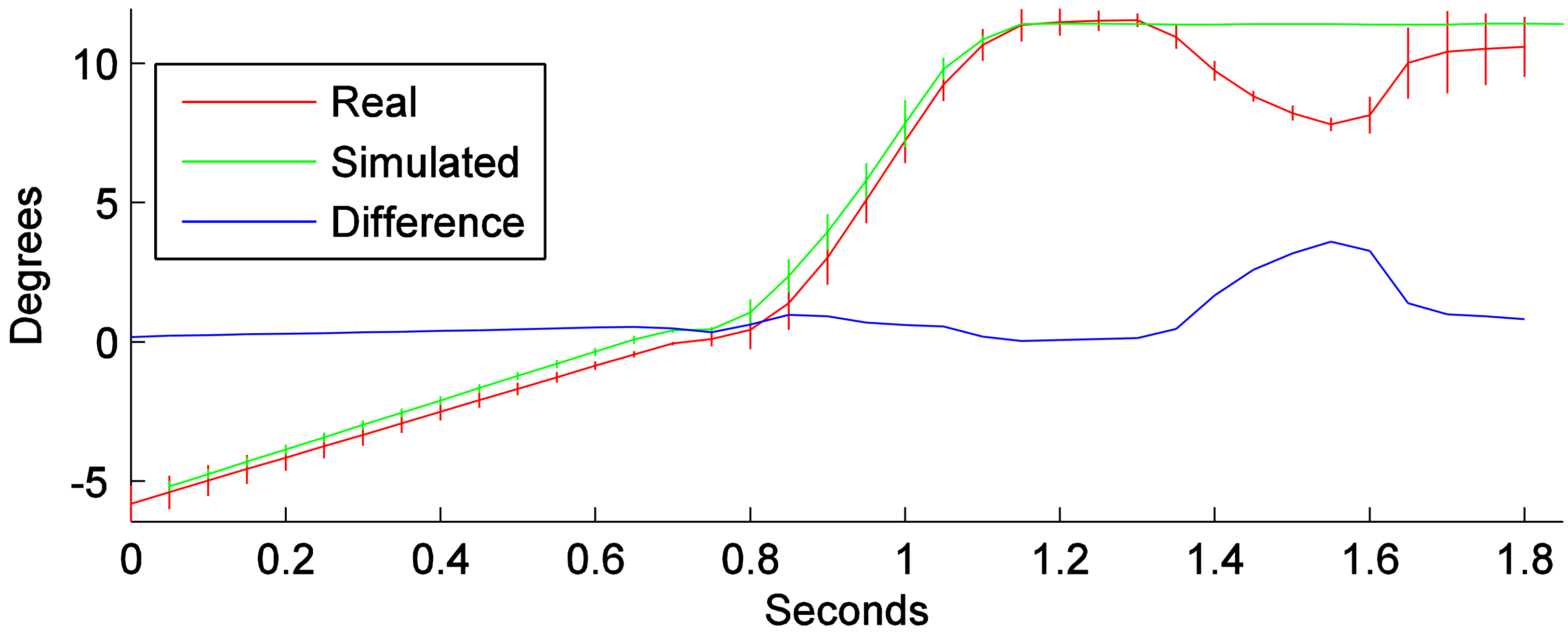
Movement of the Right Knee (pitch):

- **Good correspondence, except for deceleration**
- **More variance with the real robot, compared to the simulated robot**

21 joints



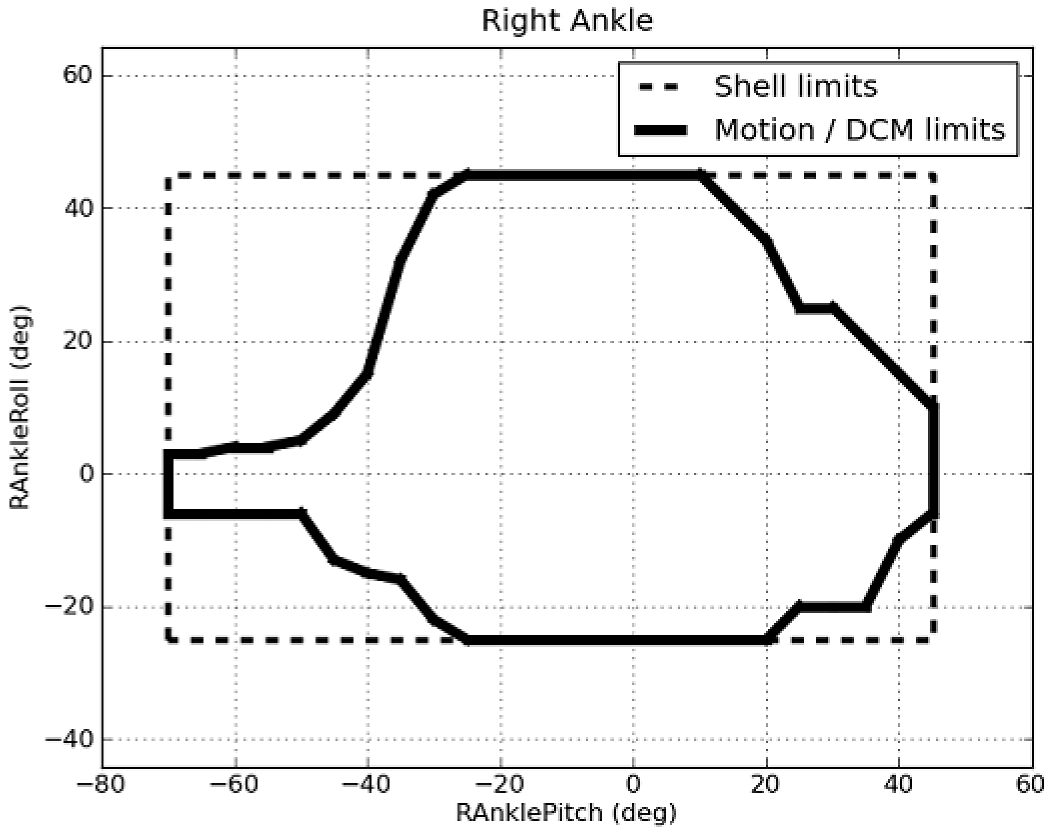
A kick



Movement of the Right Ankle (roll):

- **Good correspondence, except for around 1.5 s**
- **Angle drifts away from requested angle**

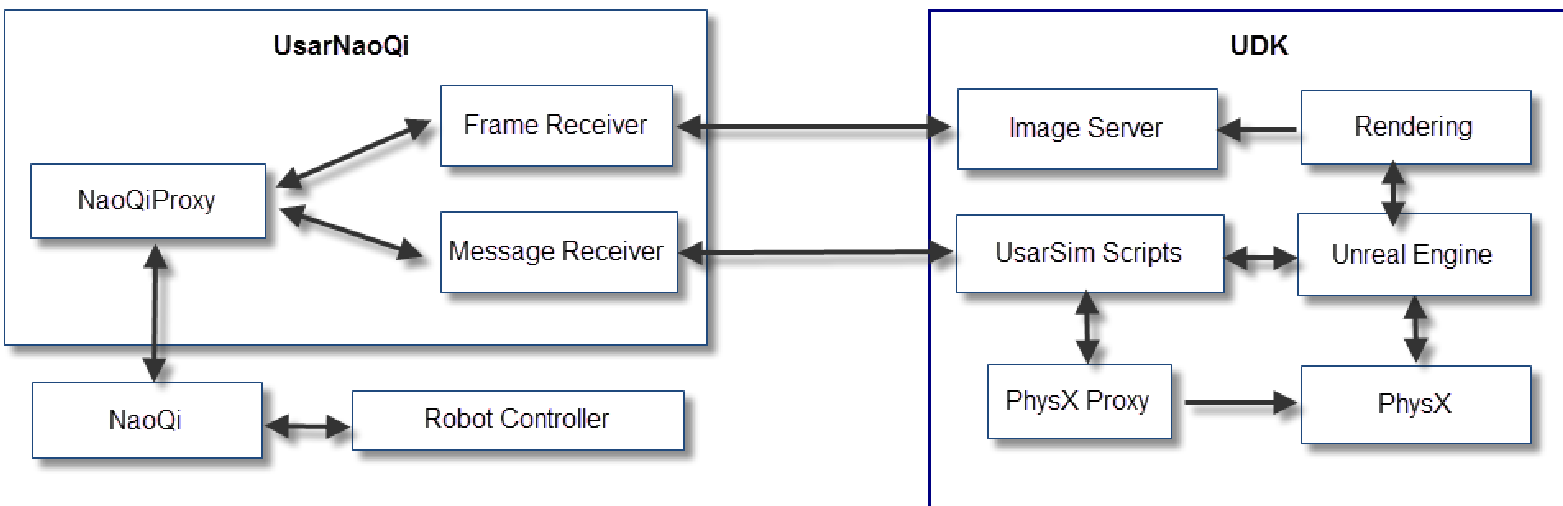
Shell limits



Reason for discrepancy Right Ankle roll during kick:

- **Hardware limits, depended on Right Angle pitch**

Full application

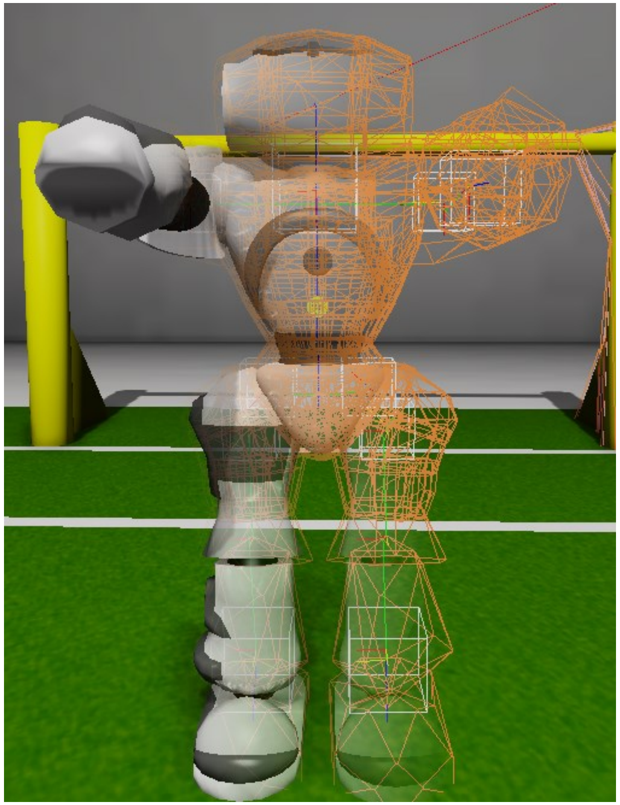


A proxy server was built which allows to command the Nao via its natural interface (NaoQi). NaoQi has e.g. a C++ and Python interface.

RoboCup Soccer

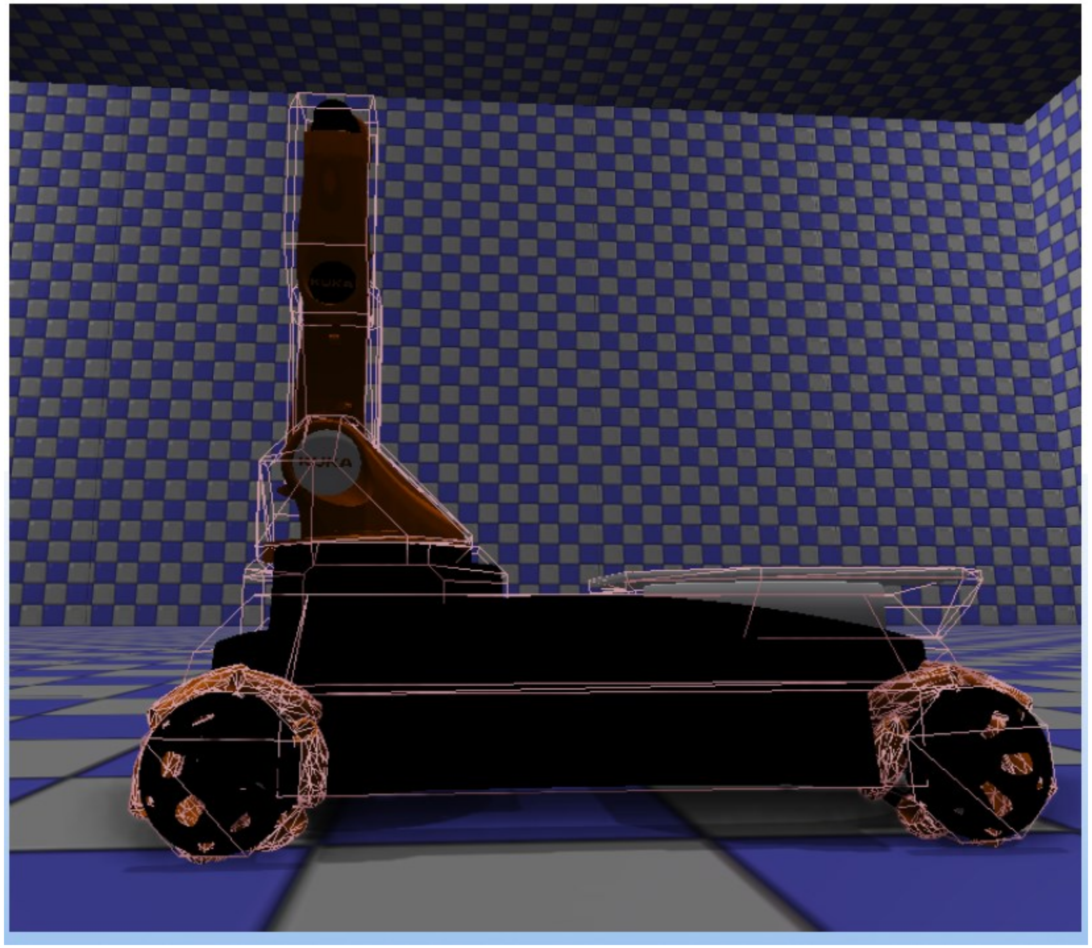
The Python code of an actual RoboCup team (Dutch Nao Team) was used to play a game of soccer.

Resumé



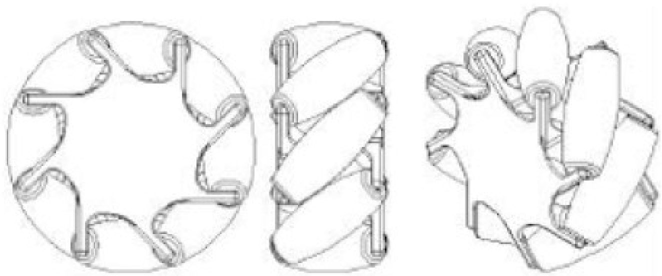
a validated humanoid robot in USARSim UDK

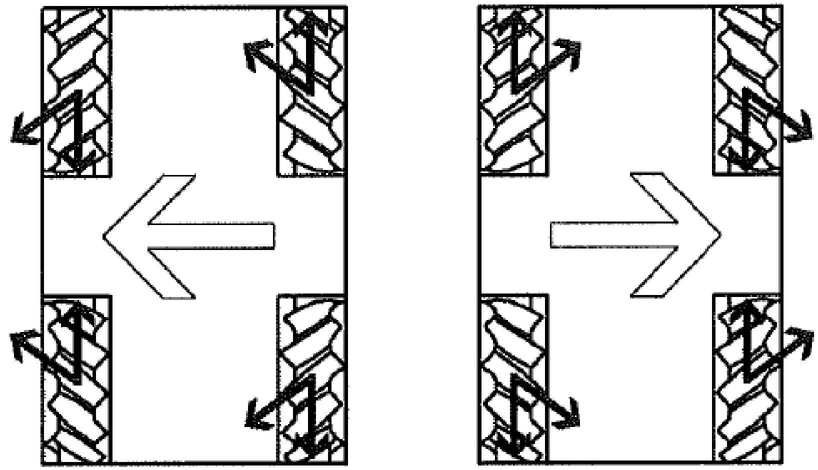
Kuka youBot

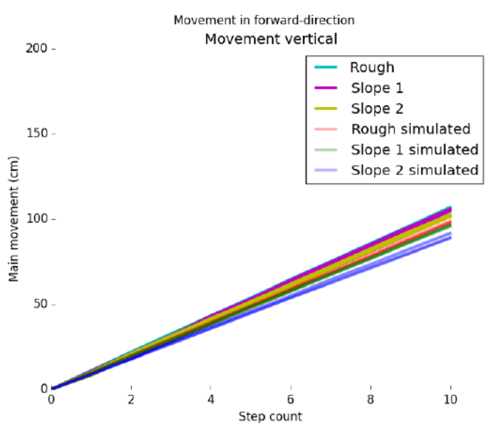


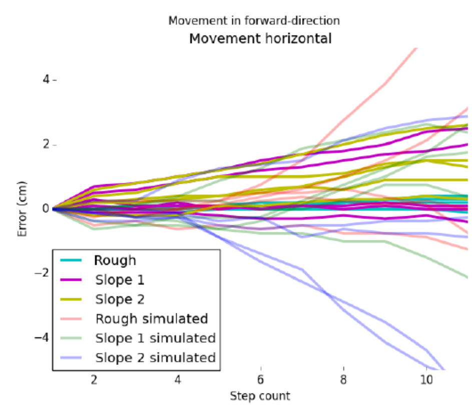
[5] Freddy de Greef, *A KUKA youBot simulation in USARSim*, Bachelor thesis, Universiteit van Amsterdam, June 2015

Mecanum wheels









Currently Kuka youBot model is ported to Unreal Engine 4.10

Unreal Engine 4.1

Realistic rendering

Unreal Engine 4.3

Indirect lighting

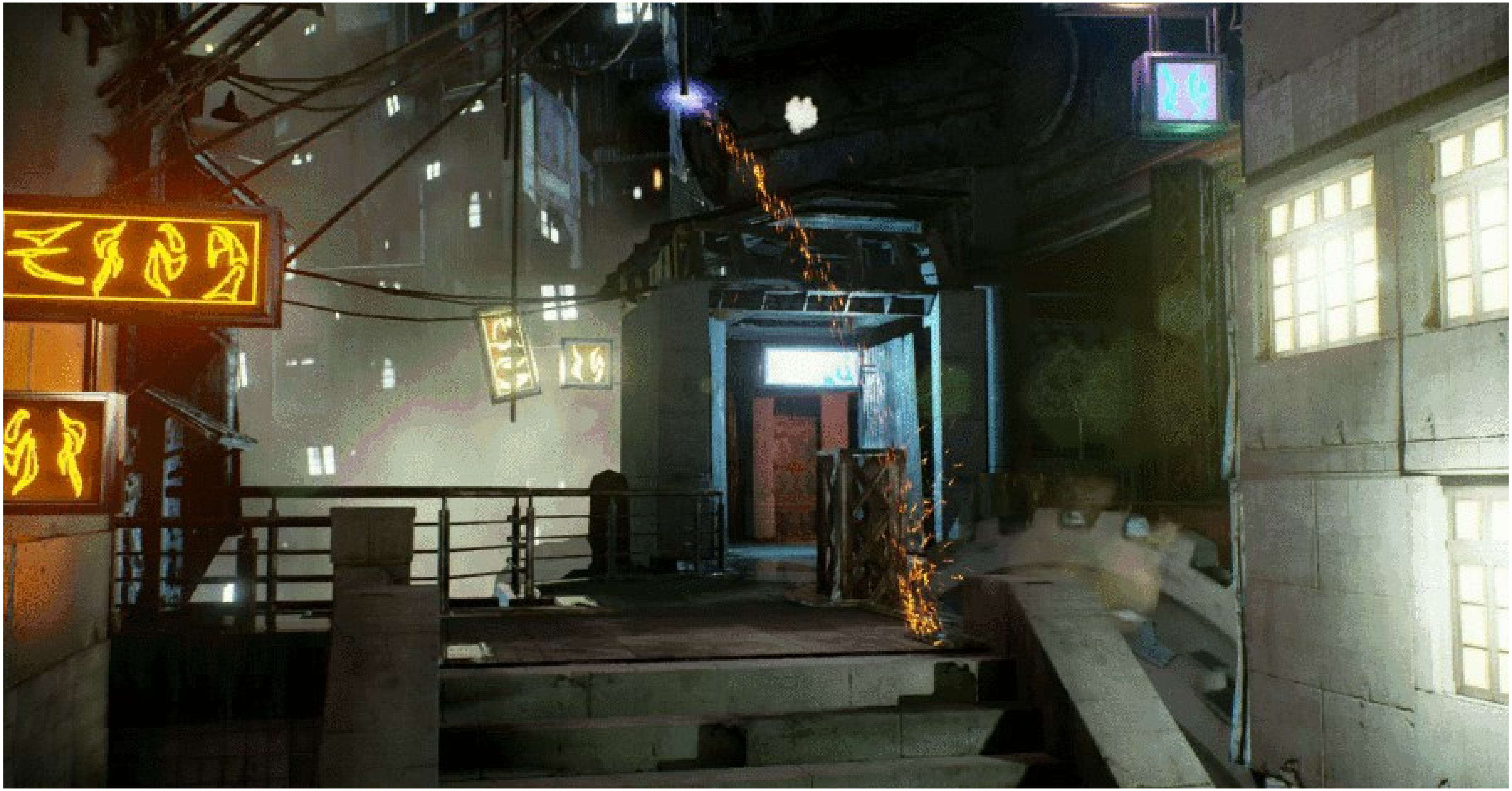
Unreal Engine 4.7

Realistic Foliage Lighting

Unreal Engine 4.8

Reflections on Translucent Surfaces

Unreal Engine 4.9



Full Scene Particle Collision

Unreal Engine 4.10

Scalable refraction and reflections

An Omnidirectional Camera Simulation for the USARSim World

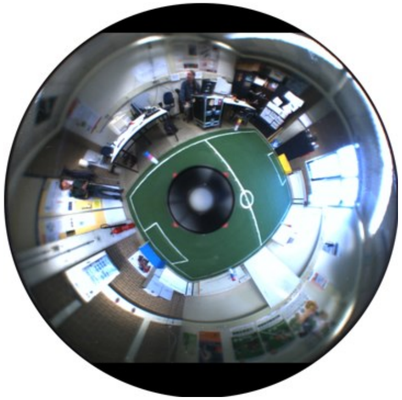
Tijn Schmits and Arnoud Visser

T. Schmits and A. Visser, **An Omnidirectional Camera Simulation for the USARSim World**, in "RoboCup 2008: Robot Soccer World Cup XII“, Lecture Notes on Artificial Intelligence series, volume 5339, p. 296-307, Springer, Berlin Heidelberg New York, June 2009.

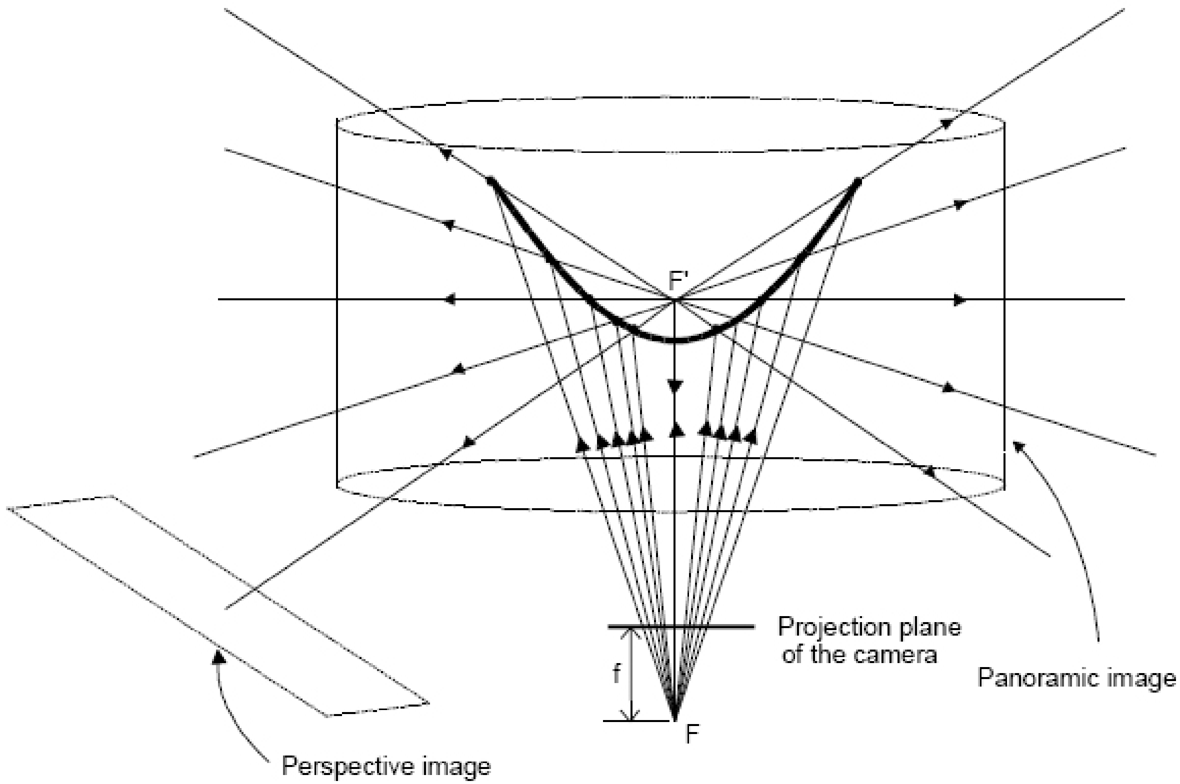
Universiteit van Amsterdam

A new sensor model is created

- Catadioptric Omnidirectional Camera
  - Mirror based design (robust and cheap)
  - Widely used in robotic research
  - Available for validation at Amsterdam
    - DragonFly® camera
    - PanoramaEye® mirror
  - Robotics:
    Navigation
    Self localisation
    VisualSLAM



Sophisticated solution: Mirror Model

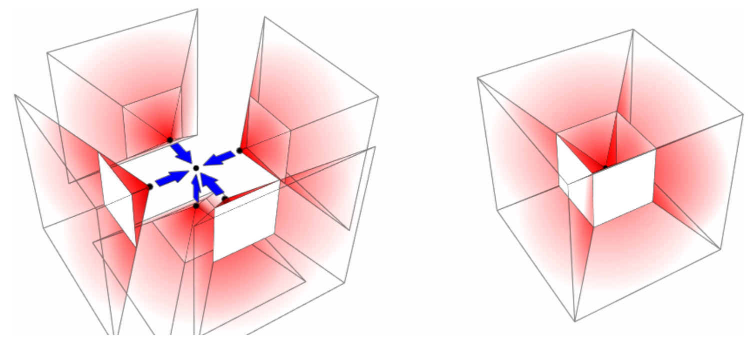


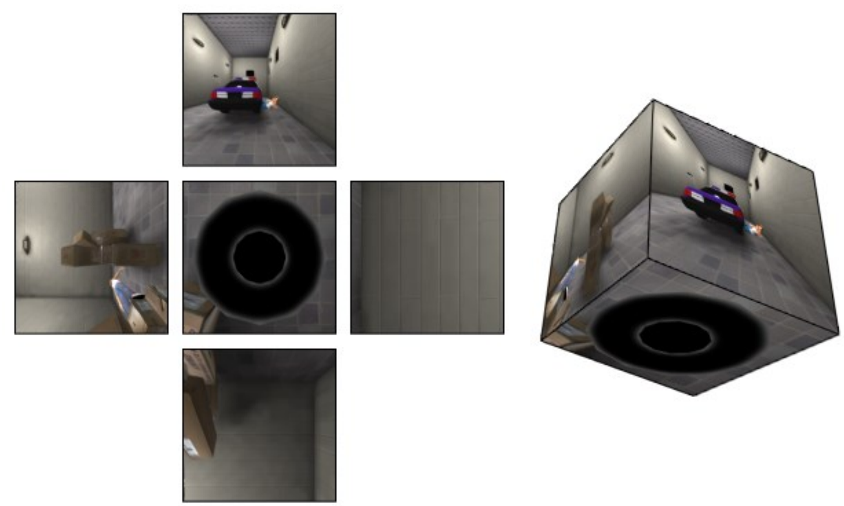
- Single Viewpoint Constraint

Simulation Model Development
- Single Viewpoint -

At the center

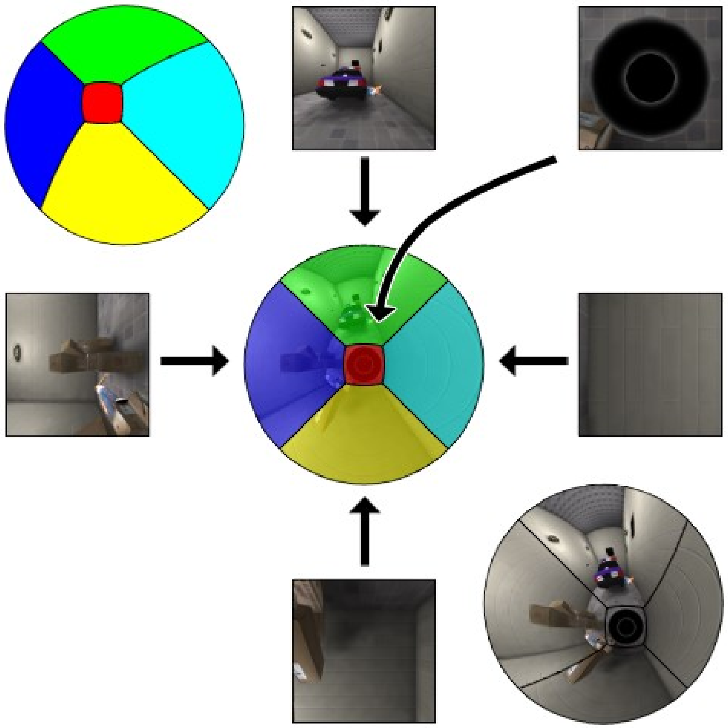
- 5 security cameras
- 90 degree FOV
- 90 degree angles
- Cube mapping
  of the environment





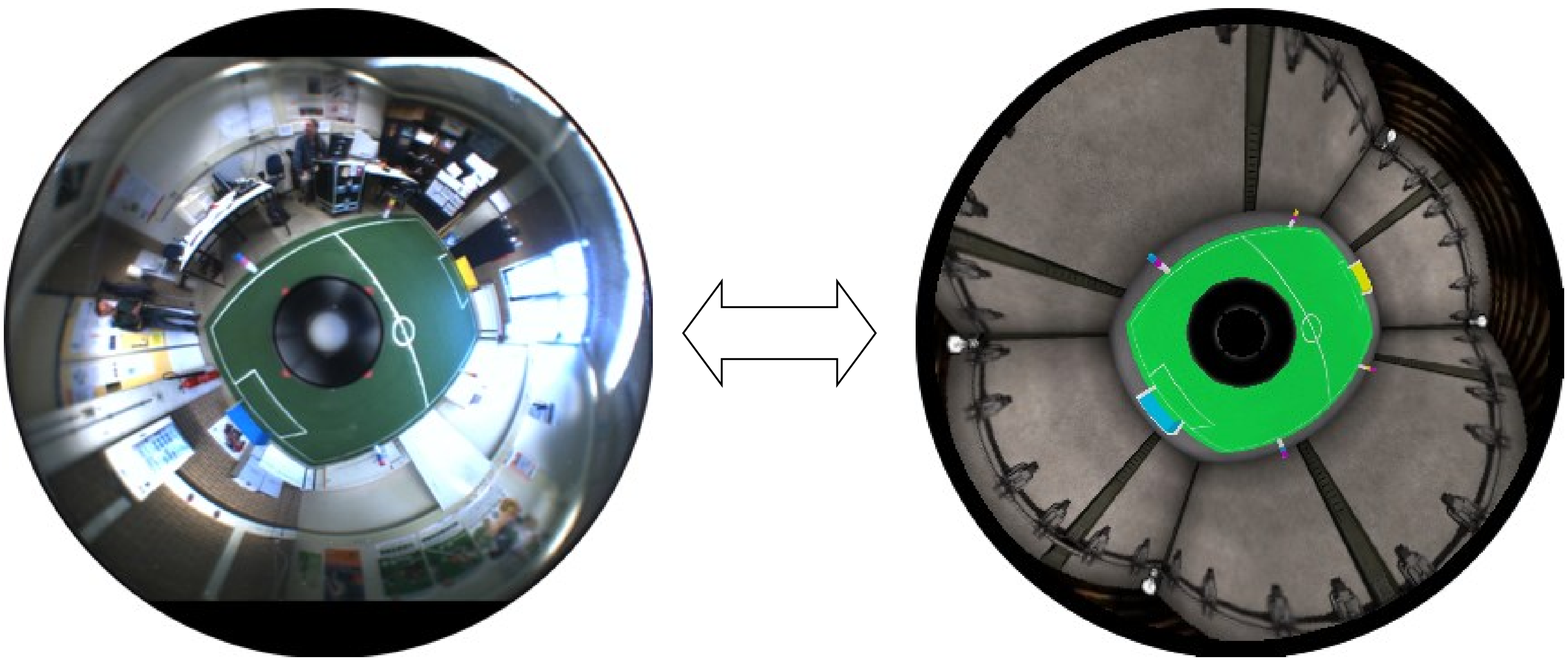
Simulation Model Development
- Single Viewpoint -

- Around the center:
  - 5 security monitors
  - surface of monitors can have any shape
  - selected parabolic
  - images of 5 cameras projected on 5 monitors
  - transformation between flat and convex surface

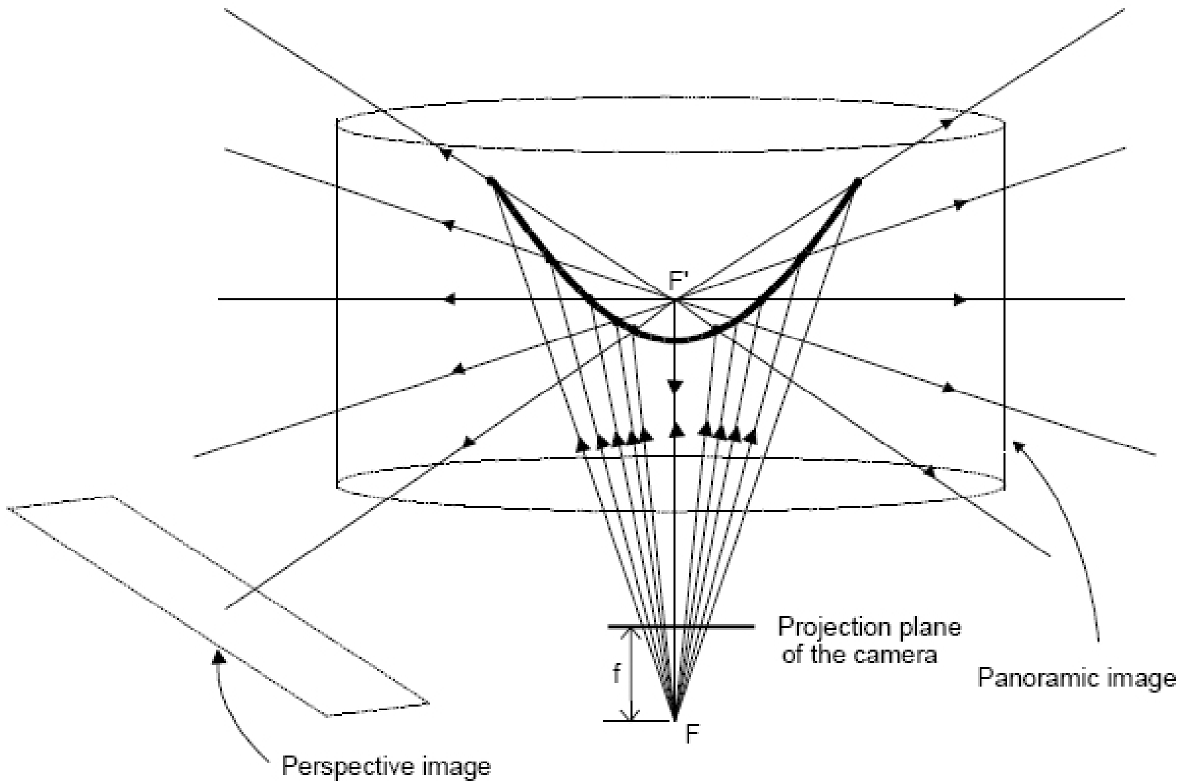


Simulation Model Development

- Verifying mirror and camera design



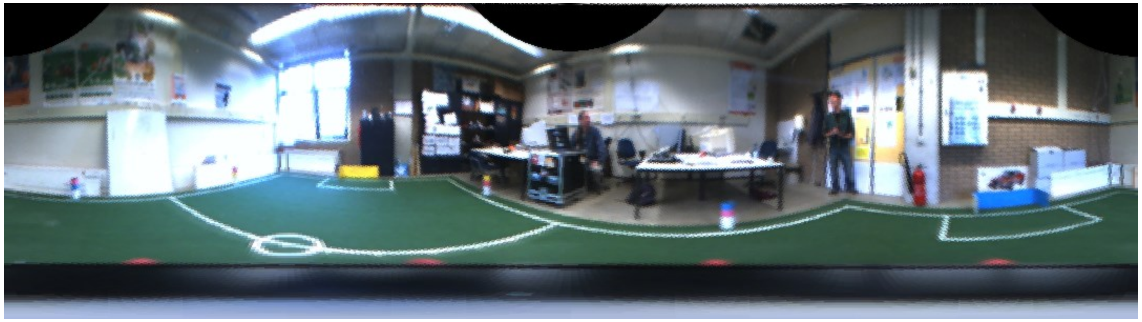
Single Viewpoint Constraint

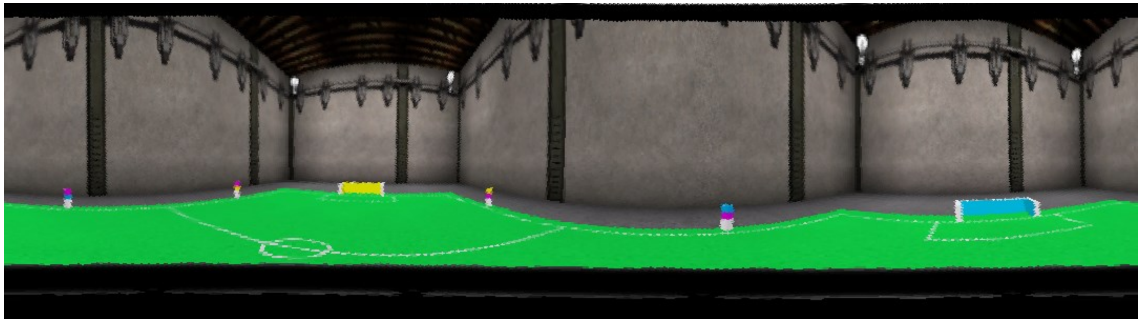


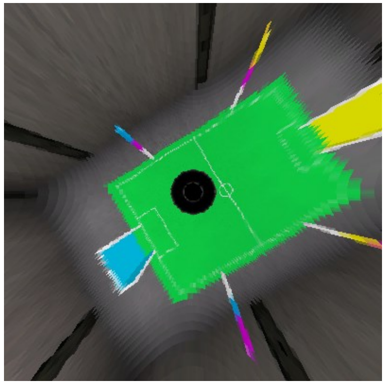
- Omnidirectional image can be translated into other perspectives

Simulation Model Development

- Verifying mirror and camera design







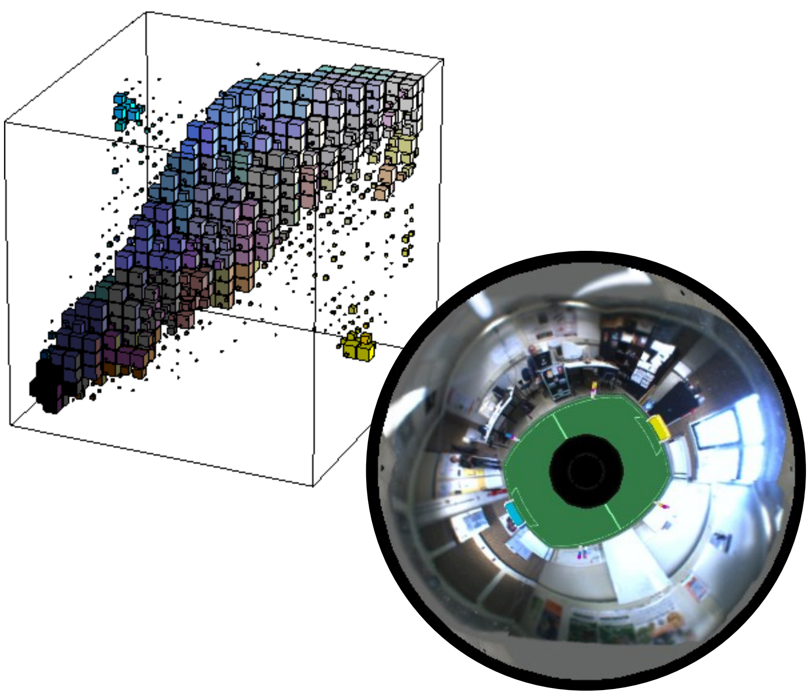
Validating the Simulation Model
- Landmark Detection -

- USARSim environment – textured: walls of the Intelligent Systems Laboratory Amsterdam ISLA

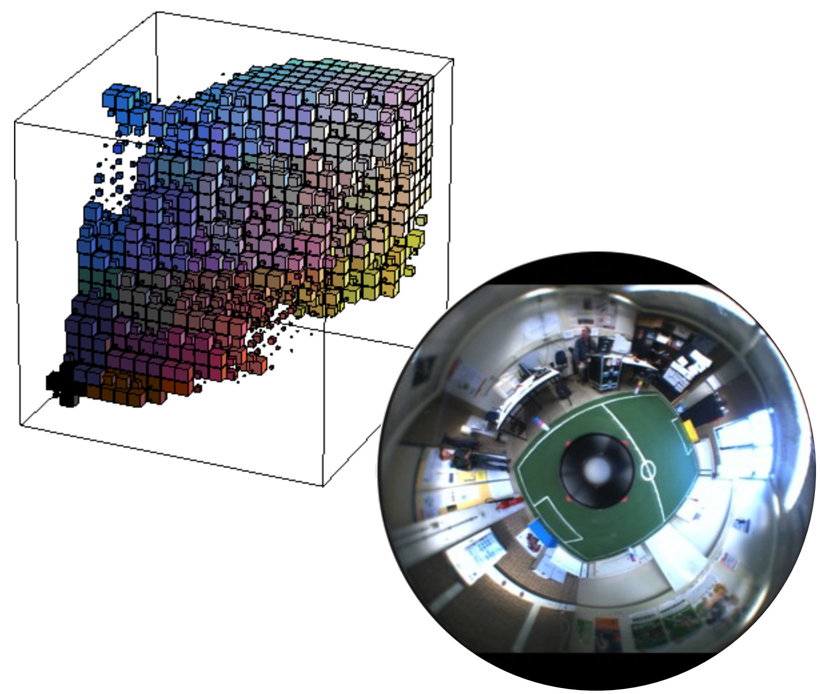
Validating the Simulation Model
- Landmark Detection -

- Results:

ISLA



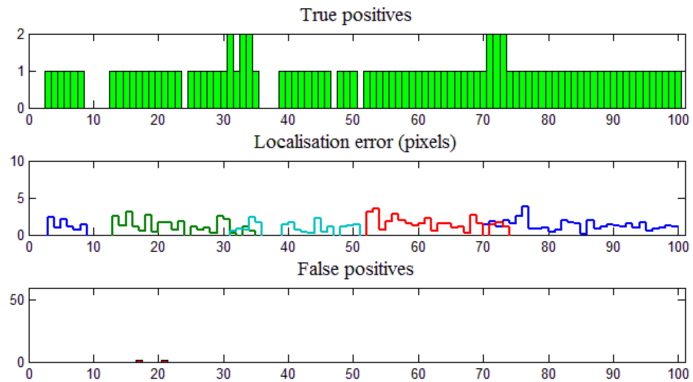
Amsterdam



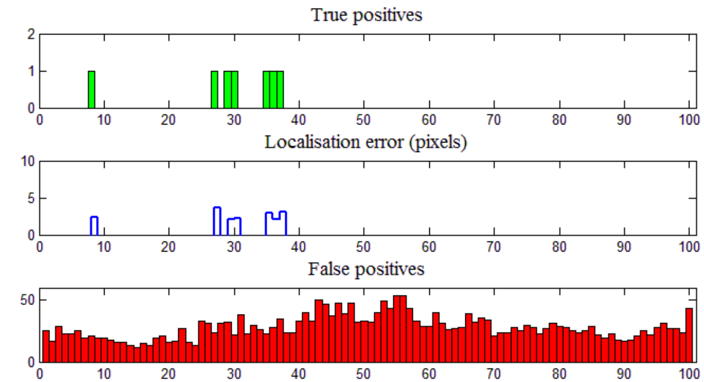
Validating the Simulation Model
- Landmark Detection -

- Results:

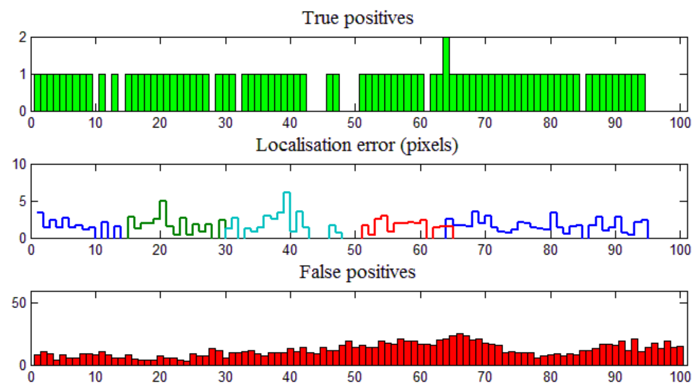
USARSim



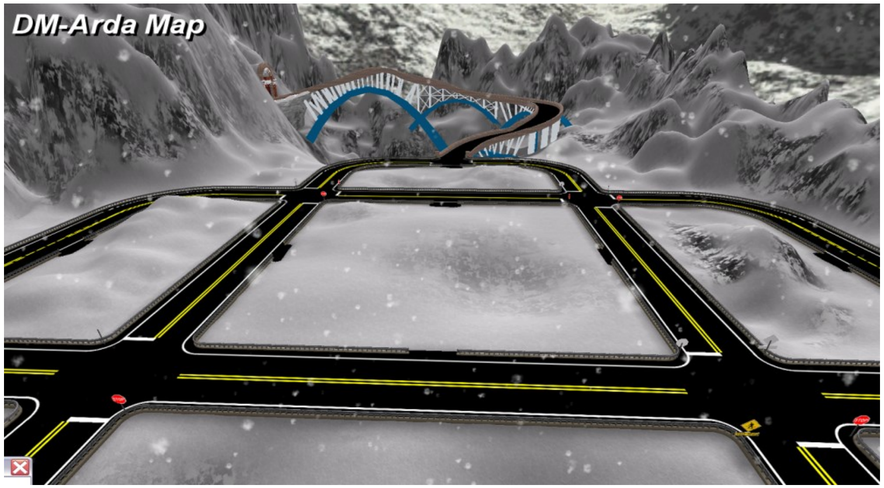
Amsterdam

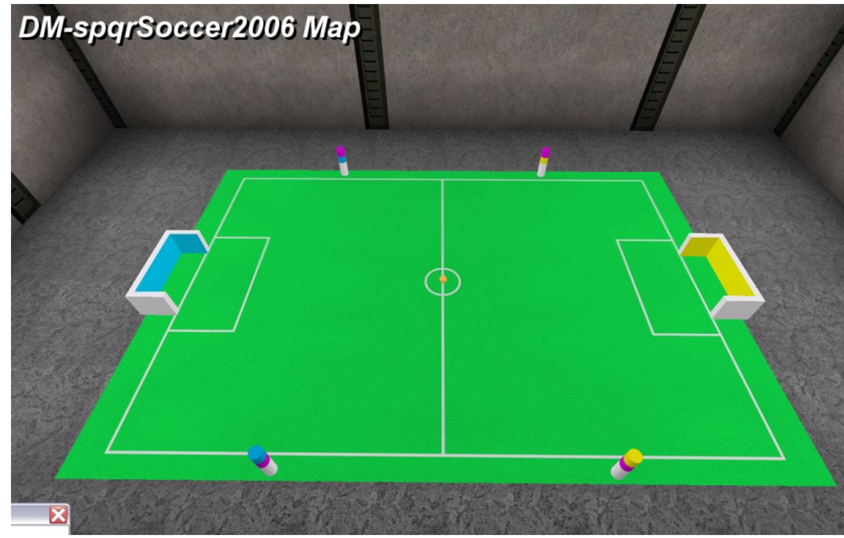


ISLA

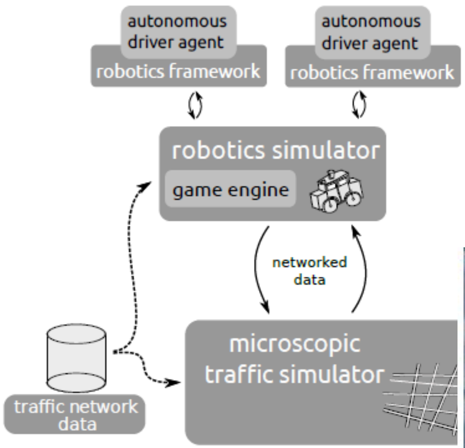


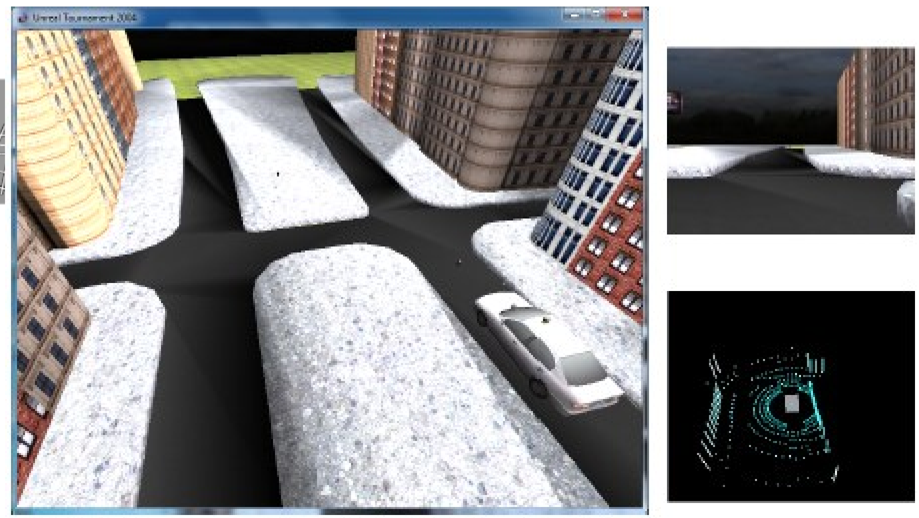
USARSim: A wide variety of worlds

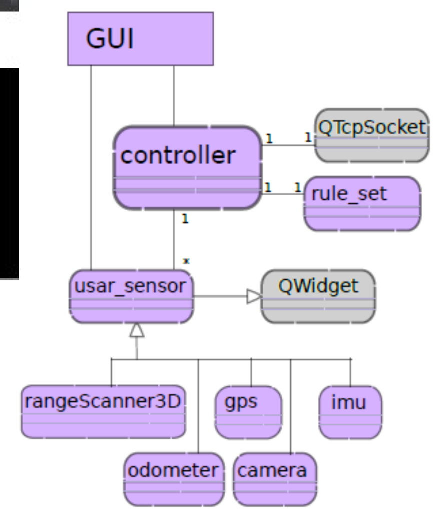




DARPA Urban Challenge

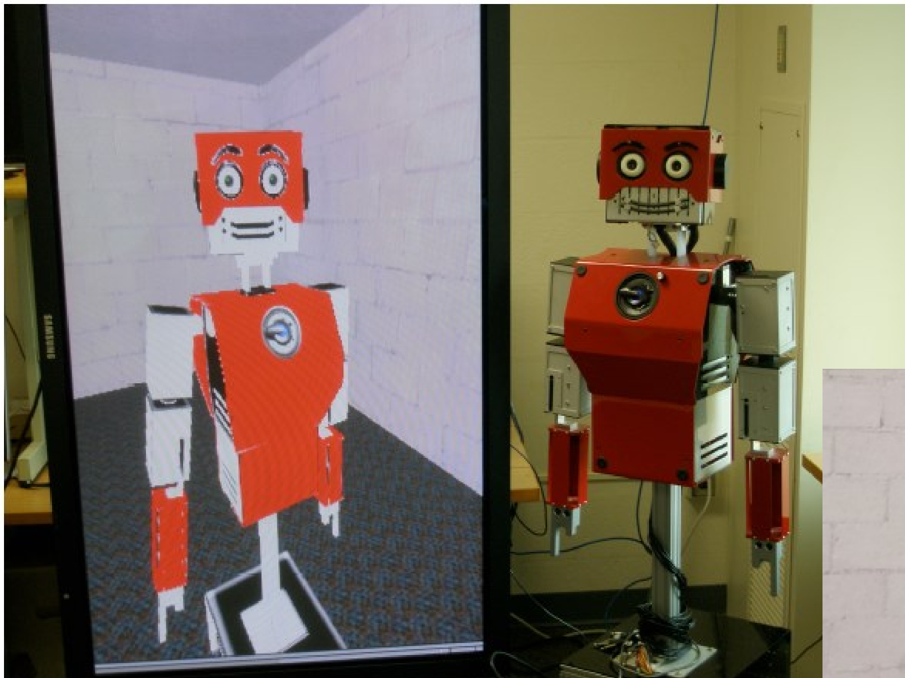






[6] Pereira, José LF, and Rosaldo JF Rossetti. "An integrated architecture for autonomous vehicles simulation." Proceedings of the 27th annual ACM symposium on applied computing. ACM, 2012.

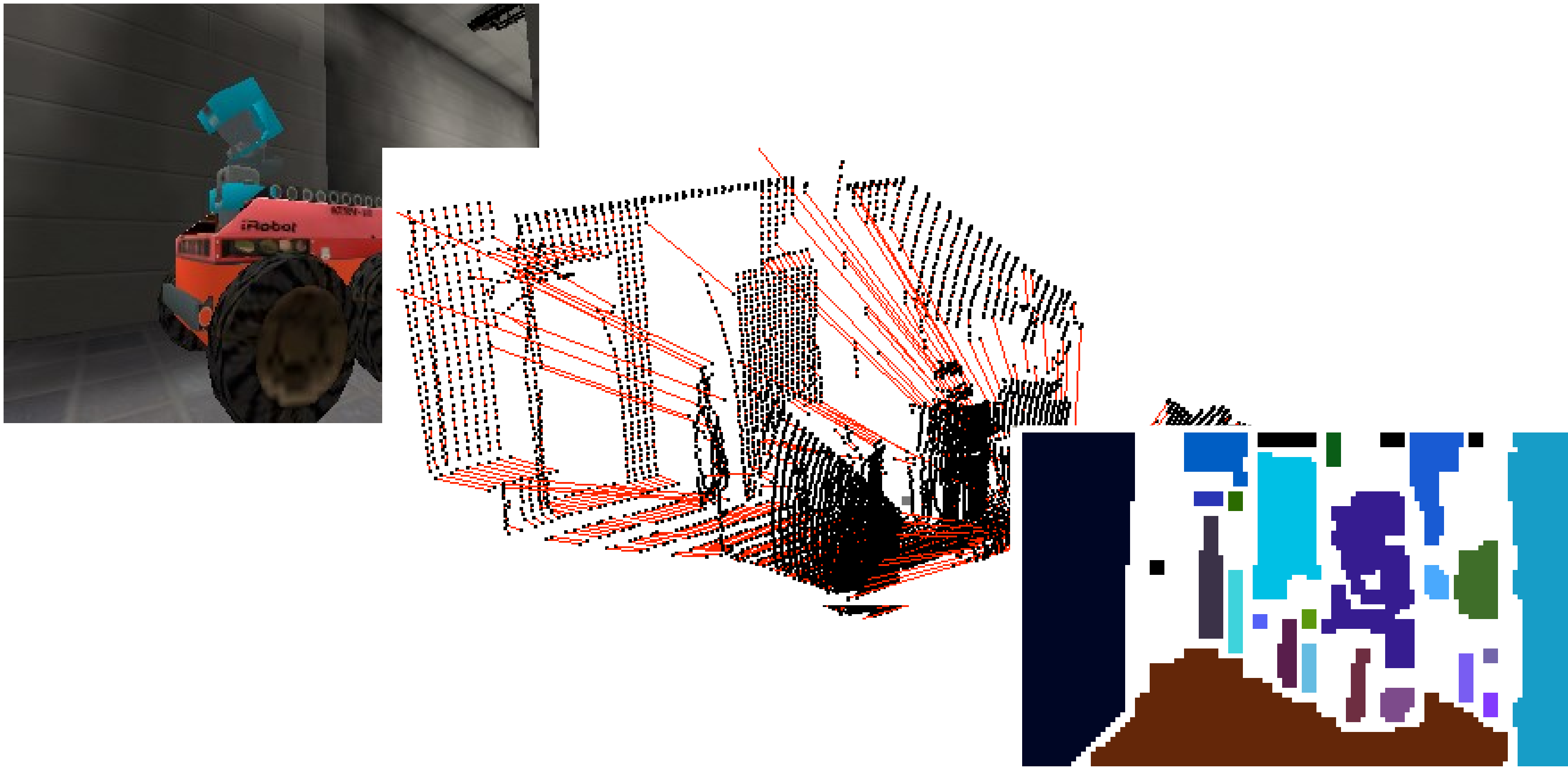
Human Robot Interaction



Happy and angry robot CRAMER

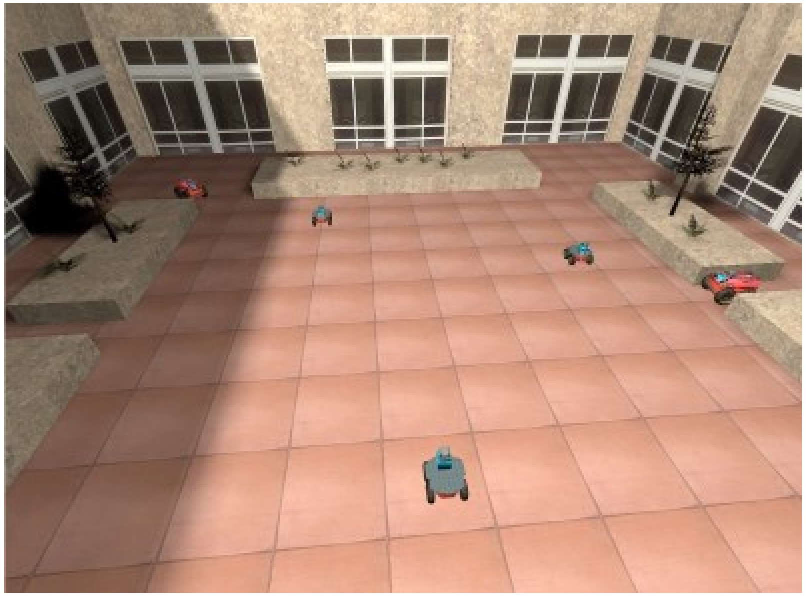
[7] Kyle Carter, Matthias Scheutz, Paul Schermerhorn. "*A Humanoid-Robotic Replica in USARSim for HRI Experiments*." Proceedings of the International Conference on Intelligent Robots and Systems (IROS 2009), Workshop on Robots, Games, and Research: Success stories in USARSim, p. 3-9.

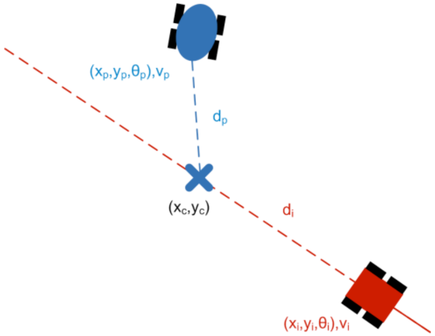
3D mapping

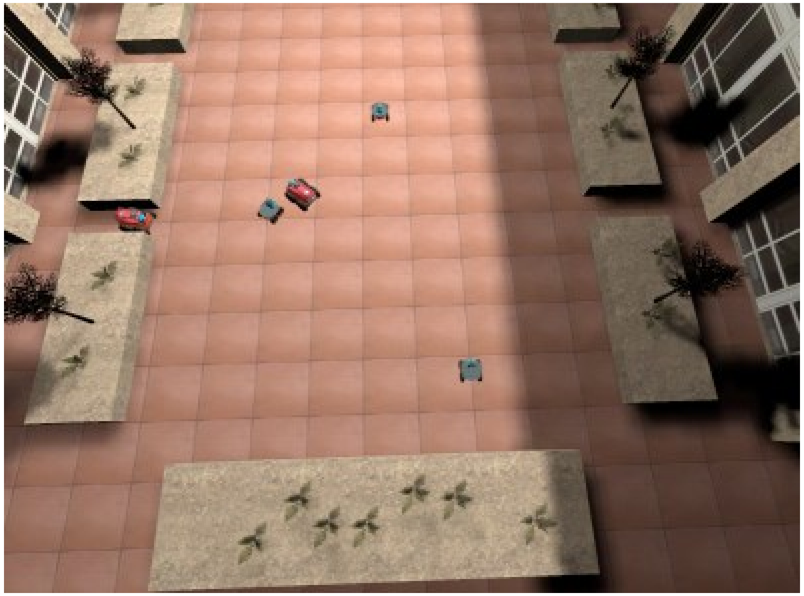


[7] Paloma de la Puente, Alberto Valero, Diego Rodriguez-Losada. "*3D Mapping: testing algorithms and discovering new ideas with USARSim*." Proceedings of the International Conference on Intelligent Robots and Systems (IROS 2009), Workshop on Robots, Games, and Research: Success stories in USARSim, p. 35-40.

Intruder Pursuit

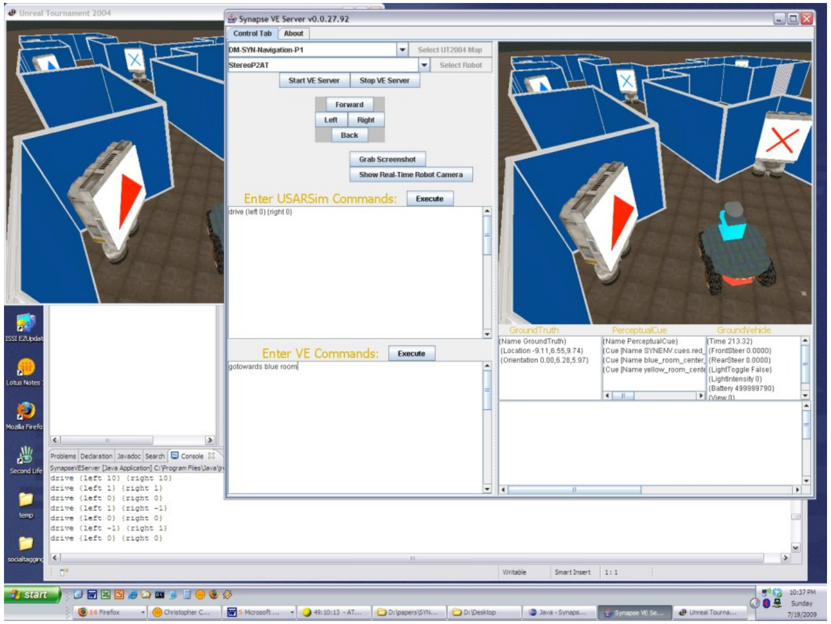


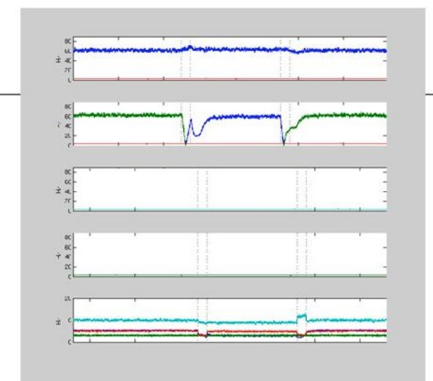




[8] Paul Ng, Damjan Miklic, and Rafael Fierro. "*A USARSim-based Framework for the Development of Robotic Games: An Intruder-pursuit Example*." Proceedings of the International Conference on Intelligent Robots and Systems (IROS 2009), Workshop on Robots, Games, and Research: Success stories in USARSim, p. 49-54.

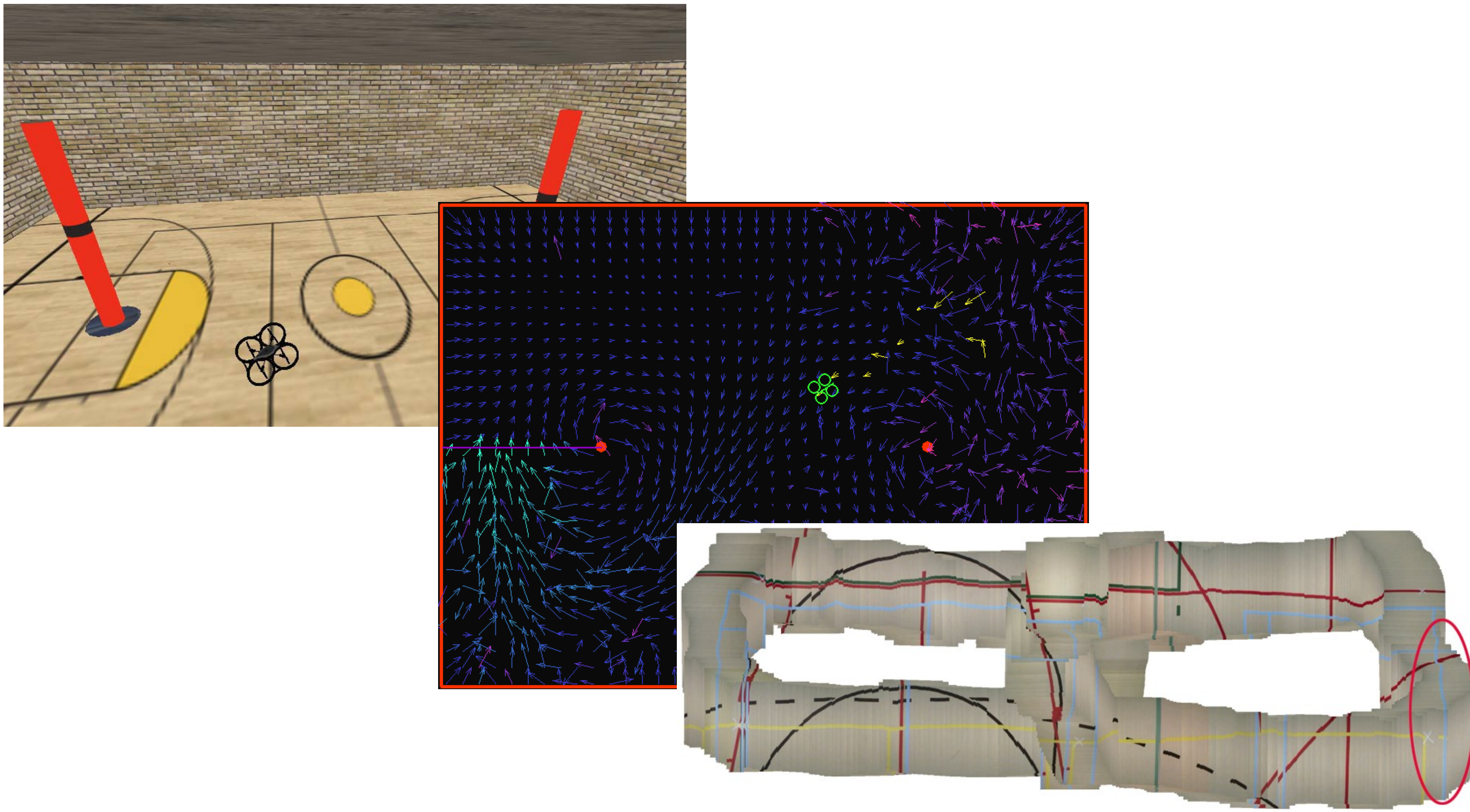
Retina model & Spiking Navigation





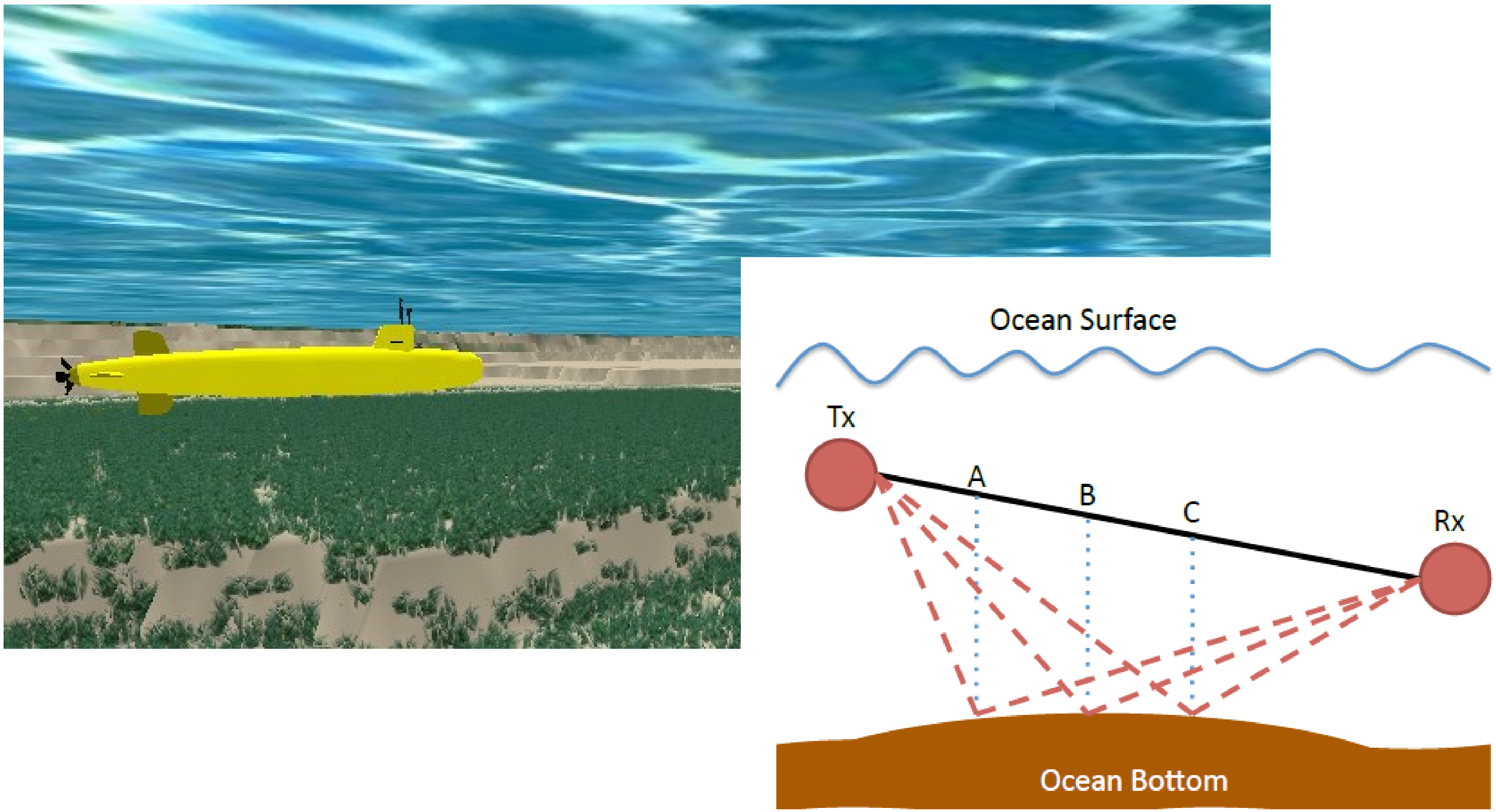
[9] Christopher S. Campbell, Ankur Chandra, Ben Shaw, Paul P. Maglio, Christopher Kello. "*Neuromorphic System Testing and Training in a Virtual Environment based on USARSim*." Proceedings of the International Conference on Intelligent Robots and Systems (IROS 2009), Workshop on Robots, Games, and Research: Success stories in USARSim, p. 60-67.

USARSim in the air



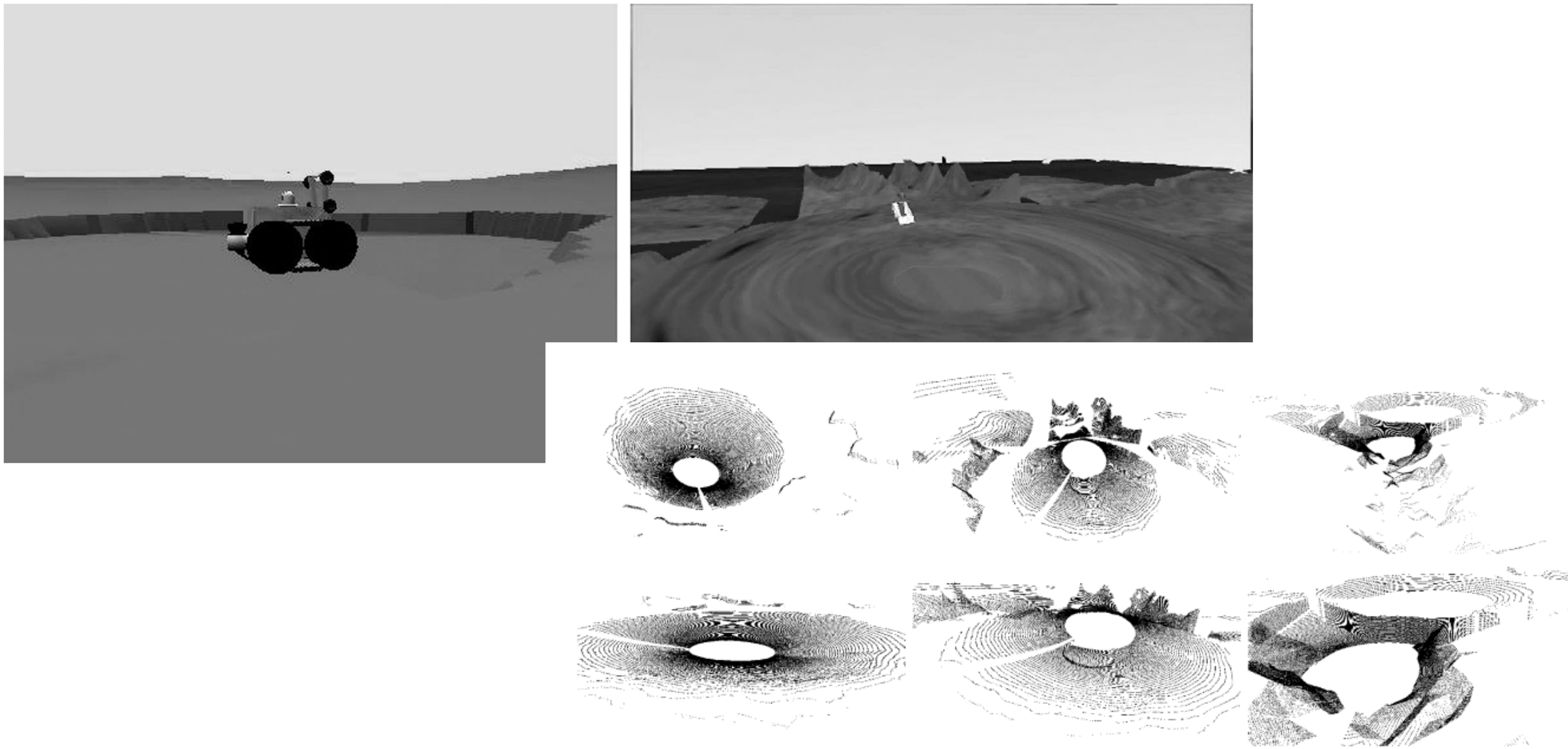
[10] Arnoud Visser, Nick Dijkshoorn, Martijn van der Veen and Robrecht Jurriaans, Closing the gap between simulation and reality in the sensor and motion models of an autonomous AR.Drone, Proceedings of the International Micro Air Vehicle Conference and Flight Competition (IMAV11), page 40-47, September 2011.

Underwater USARSim



[11] Sehgal, Anuj, Daniel Cernea, and Andreas Birk. "Simulating Underwater Acoustic Communications in a High Fidelity Robotics Simulator." 7th IFAC Symposium on Intelligent Autonomous Vehicles, University of Salento, Lecce, Italy, 6-8 Sept. 2010. Elsevier, 2010.

USARSim in Space



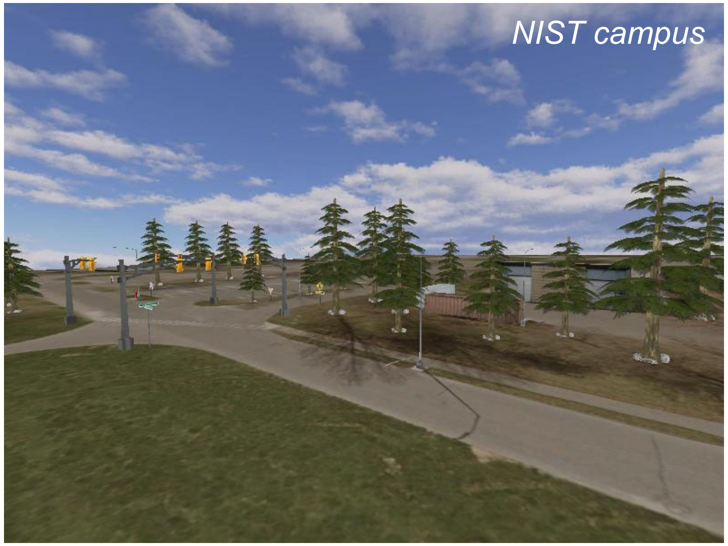
[11] Narunas Vaskevicius , Andreas Birk , Kaustubh Pathak & Sören Schwertfeger (2010) Efficient Representation in Three-Dimensional Environment Modeling for Planetary Robotic Exploration, Advanced Robotics, 24:8-9, 1169-1197

Conclusion

Many challenges can be realistically modelled in USARSim.

USARSim provides:

- Researchers rapid prototyping tools.
- Extensive training possibilities for Machine Learning applications
- Students quick access to robotic testbeds



- **Robots, Games, and Research: Success stories in USARSim**
  A full day workshop held at IROS 2009
  Steve Balakirsky, Stefano Carpin and Mike Lewis
- **USARSim/MOAST: Highly Realistic Simulation and Control for Multi Robot**
  A full day workshop held at ICRA 2006
  Stefano Carpin, Mike Lewis, Adam Jacoff, and Stephen Balakirsky
- **Urban search and rescue: from Robocup to real world applications**
  A full day workshop held at IROS 2004
  Stefano Carpin, Andreas Birk, Daniele Nardi, Adam Jacoff and Satoshi Tadokoro

www.robocuprescue.org/wiki/

Publications on Virtual Robots and USARSim

Research using USARSim (incomplete chronological list)

- Arnoud Visser, Nobuhiro Ito and Alexander Kleiner, "RoboCup Rescue Simulation Innovation Strategy", in RoboCup 2014: Robot World Cup XVIII, Springer Lecture Notes on Artificial Intelligence series, volume 8992, May 2015, pp. 661-672. pdf .
- Tomoichi Takahashi and Masaru Shimizu - How can the RoboCup Rescue Simulation contribute to emergency preparedness in real-world disaster situations?, Proceedings of the 18th RoboCup Symposium, João Pessoa, July 2014. pdf.
- Masaru Shimizu, Tomoichi Takashi (2013), "Training Platform for Rescue Robot Operation and Pair Operations of Multi-Robots", Advanced Robotics SSRR issue, Vol.27, No.5, pp.385-391, March 15, 2013. publisher.
- H.L. Akin, N. Ito, A. Kleiner, J. Pellenz and A. Visser (2013), "RoboCup Rescue Robot and Simulation Leagues", AI Magazine, Vol 34, No.1, pp.78-86, 2013. publisher.
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- Z. Kira, R.C. Arkin and T. R. Collins (2010), "Design Process for Robot Capabilities and Missions Applied to Microautonomous Platforms, Defense Technology Information Center.
- M.A.Sharbafi, S. Taleghani, E. Esmaeili and A.T.Haghighat, O. Aghazadeh (2010). "ICE Matching, a Novel Approach for Localization Problem", Proc. of IEEE International Conference on Control, Automation and Systems, p. 1904-1907, October 2010.