PURESAFE
Preventing hUman intervention for IncREased SAfety inFrastructures Emitting ionizing radiation

RP 8

DESIGN AND EVALUATION OF MODULAR ROBOTS FOR MAINTENANCE IN LARGE SCIENTIFIC FACILITIES

ESR: Prithvi Sekhar Pagala

Supervisor: Manuel Ferre
Universidad Politécnica de Madrid

Project: 07/11 – 07/14

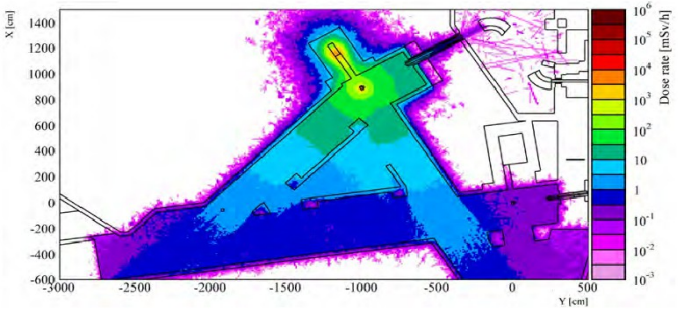
Final Conference, 19th – 23rd January 2015
Geneva, Switzerland

Background Information

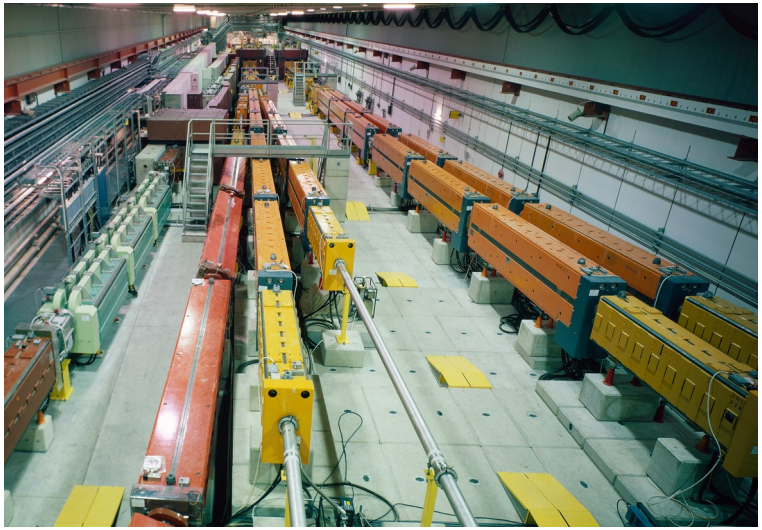
- ESR – Prithvi Sekhar Pagala
- Supervisor – Manuel Ferre
- Organisation – Centre for Automation and Robotics
  Joint center (UPM - CSIC)

- University - Universidad Politécnica de Madrid
- PhD Supervisor - Manuel Ferre and Manuel Armada
- Defended – 7th July 2014

Environment



Radiation Map

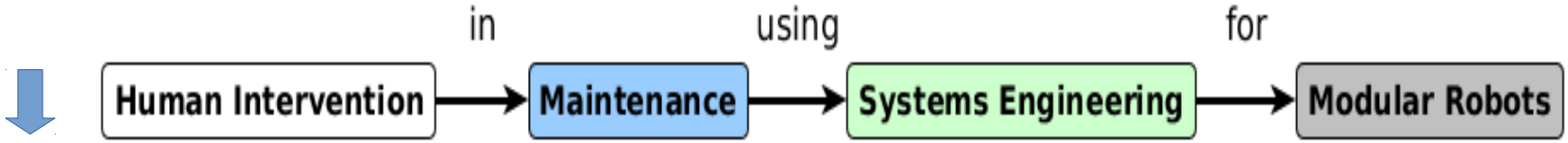


Multiple Beamlines (TCC2 – North Hall)

TIM robot passing LHC access door

Single Beamline (LHC Mockup)

Requirement

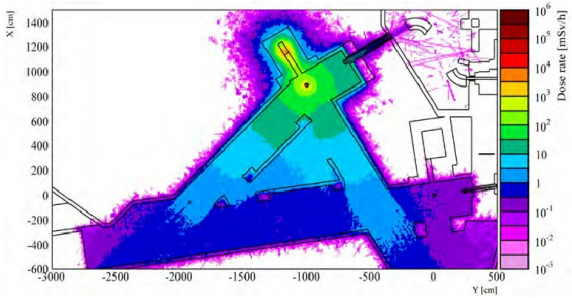


Needs

- Flexible solutions for use across facility
- Adaptability to tasks
- Extendability of lifetime
- Reusability
  - Tools, modules, interfaces and reduce repetition
- Cost reduction
  - Not compromising safety and reliability

Modular Robot Design

Why Heterogeneous ?



Ionising radiation Map

- Simple, Isolated Electronics
  - Ionising Radiation
    - High energy particles cause SEE (Single Event Effects)
    - Causing reset, burnout and latch-up in Silicon

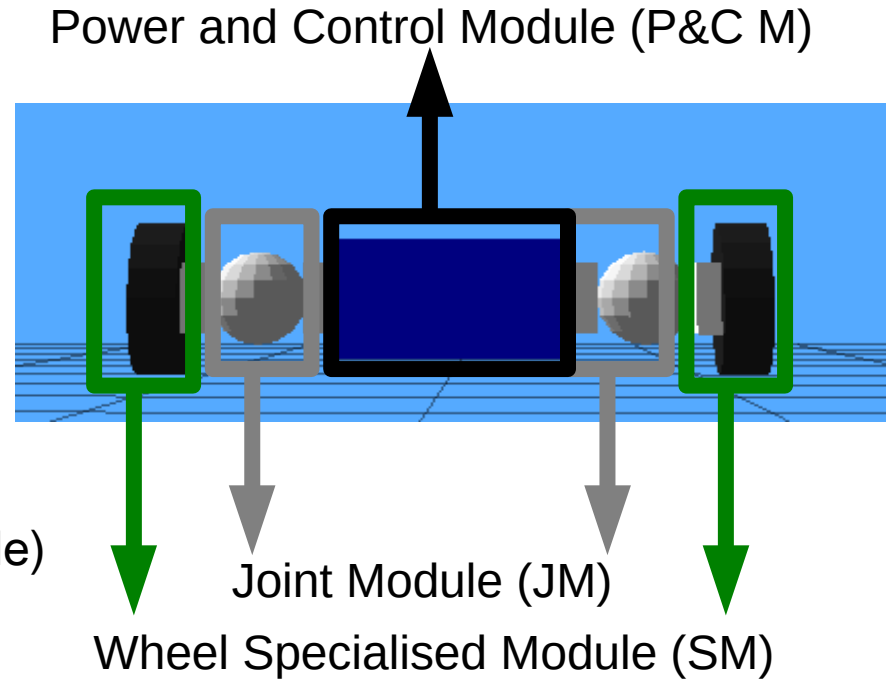
- Modularised for functionality
  - Actuation, Electronics, Task specific additions
    - Task determines the torque and speed necessary
    - Location determines tools and radiation hard modules
    - Selective upgrades over lifetime and during maintenance

Generic Modular Robot

Three types of modules :

J – Module (Joint Module)

- Actuation 1-3 DOF
- Reused from previous works
  - Axis of rotation intersect



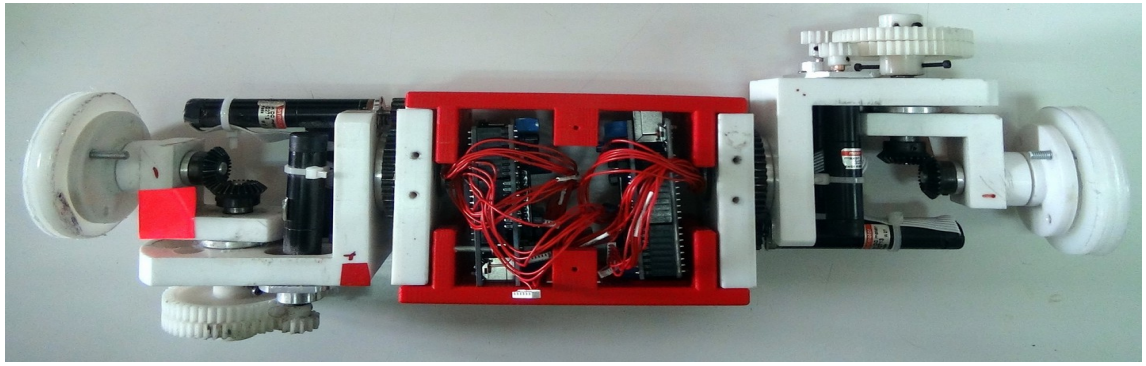
PC Module (Power & Control Module)

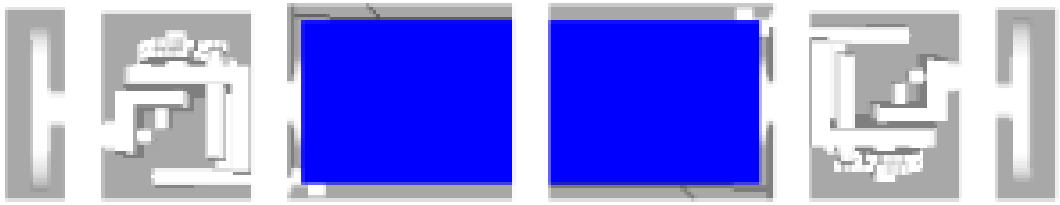
- Electronics and power
  - Simple and spread electronic chips

S-Module (Specialized Module)

- Task specific tools, radiation probe, camera, light, gripper and others

Modular Robot



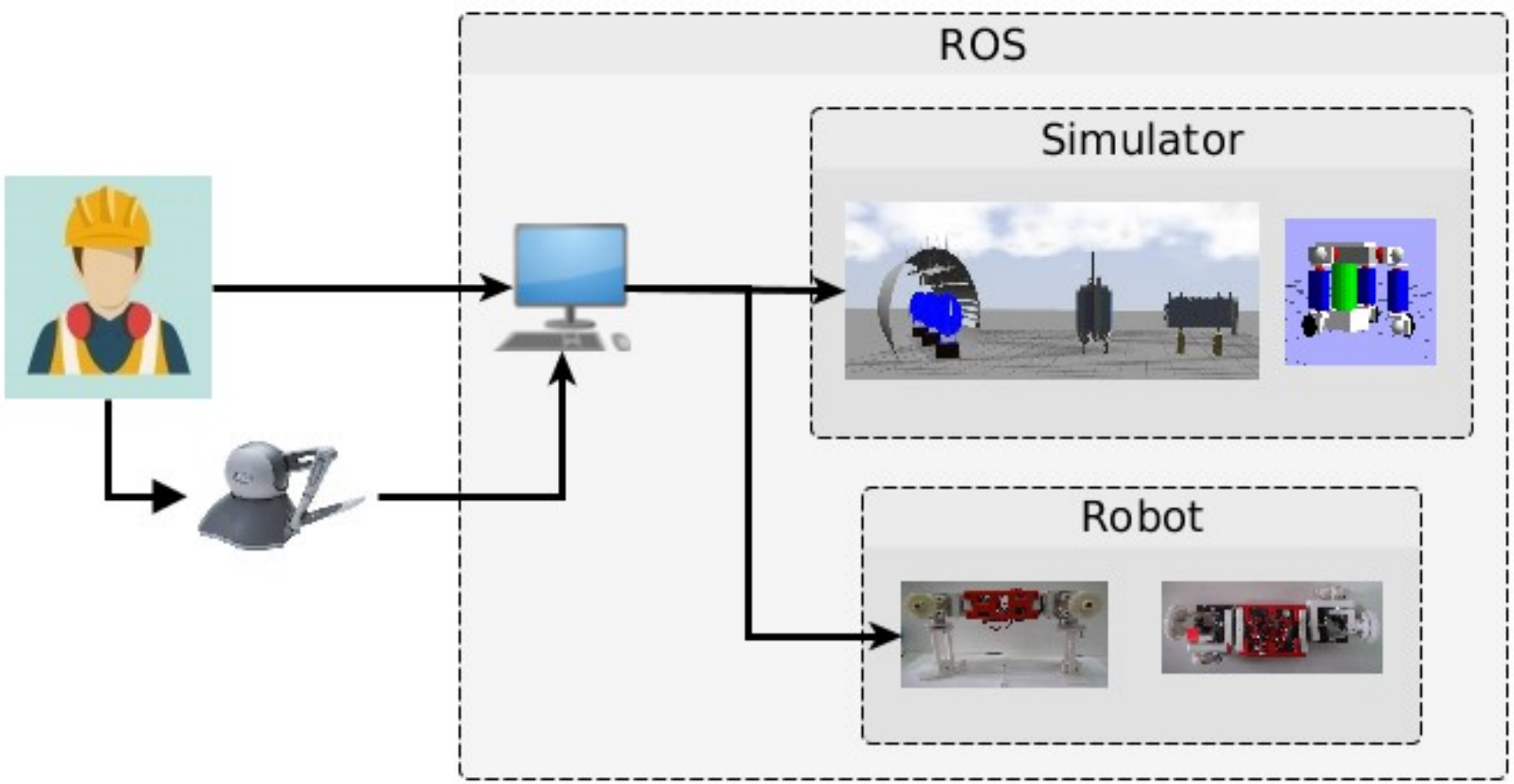


Wheel , Joint , Two Power and Control , Joint, Wheel

S module, J Module, P&C Modules

- Specialised module (SM) connect to PC or J module
  - Sensor SM require power and communication channels
- Joint module has to connect to PC module
- Power & Control (PC) modules are placed together for easier shielding

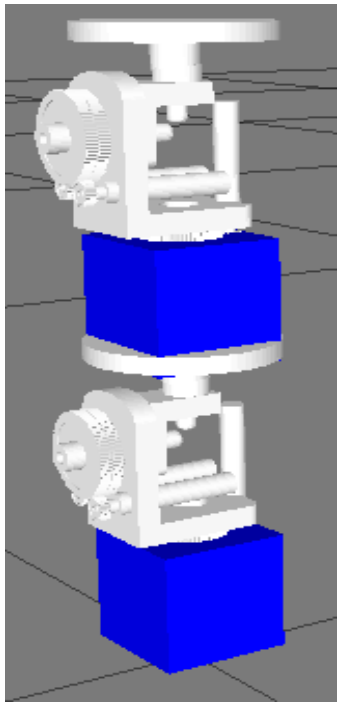
System Interface

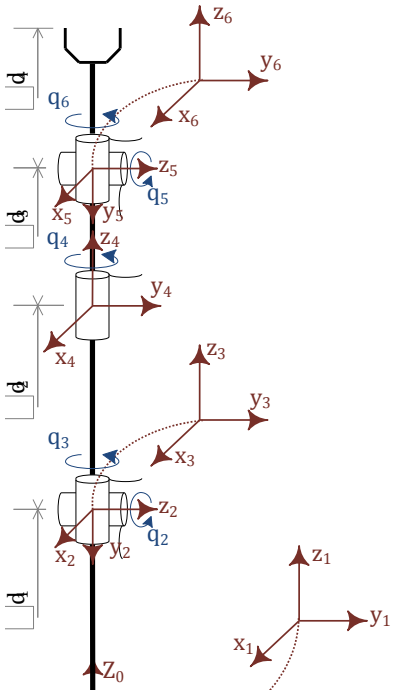


Operator – HMI – Middleware – Simulator or Robot and Visualisation

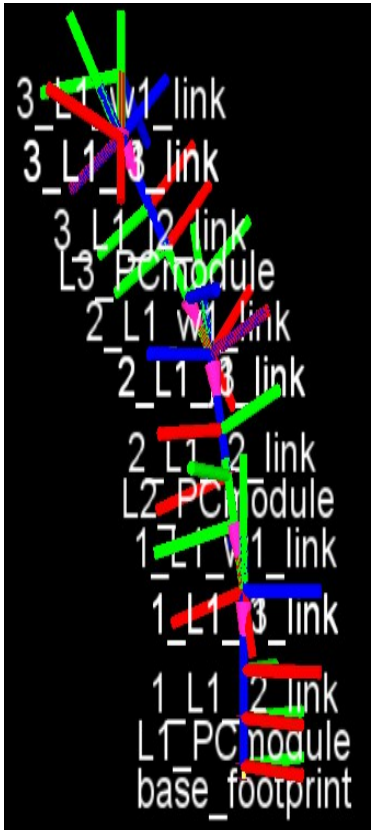
Simulator- 3D with physics engine (ODE, bullet), sensors and plugins support
Driver and robot packages for the robot and simulator were made

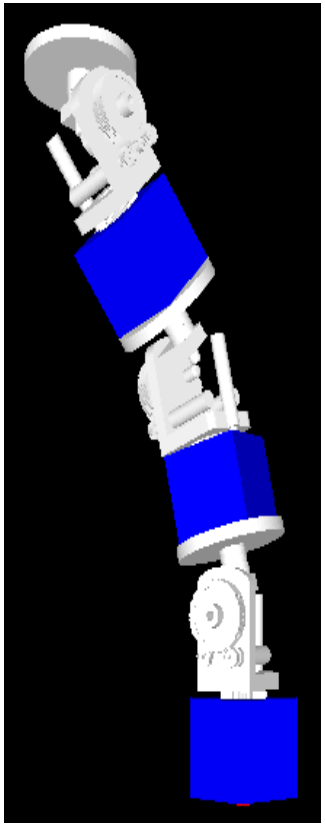
Configuration: Arms





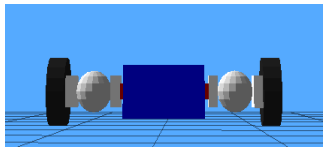
2 Joint Module (JM) Arm Configuration type 2

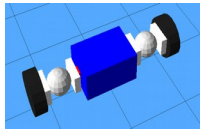


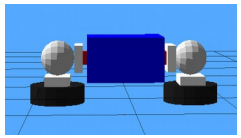


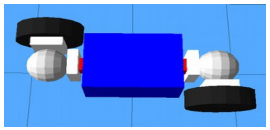
3 Joint Module (JM) Arm Configuration type

Configuration: Mobile Platform







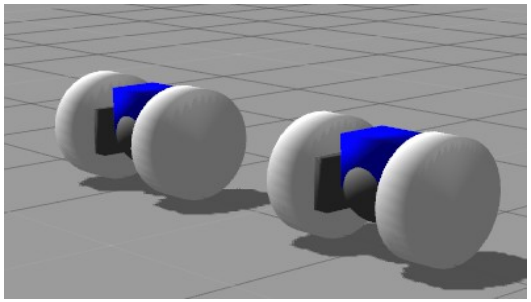


Wheel rotation motor

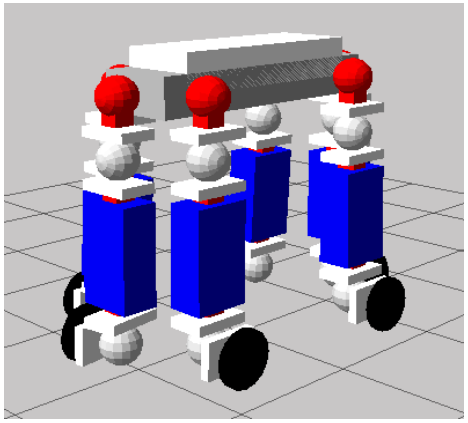
Joint rotation

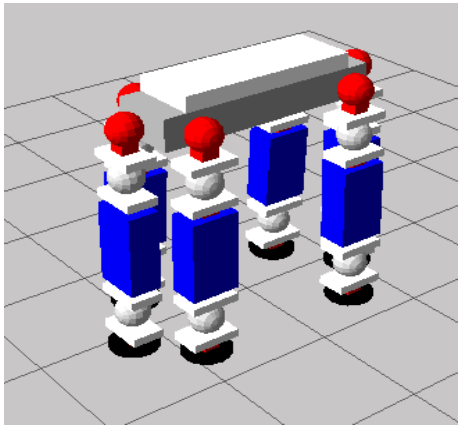
Tangential wheel

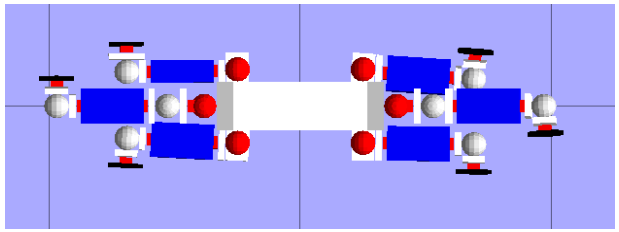
Wheeled modular robot configuration(MRC)
(2- Joint modules, Control modules and wheels S modules)



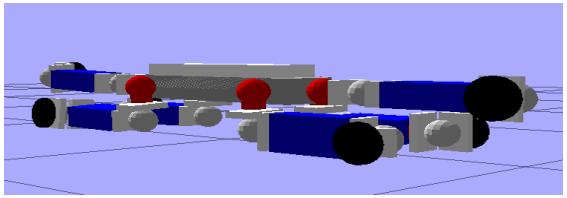
Simple mobile robot configuration (JM, PCM, 2 wheels)





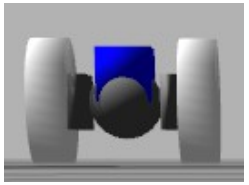


Reduced footprint (top, ortho view)

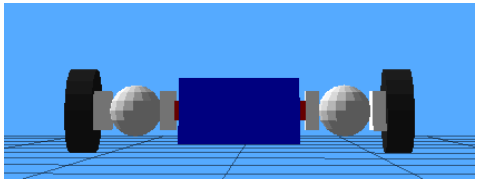


Multiple Leg/arm modular robot configuration (MRC)
Wheeled locomotion, legged locomotion

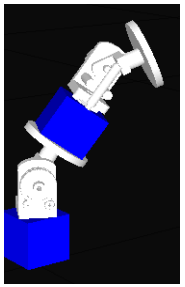
Cost of Robot Configuration



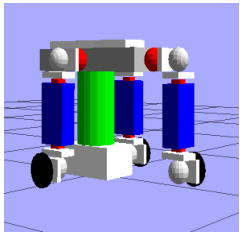
Minimal robot



Wheeled robot



Manipulator arm

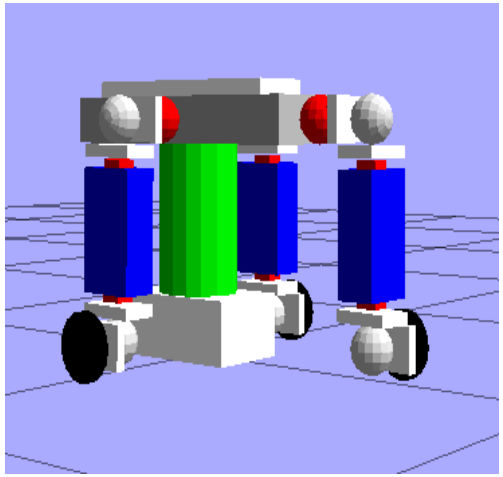


3 Arms/legs robot with powerbase

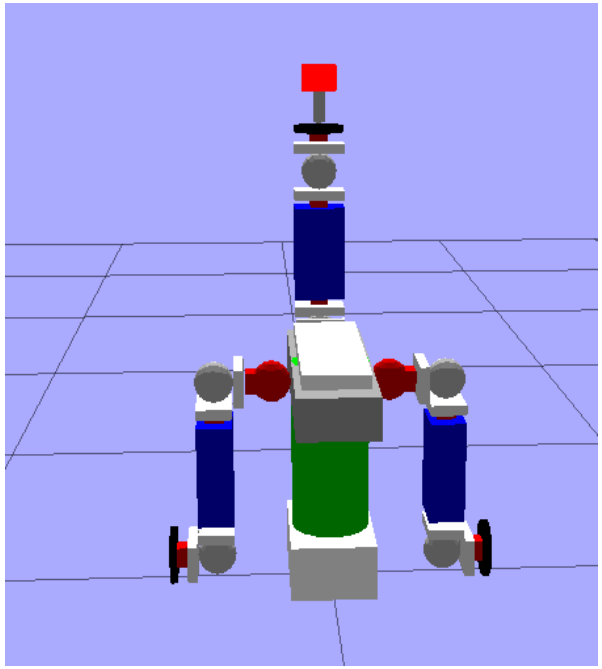
Configuration	Modules P&C (0.4)	J (0.4)	S (0.2)	Max DoF	Cost
Minimal robot	1	1	2	3	1.0
Wheeled robot	2	2	2	6	2.0
Arm manipulator (6 DoF)	2	2	3	6	2.2
Two arms with powerbase	4	4	9	12	5.0
Three arms with powerbase	6	6	12	18	7.2

Value- weighting factor with respect to manufacturing and maintenance cost
P&C- Power and control module
J- Joint module, S- Specialised module

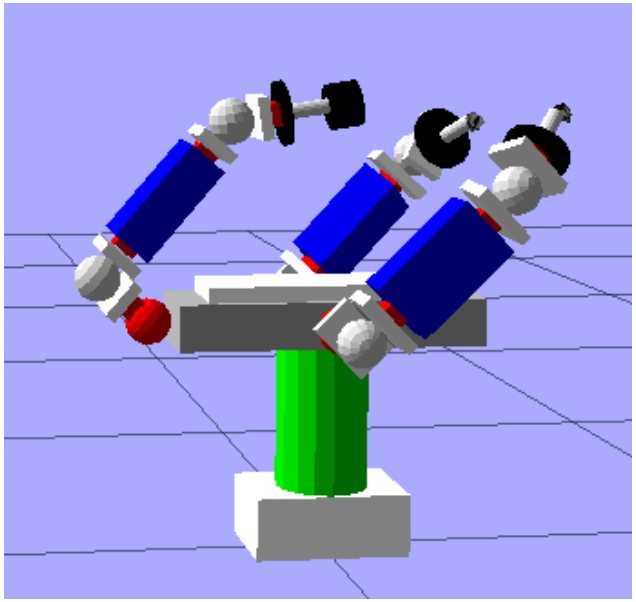
Robot Configuration- Tasks



Locomotion MR configuration



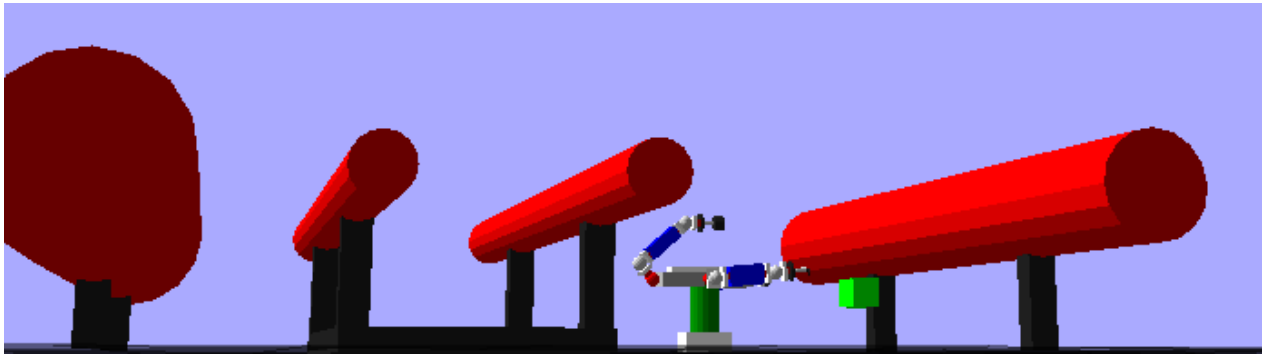
Radiation Map generation during locomotion



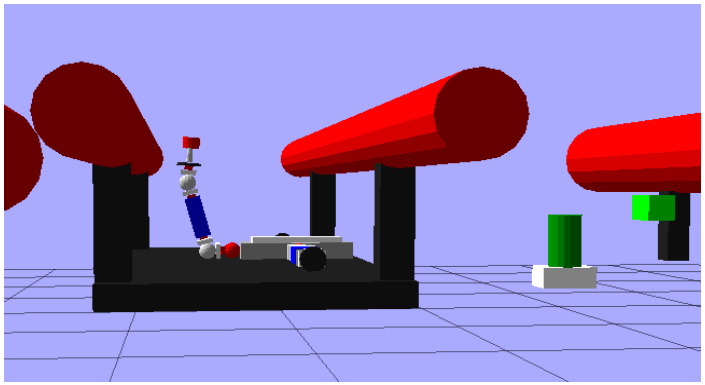
Manipulation MR configuration

Required sections of the accelerator store Powerbase in safe zones along with section specific tools

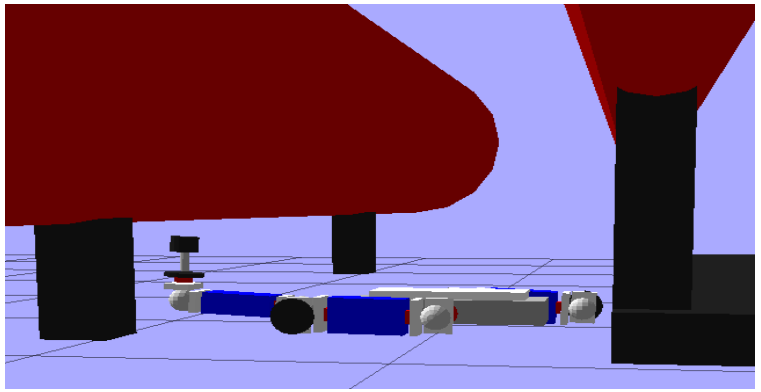
Multi-beam line task execution



Remote manipulation
On maintenance console



Remote radiation survey
At beam height



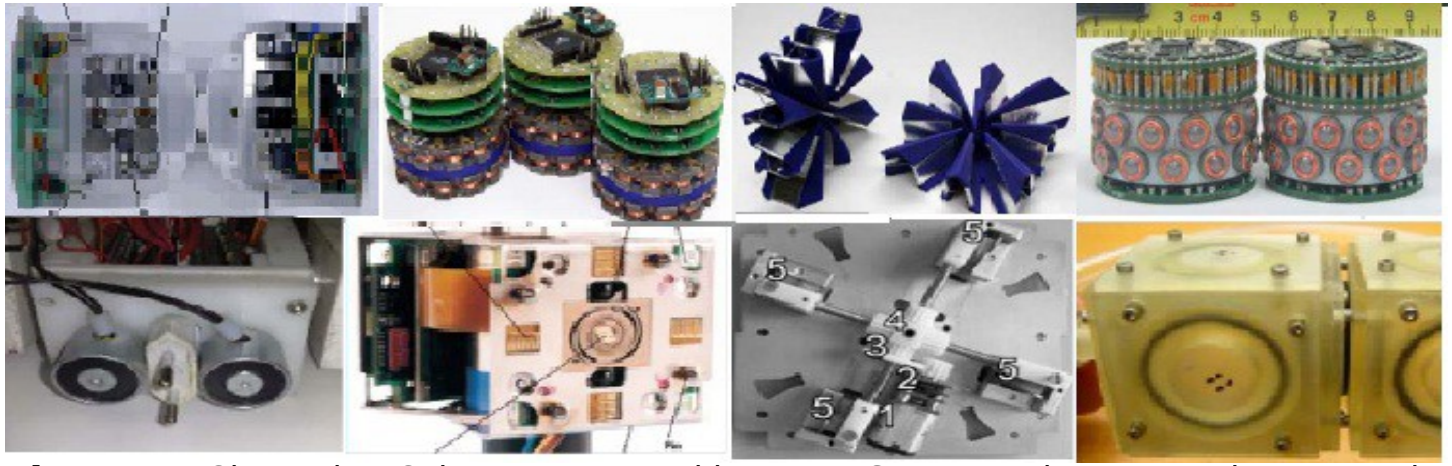
Remote inspection

[P. S. Pagala, J. Baca, M. Ferre, et al., “Modular robot system for maintenance tasks in large scientific facilities”, International Journal of Advanced Robotic Systems, vol. 10, no. 394]

Standardising Connector

Requirement and guidelines

- Alignment
  - Connector to tool
  - Guided with decreasing DoF
  - Gender
- Strength
  - Forces due to payload
- Scalable
  - Application dependent
- Energy & Communication
  - Interface for transfer
  - Contact success
- Maintenance & Manufacturing
  - Simple mechanism



[L-R][T-B] M-TRAN, Claytronics, Cubes, Programmable matter, SMART, PolyBot, Roombots, Vacuubes

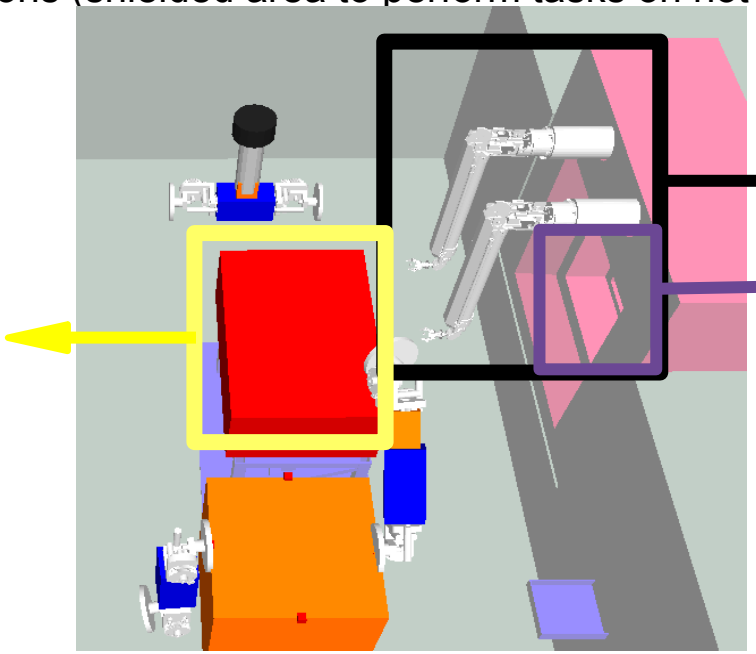
Collaboration with OTL (UK)

Collaboration- Robots

Collaboration with existing robots in facility

- Additional viewing
- Manipulation

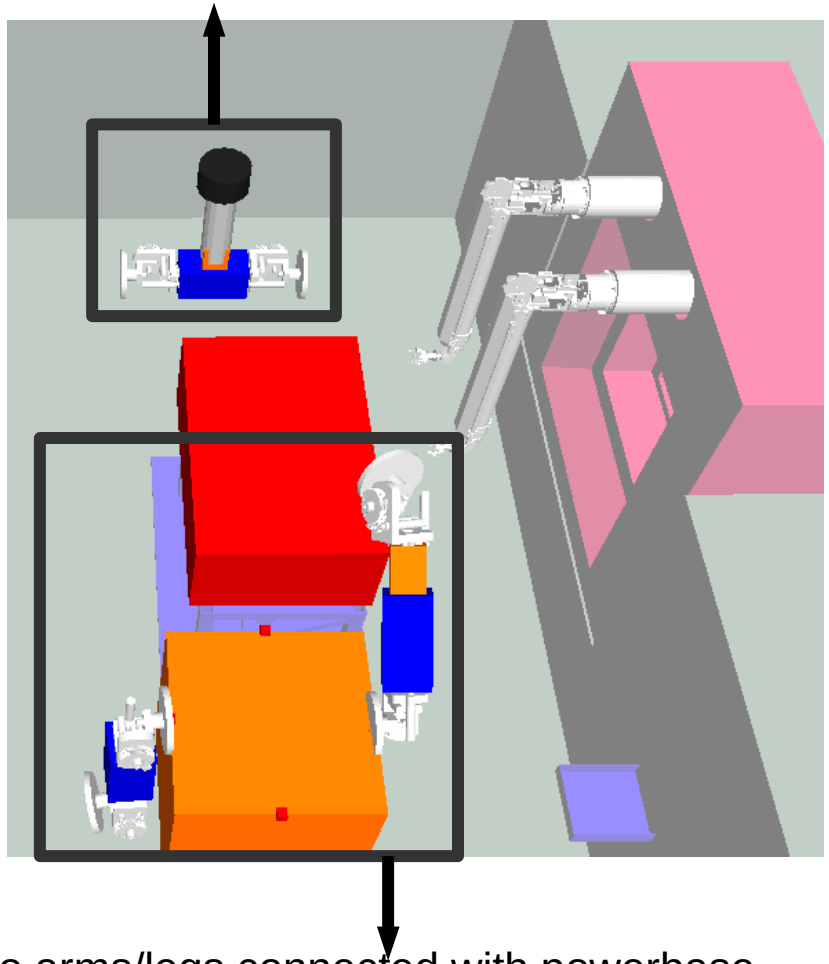
Like hot cell operations (shielded area to perform tasks on hot /radioactive objects)



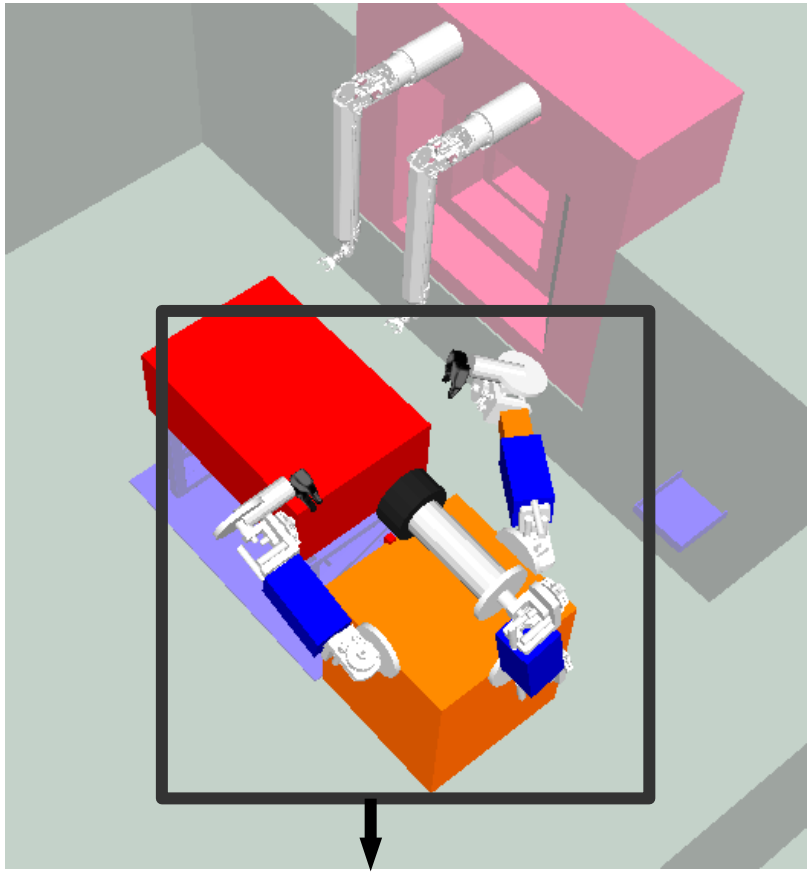
Collaboration with GSI (Germany)

Collaboration- Robots

Mobile robot with prismatic camera module

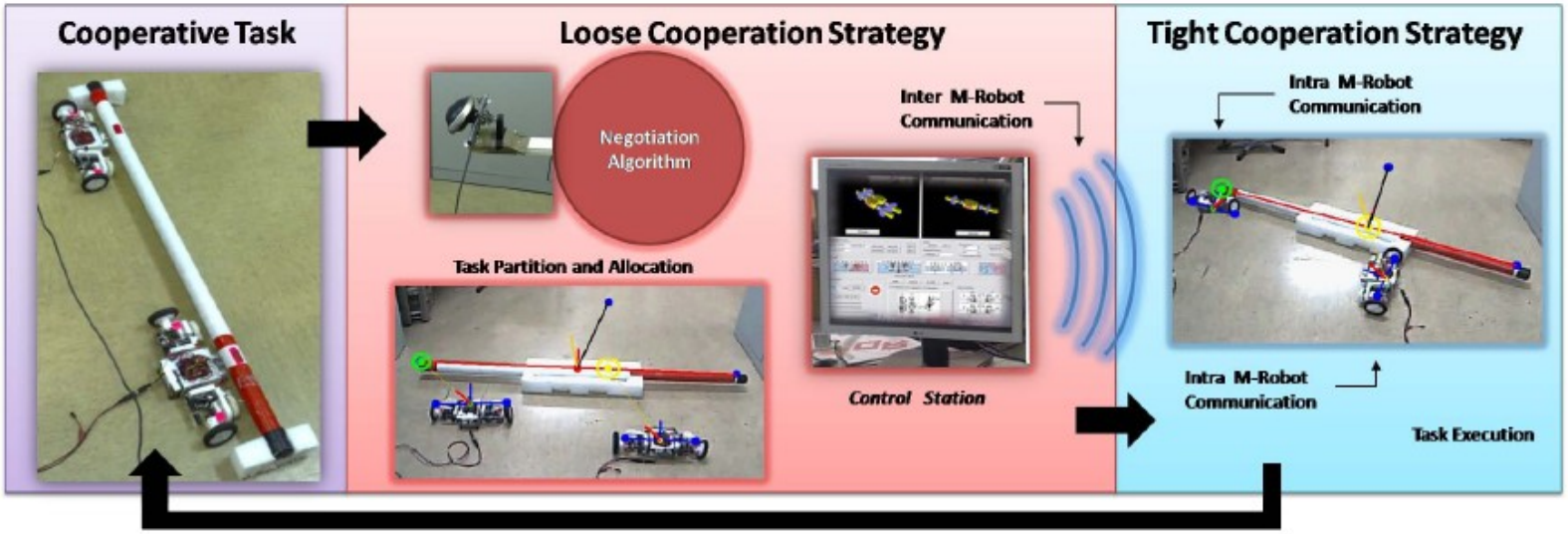


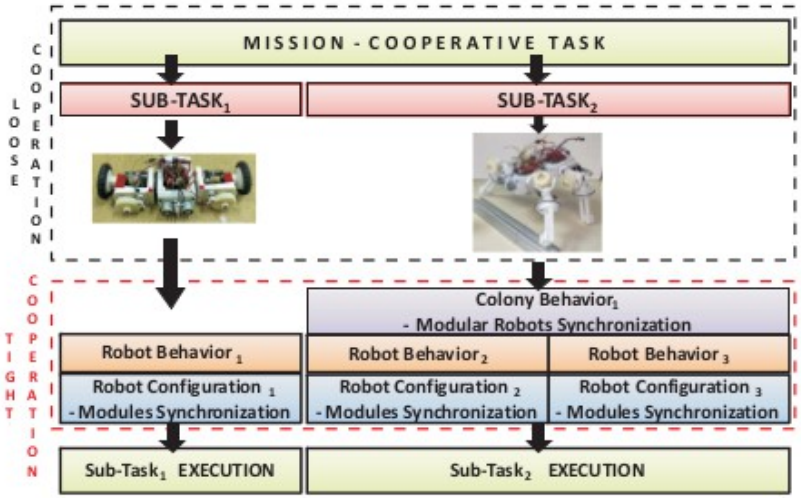
Two arms/legs connected with powerbase



Robot configuration to perform manipulation task

Cooperation between MRCs



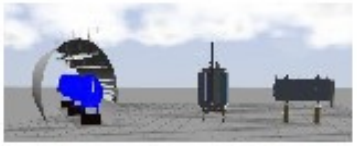
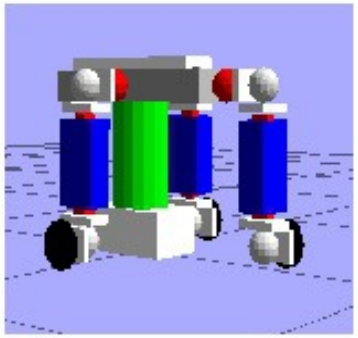


Sub dividing the tasks

Implementing the tight loose strategy for cooperation between the different modular robot configurations

MRCs- Modular robot configurations

Modularity in Robots

Approach			
	Simple	**Intermediate**	**Advanced**
Control	 Mobile robot	 High level tools	 Heterogeneous modular robot
Electronics			
Mechnical	 Robot manipulator	 Modular manipulator	 Homogeneous modular robot

OpenSE- 3 approaches for robot subcomponents

Simple
- Existing robots

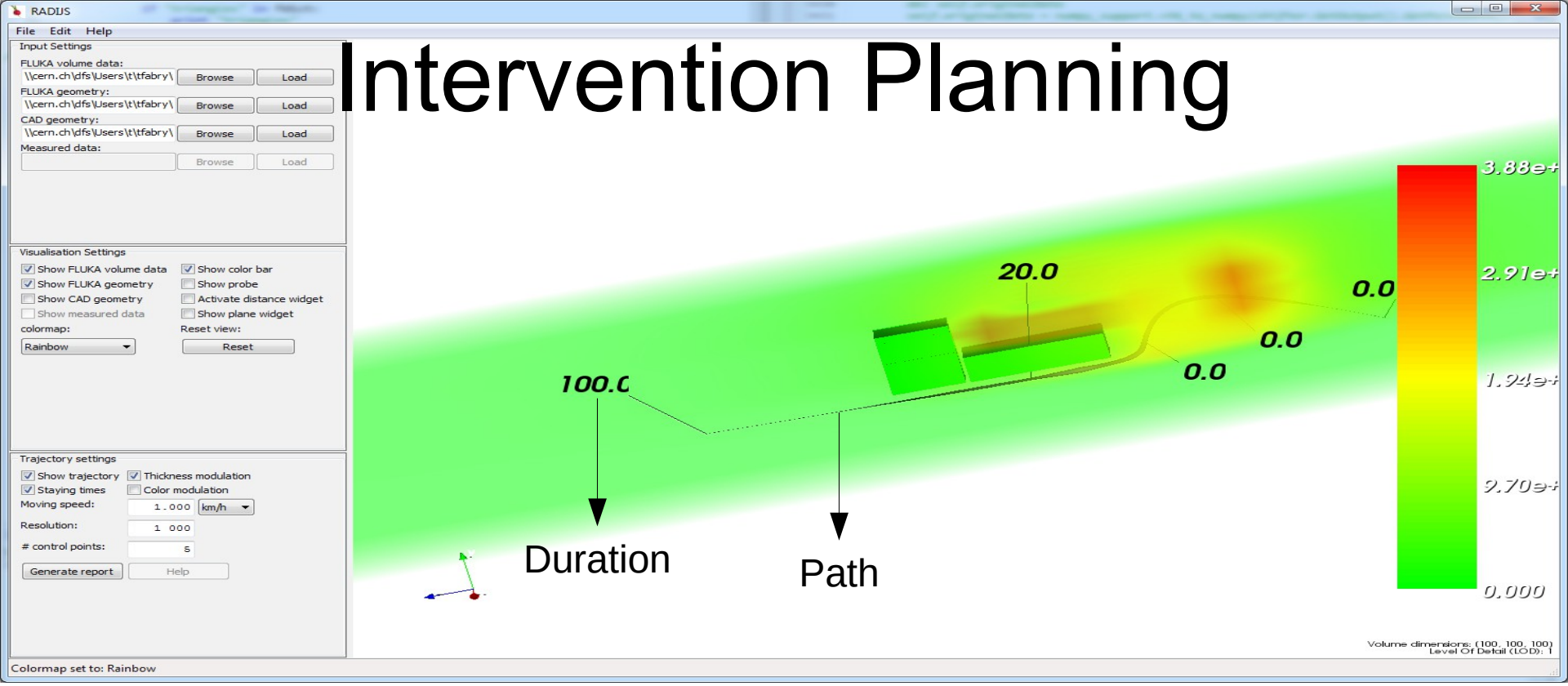
Intermediate
- Sharing tools, code, standards and interfaces

Advanced
- Modular robots

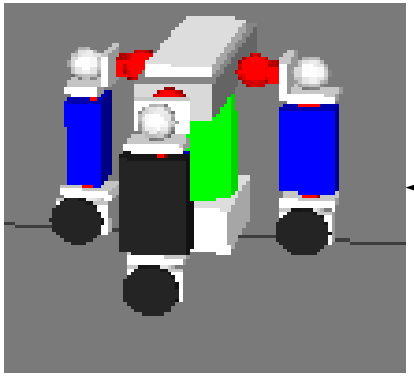
Increased operational utility and life cycle costs reduction

- Robot design , testing, deployment, maintenance, decommissioning cost
- Robust and amendable performance, reduction in development time

Intervention Planning



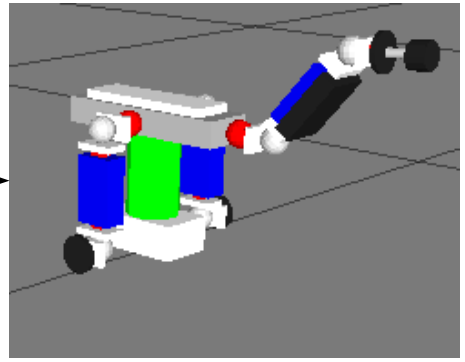
Planning tool [4] for human intervention- Modular robot execution added



Reconfigured robot configuration with shielding

Locomotion

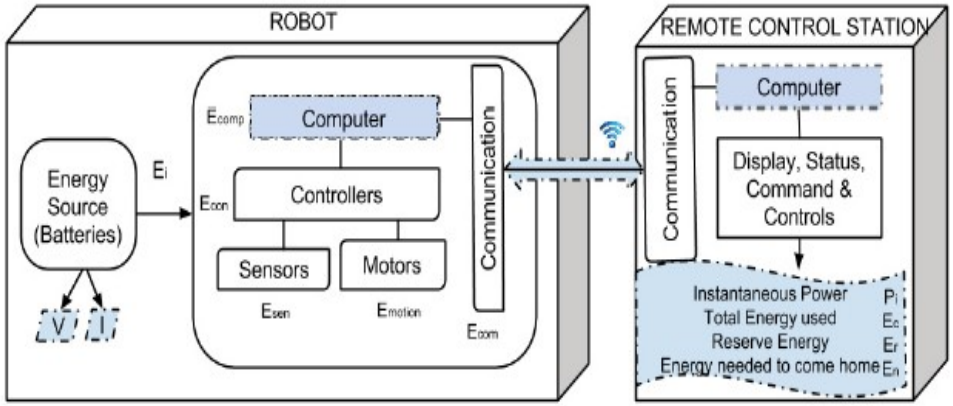
Inspection

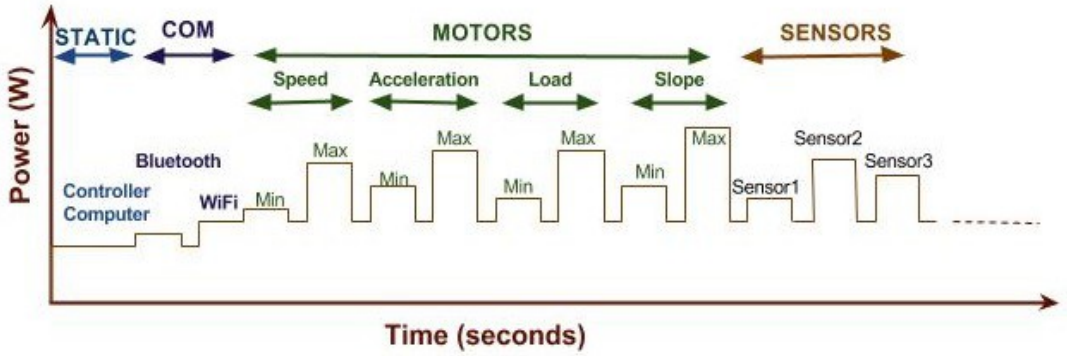


Collaboration with CERN (Geneva)

Energy Management

- Due to increased use of mobile robot platforms
  - New challenge from safety and reliability sides
- Energy consumption modelling, prediction and optimisation are important



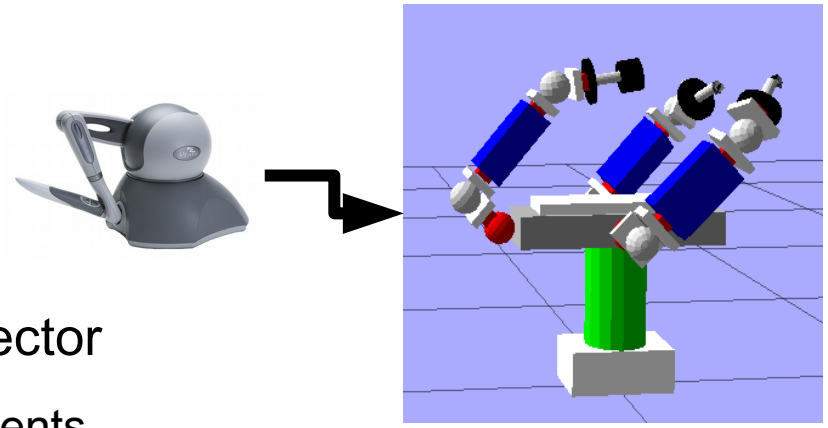


Collaboration with CERN

Force Estimation

Having alternative method to verify sensor value

- For improving reliability
- Without major changes to the facility



An application:

External force estimation at the end-effector

- Sensor will be closest to activated components
- Alternative method to validate the values

Using the state of art in manipulator

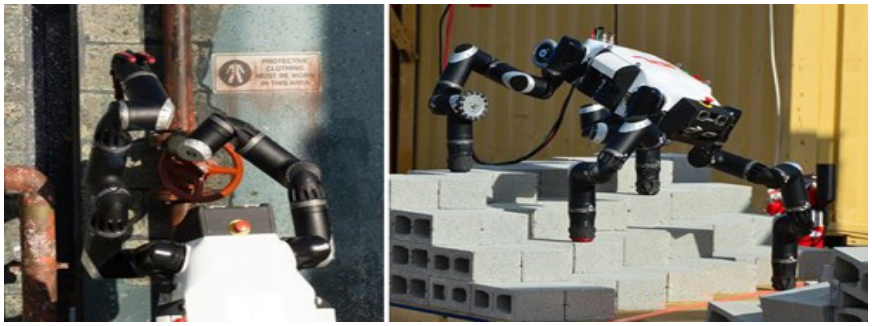
- Current consumption
- Robot Model
- Tests for unknown robot parameters

Collaboration with Oxford Technologies LTD (UK)

Conclusion

- Modular robots are compatible with a RAMS approach
- They are alternatives to conventional robots for application in large scientific facilities
  - Provide flexible platform for use in entire facility
  - Needs extensive testing before inclusion
- Considerable cost saving over lifetime of the deployment
  - Testing and development time of robots and algorithms
  - Maintenance and decommissioning
- Modularity increases functionality of even the existing robots

Tartan



RoboSimian

Collaborations

Oxford technology limited (OTL, UK)

- Connector mechanism
- Sensor estimation

European Organization for Nuclear Research (CERN, Geneva)

- Requirements, needs, tasks
- MR intervention planning
- Energy management

GSI Helmholtz Centre for Heavy Ion Research (GSI, Germany)

- Hot cell collaboration

Publications

Journals

P. S. Pagala, J. Baca, M. Ferre, et al., “Modular robot system for maintenance tasks in large scientific facilities”, International Journal of Advanced Robotic Systems, vol. 10, no. 394, IF- 0.8

P. S. Pagala, M. Ferre, and L. Orona, “Evaluation of modular robot system for maintenance tasks in hot cell”, Fusion Engineering and Design, 2014, IF- 0.9

J. Baca, P. Pagala, C. Rossi, et al., “Modular robot systems towards the execution of cooperative tasks”, Rob. Auton. Syst., 2015, IF – 1.6

Conferences and others

P. Pagala, M. Ferre, and M. Armada, “Design of modular robot system for maintenance tasks in hazardous facilities and environments”, in ROBOT2013, Springer, 2014, pp. 185–197

P. S. Pagala, F. Suarez-Ruiz, and M. Ferre, “Energy consumption perspective of bilateral control architectures”, in EUROCON, 2013 IEEE, IEEE, 2013, pp. 1468–1473

R. Parasuraman, P. Pagala, K. Kershaw, et al., “Energy management module for mobile robots in hostile environments”, in Advances in Autonomous Robotics, Springer, 2012, pp. 430–431

E. del Sol, P. Pagala, R. King, et al., “External force estimation for telerobotics without force sensor”, in ROBOT2013, Springer, 2014, pp. 631–644

R Parasuraman, P Pagala, K Kershaw, et al., “Model based on-line energy prediction system for semi-autonomous mobile robots”, in ISMS, 2014, yet to appear online

P Pagala and M. Ferre, “Designing robots for modularity”, in Open System Engineering, 2014, Submitted

T Fabrey, P Pagala, M. Ferre, “Intervention planning for modular robots in environments with ionizing radiation” , under internal review

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Thank you