Microcosm – A Systems Engineering and Systems Integration Sandpit

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RGM – 27th February 2009

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Outline

- Introduction
- *Microcosm* Facility
  - Use-Cases
  - Development Model
  - High-Level Architecture
    - MPS (Microcosm Physical System)
    - MIMS (Microcosm Information Management System)
    - MASCS (Modeling And Simulation Control System)
  - Implementation of the Systems Engineering and Systems Integration (SE&SI) Sandpit
    - Stage One Operational Scenario
    - Work-in-Progress Demos
- Summary and Demonstration

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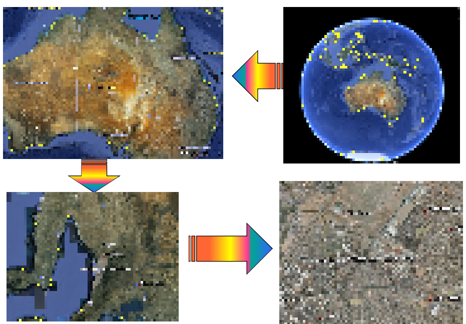
Orientation



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University of South Australia

Number of Students	2003	2004	2005	2006	2007
Total	31,828	32,951	32,266	33,680	34,603

Staff (FTE)	2003	2004	2005	2006	2007
Total Continuing and Fixed Term FTE	2,005	2,086	2,103	2,157	2,266
Academic	858	891	920	955	1,010
Professional	1,147	1,195	1,183	1,202	1,256
Casual FTE	363	343	348	367	405

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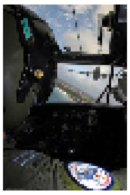
Defense and Systems Institute DASI

- The Defense and Systems Institute (DASI) is Australia's largest provider of research and education in systems engineering and information assurance for Defense, industry and government agencies.
- DASI is internationally known for its postgraduate education programs and research linked to integration of large and complex defense systems, modeling and simulation of military systems and networks, and information assurance for critical infrastructure protection



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Defense Science and Technology Organization (DSTO)

•**Mission:** The Defense Science and Technology Organization (DSTO) is the Australian Governments lead agency charged with applying science and technology to protect and defend Australia and its national interests.

•**DSTO supports Australia's defense by:**

- Investigating future technologies for defense applications.
- Ensuring Australia is a smart buyer of defense equipment.
- Developing new defense capabilities.

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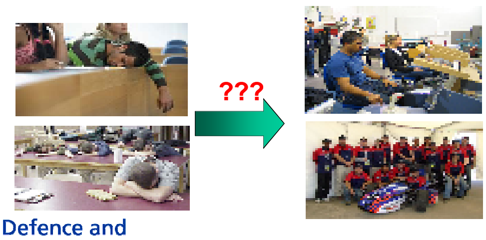
Introduction

- In recent years there noticed a marked reduction in interest by young people in Science and Engineering Education.
- Thus it is not possible to develop systems integration expertise from text books alone, and teaching laboratories are required to support education programs.



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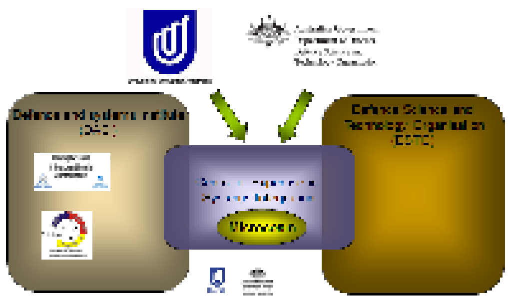
Microcosm Facility



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Microcosm Facility - Aims

- The major aims are to provide:
  - DASI and DSTO with an environment where SE&SI teaching and research can be carried out.
  - a focus for training staff in SE&SI practices.
  - a "*Sandpit*" which can be used to develop and evaluate system configurations and operation, stage demonstrations, and conduct experiments.
  - an environment where tangible systems can demonstrate the challenges of SE&SI to Australian defence organisations

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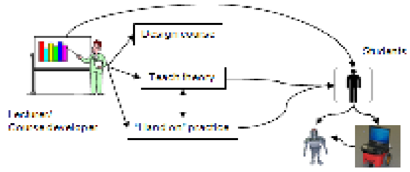
Microcosm Facility

- Use Cases:
  - ***Simulation and Analysis:*** Provide an environment for the development and integration of hardware and software modules, and the execution of hardware-in-the-loop simulation.
  - ***Education Activities:*** Offer postgraduate programs (MEng & PhD) in SE&SI, professional and cross-disciplinary SE&SI training.



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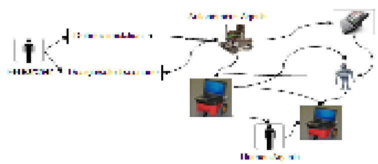
- *Use Cases (Cont.)*
  - ***Human-Agent-Based Modelling for Systems Engineering:*** Investigate human-machine interface, agent teaming, human replacement agent, and socio-technical models.
  - ***Autonomous Vehicles Research:*** Foster research and development in mobile unmanned vehicles including; swarming autonomous vehicles, cooperative robots, task allocations, robustness and reliability models, vision systems, and localization and mapping.



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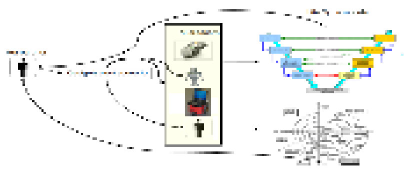
- *Use Cases (Cont.)*
  - ***Systems Engineering Approach to Model Development:*** Foster model-based systems engineering research and development to support system engineering processes
  - ***Systems Enhancement Research:*** Provide tools for system analysis including; system parameterization, optimization, system enhancement and algorithm development



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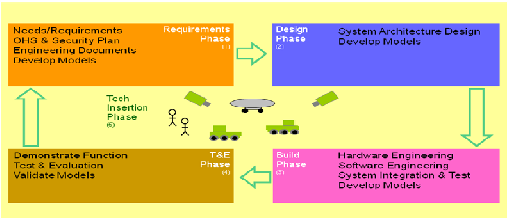
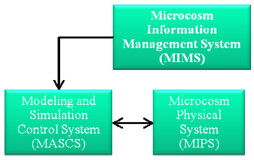
Microcosm Development

- The *Microcosm* adopts the Spiral development model with five phases:
  - Requirements phase
  - Design phase
  - Build phase
  - Test and Evaluation phase
  - Technology Insertion phase



Microcosm Overall Architecture

- Microcosm high-level architecture has three subsystems:
  - Modeling and Simulation Control System (MASCS)
  - Microcosm Physical System (MIPS)
  - Microcosm Information Management System (MIMS) -



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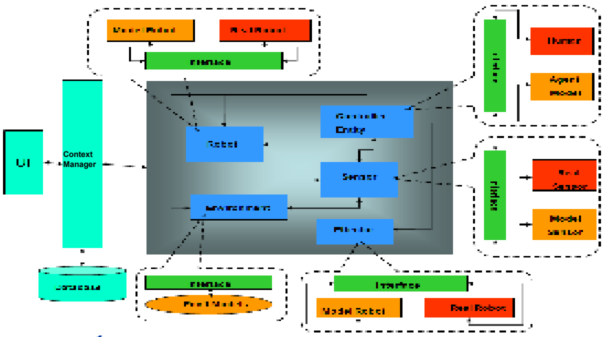
MASCS High-Level Architecture



MIMS - Wiki

- MIMS is an integrated information management systems that captures all data pertinent to the systems engineering processes of the microcosm spiral development model.
- Wiki is currently being used as a central repository to store all data, source codes, diagrams, systems and subs-system designs, requirements and changes, models, tools, major project decisions, process analysis information, technical review reports, OT&E documentations, process and process metrics, trade-off analysis and other relevant system engineering process products.
- In addition, the MIMS provides a means to capture lessons-learnt spread across the entire project life cycle, promoting the "*learn-by-reflection*" methodology.

http://www.cedisc.com/coesi/microcosm/index.php/Mainpage

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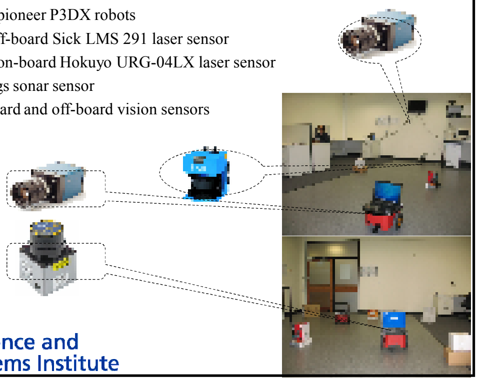
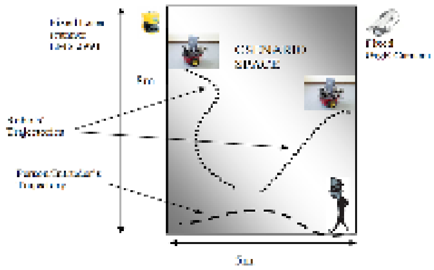
Microcosm Physical Systems (MPS)

- Two pioneer P3DX robots
- An off-board Sick LMS 291 laser sensor
- Two on-board Hokuyo URG-04LX laser sensor
- 8-rings sonar sensor
- Onboard and off-board vision sensors



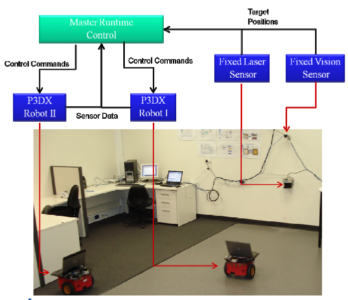
Implementation: Stage One Operational Scenario

Operational View - OV1

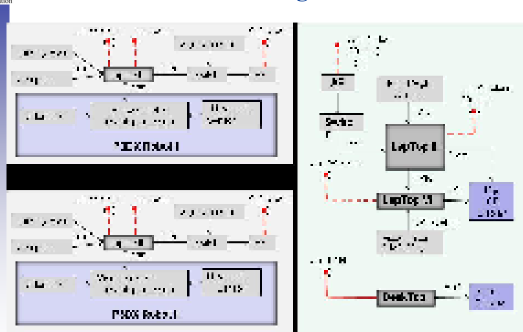


Implementation

SV2 – Hardware



SV2 – Decomposition Hardware Configuration



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Implementation

SV2 – Software

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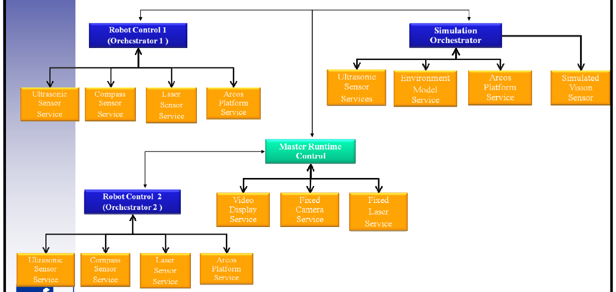
SV2 – Decomposition

Software Configuration - Service Based Architecture



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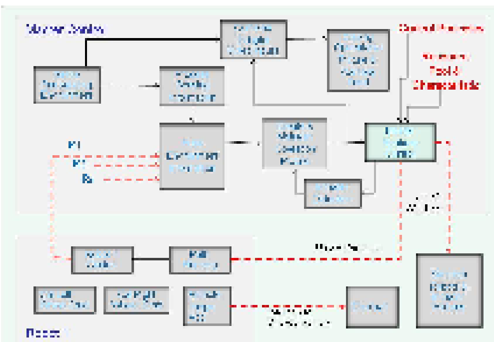
Functional Flow Diagram



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Features of Microcosm

- Tightly integrated information repository, simulation environment and physical solution that can support Model-Based Systems Engineering (MBSE) research and practice
- Scalable, IP-based, open architecture that mirrors next generation military systems.
- Potential international connectivity to investigate geographically dispersed systems development, operations, and use cases.

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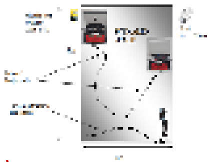
Microcosm Demo

- System Startup
- Detect and track a single intruder
  - Robot 1: Mobile
  - Robot 2: Pivot
- Obstacle Avoidance
- Engage Intruder
- Return to Base
- UWB Positioning (Stage 1.5)
- Image based detection and tracking (Stage 2)



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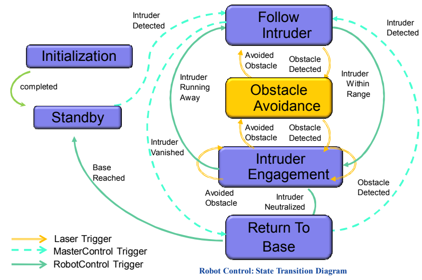
Control Algorithm (Finite State Machine)



Robot Control: State Transition Diagram

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Systems Engineering issues covered during the development of stage 1

1. System definition and requirements analysis.
2. Functional analysis.
3. Trade studies.
4. Modeling and simulation.
5. Specification generation.
6. Configuration management.
7. Risk analysis and management.
8. Test and evaluation.
9. Reliability.
10. Maintainability.
11. Interoperability.
12. Compatibility.
13. Logistics supportability.
14. Safety.
15. Training.
16. Electromagnetic compatibility.
17. Parts engineering.
18. Survivability and vulnerability.
19. Diagnostics.
20. Power efficiency.
21. Trusted systems.
22. Test design.
23. Verification and validation.
24. Model Based SE.
25. Interface design and specification.
26. Interface control.
27. Real-time software integration.
28. Management of software-intensive projects.
29. Network-related performance mgmt.
30. COTS software risk assessment.
31. COTS software risk mitigation.
32. COTS software integration.

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Lessons Learned (1)

Id	Lesson Learnt Description	Typical Industrial Solution
1	Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) e.g., one system component disrupting the performance of another system component. In particular the initial placement of the wireless camera disrupted the sensitivity and operation of the magnetic compass.	Addressed by allocating an EMI/EMC engineer to evaluate the system design and the physical layout of the system components.
2	COTS equipment capability/performance issue e.g., CPU loading excessive effectively locking out other processes.	Addressed by specialty hardware and/or software engineers who would model the system architecture and evaluate the system design prior to committing to specific system/software architectures.
3	Due to a software issue, the robot vehicle went ‘rouge’ during a test, which could have resulted in damage to the robot, before manual action was forthcoming to secure the robot’s motion.	Addressed by a safety engineer who would have generated a procedure to address such an eventuality and would have required a hardware safety interlock and/or a ‘kill switch’ be inserted into the system design.

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Lessons Learned (2)

Robot vehicle's localisation system was unable to cope with measurement inconsistencies, introduced by the environmental conditions (i.e., uneven floor surfaces).	Addressed by modelling engineer who would model the function of the system in the 'real world' with predicted 'real world' sensor input errors.
System data was stored in a common folder on a server but system baselines were not clearly defined. It was difficult for the system engineers to identify tested modules from modules that were being actively modified.	Configuration Management processes would generally make the accessing on non-baselined data difficult and requiring a conscious effort on the part of the systems engineer to access.
COTS interface measurement units disconnects e.g., data published and encoded in imperial units but subscriber assumes metric encoding e.g., data fidelity with publisher and subscriber assuming different level of data accuracy (i.e., decimal places).	A Data Server would be defined to use a standard set of measurement units e.g., S.I. units.

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Lessons Learned (3)

COTS interface message disconnects, incomplete and/or ambiguous documentation can lead to erroneous assumptions regarding the interface.	A Data Server would be defined to support all data source and sink interfaces and would typically report deviation from expected data values. Industry works on the heuristic that Interface Control Documents are only up to 60% complete for reasons of data security, Intellectual Property and competitive advantage.
COTS interface asynchronous vs. synchronous communication e.g., data provided periodically by one system component but only required on demand by another system component.	A Data Server would buffer the messages and would be defined to compensate for differing message frequency and message protocols.
COTS equipment should be considered as a 'black box' i.e., there is typically an inability to modify the functionality of the COTS equipment (e.g., no access to source code).	A Data Server can contain an appropriate model of the COTS equipment or of the real world and predict the value of the required data (e.g., using historic data provided by the COTS equipment) to compensate for data latency issues.

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Lessons Learned (4)

10	COTS equipment failure e.g., system redundancy, system component failures.	Addressed by developing and executing models that are used to prove the system architecture prior to committing to the system design. The executable models can also be used to replace the failed system components, during system integration, so as not to overly impact progress in the face of a failed system component.
11	Limited resources and limited ability to recover schedule slips as all team members are typically fully committed to the task .	Addressed by moving staff to the project to recover on a schedule slip. Projects are managed along the critical path, which is closely monitored so as to reduce the initial occurrence of a schedule slip in the first place.
12	Under estimation of work effort, due to inexperience in systems engineering estimation.	Addressed by experienced engineers developing detailed low-level effort estimates in light of a detailed understanding of the systems engineering process.
13	Under estimation of system testing effort, due to inexperience in systems testing.	Addressed by experienced engineers developing detailed test strategies early on in the project and hence in a better position to estimate the work effort.

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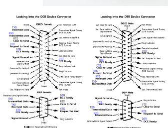
Lessons Learned (5)

1. ***Mechanical/electrical/electronic/software compatibility – Interfacing Interoperability***
   - **RS232/RS485 hardware compatibility**
     - Connectors (vendor special connector)
     - RS485/USB convertors ($800 vendor Vs. $50 solution)
   - **RS232/RS485 software compatibility**
     - Non standard baud rate (500KB)
     - Multiple standards
   - **Vendor software**
     - Black box
     - Does not support C#



Lessons Learned

1. Obtain as much data as possible on interfaces before commitments.
2. Allow resources for non-compatibilities

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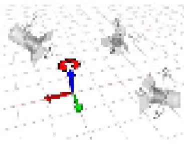
Lessons Learned (6)

2. Conversions

- **Unit conversion**
  - Robot – *mm*
  - Laser scanners – *cm and mm*
  - Microsoft Robotics Studio – *m*
  - Graphic displays - *pixels*
- **Coordinate system**
  - MRS uses non standard coordinate system
  - Absolute Vs. relative system
  - Dynamic Vs. static system



Lessons Learned

1. Clarify and document required conversions
2. Test conversions in simulation first

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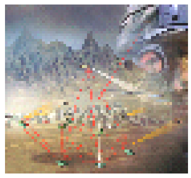
Lessons Learned (7)

3. Communication

- **Synchronous Vs. Asynchronous**
  - Computer/SICK - asynchronous, continues
  - Computer/Hokuyo - discrete, synchronous
  - Computer/computer -
- **Fast/Slow communication channels**
  - Computer/robot
  - Computer/speech synthesizer
- **Network communication design**
  - Speed
  - Load
  - Data types
- **Protocols**
  - Third party Vs. self made
  - Reliability Vs. time



Lessons Learned

1. Clarify and document communications (hardware and software)
2. Test communication bottom-up

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Lessons Learned (8)

4. COTS/Vendors software

- **SICK laser scanner**
  - Does not support fast communication
  - Limited configuration changes
  - Limited display option
  - No software interface options
- **Advanced Robotics Control and Operations (ARCOS) Firmware**
  - Encoders' resolution (2 Vs. 4 Bytes)
  - Zero speed command
- **MRS**
  - Variables types
  - Required Communication
  - Service Vs. Driver configuration

Lessons Learned

1. Prefer open source code than "black box" packages
2. Allocate resources for modifications even when vendor's software is available

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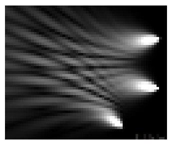
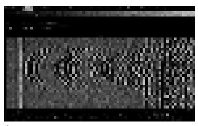
Lessons Learned (9)

5. Interferences

- **Electromagnetic Interference (EMI)**
  - Compass/Robot
  - Wireless Camera/Environment
- **Ultrasonic noise**
- **Physical interference**
  - Laser scanners/intruder
  - Laser scanner/robots
  - Robots/intruder
- **Visual noise**
  - Object detection (colour and motion)
  - Light conditions





Lesson Learned

EMC/EMI is very hard and expensive to predict

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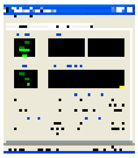
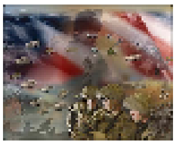
Lessons Learned (10)

6. ***Task allocation and workload***
   - **Computers**
     - Cycle time (device control, communication)
     - Memory usage
     - CPU usage
   - **Devices**
     - Laser scanners – Cycle time Vs. resolution Vs. coverage
     - Vision – image analysis, stereo vision, cycle time
   - **Human**
     - Autonomous Vs. Supervisory Vs. Manual control
     - Displays design
     - Situation Awareness





Lessons Learned
1. Agents' workload must be considered at any time
2. Test and verify agents'' workload in regular and extreme conditions

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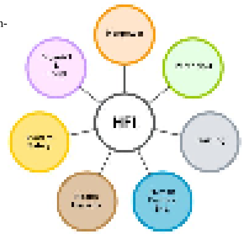
Lessons Learned (11)

7. ***Human System integration (HSI)***
   - **Development**
     - Interdisciplinary background (Eng. Vs. Non-Eng.)
     - Interfaces (software, documentation)
     - Personnel changes
   - **Operation**
     - Human task allocation
     - Displays design
     - Failure identification
     - Safety
     - Training



Lessons Learned
1. Include HR and HF experts in the development team

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Lessons Learned (12)

8. ***Risk realization***
   - **Software**
     - Single device failure
     - Communication failure
   - **Hardware**
     - Device failure
     - Safety
     - Reliability
     - Durability
   - **Redundancy**
     - Cost
     - Interferences
     - Integration

Lessons Learned
1. Perform risk analysis as early as possible in the system lifecycle
2. Utilize simulation for risk analysis

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Lessons Learned (13)

9. ***Management in small/medium project***
   - **Resources allocation**
     - Schedule
     - Manpower
     - Budget
   - **Documentation**
     - Details
     - Resources

Lessons Learned
1. Little opportunity to recover in small and medium project
2. Allocate more resources to Integration and test than industry standards.

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Lessons Learned (14)

- Microcosm learned many of the classical lessons to be found in SE literature.
- Most difficulties in systems projects can be traced back to
  1. Financial constraints
  2. Compressed schedule
  3. Lack of time and resources to acquire technical knowledge before architectural design through analysis, M&S, prototyping.

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Future Microcosm Development Ideas

Teaching

Develop two interactive systems engineering training and learning packages (e.g. System of systems integration; Network-centric communications and coordination)

- **Prepare and deliver workshop on lessons learned to DSTO and Industry participants**
- **Employ Microcosm to existing DASI Courses**
- **Develop outreach capability to involve high schools in Microcosm-based learning to foster interest in engineering as a career**
- **Incorporate higher degree students into Microcosm work**

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Future Microcosm Development Ideas

Technical

- **Incorporate aerial capability (e.g. blimp, suspended camera, helicopter)**
- **Deploy extra fixed sensors (e.g. laser range finders, UWB, cameras) In particular develop the UWB as a surrogate for GPS capability and also integrate UWB positioning into robot control system**
- **Develop absolute 3-dimensional position sensing capability**
- **Incorporate on-board heading sensors (to replace magnetic compass)**
- **Replace current communication network (UniSA) with a Local Area Network**
- **Extend capabilities to multiple agents and intruders**

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Future Microcosm Development Ideas

- **Simulation**
  - **Develop context manager based user interface.**
  - **Develop and test the simulation system with the capability to stimulate and be stimulated by the physical components.**
  - **Research MBSE architecture issues and other requirements**
  - **Develop human-in-the-loop capability (may be next phase)**
- **Systems Engineering**
  - **Develop and practice sound SE approach to future development work**
  - **Develop documentation for non-microcosm-team-member users, based on teaching and research use cases. Will need to include system description and user manuals.**

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Proposed Outcomes

- Increased community interest in STEM as a career field.
- Increased capability to provide systems integration leadership.
- Enhanced technical integration skills within the COESI community.
- Enhanced learning outcomes in postgraduate course work through the use of Microcosm in laboratory sessions.
- Increased capacity to provide knowledge, services and education to the defence community.
- Increased number of integration practitioners formed through interaction with COESI.

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Summary

- COESI has successfully delivered *Microcosm* Stage 1 ***before time, on budget and to the customer requirements.***
- The Microcosm Facility *"Sandpit"*:
  - Evolutionary environment based on Open-architecture principles
  - Mixes real components and synthetic models
  - Developed based on the object-oriented
- *Microcosm* is a SE&SI *"Sandpit"* that supports:
  - Education and training
  - SE&SI research and development
  - Foster good SE&SI practice

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Video Demonstration - 1

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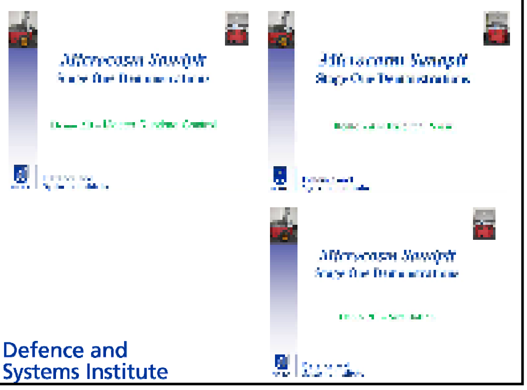
Video Demonstration - 2



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