Microcosm – A Systems Engineering and Systems Integration Research and Learning Sandpit

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Abstract

This paper describes the *Microcosm* program established by DSTO and UniSA to research and to promote good systems engineering and systems integration practice. The initial focus of the *Microcosm* project is research into the application of Model-Based Systems Engineering (MBSE) in complex systems engineering and systems integration programs. The paper outlines what *Microcosm* seeks to achieve with particular focus on the high-level architecture of the Stage 1 solution. The paper concludes by describing the Stage 1 implementation of the *Microcosm* '*sandpit*' including the information management environment, the simulation, modelling and control environment, and the physical systems including unmanned ground vehicles, sensors, communications infrastructure and effectors.

1. Introduction

A key challenge confronting Defence today is the management of acquisition programs for large-scale, complex systems that need to be tailored to national Defence requirements. A major contributor to this challenge is the rapidly changing nature of electronics systems, particularly those related to sensors, combat and mission systems, weapons and countermeasures, avionics, and communications (Nandagopal 2006). In order to meet this challenge, it is necessary to build indigenous systems engineering and systems integration (SE&SI) expertise and experience.

Typically in Australia, complex military systems (ie, military platforms) are procured through the selection, tailoring, and then integration of (1) Military Off-The-Shelf (MOTS) systems, (2) Commercial Off-The-Shelf (COTS) systems, and (3) some developmental systems. Many of these MOTS and COTS systems are sourced internationally from our allies and then supported through-life by multi-national prime contractors operating in Australia. There are many challenges that arise from procuring complex military systems in this manner.

As an investment in addressing SE&SI challenges, Defence Science and Technology Organisation (DSTO) established the Centre of Expertise in Systems Integration (CoESI) on 1 July 2006 with the University of South Australia (UniSA). One of the aims of CoESI is to focus national resources on system integration with an initial emphasis on building a SE&SI '*sandpit*' (Mansell 2008). This '*sandpit*' environment is used to explore and advance good SE&SI practice, and to research novel SE&SI methods through the provision of a practiced based training and learning environment. *Microcosm* (the name given to this project) will support DSTO, UniSA, Australian defence organisations and affiliated defence industry.

A central focus of the *Microcosm* project is the *Microcosm* '*sandpit*' environment where the physical elements (humans, computers, unmanned vehicles, deployable sensors, laboratories, and simulators) are housed. The Stage 1 implementation of the *Microcosm* '*sandpit*' (delivered Dec 2008) involved the procurement of unmanned ground vehicles, ground based sensors, communications infrastructure, a mission control segment, and modelling and analysis environment. The initial focus of the *Microcosm* project is (1) research into the application of Model Based Systems Engineering (MBSE) in complex SE&SI programs, and (2) establishment of a practice based SE&SI training environment.

A MBSE methodology is characterised by Estefan (2008) as the collection of related processes, methods, and tools used to support the discipline of systems engineering in a "model-based" or "model-driven" context. Blanchard and Fabrycky (2006) identify the following models as being relevant to systems engineering: economic, decision making, human, maintainability, manufacturing process, physical and reliability. A rigorous mathematical development of MBSE theory was developed by (Wymore 1993).

MBSE differs from traditional systems engineering (sometimes referred to as document-centric systems engineering) in that it is underscored by a central system model, or suite of models, that capture the customers capability expectations, system requirements, architectural design, design implementation decisions, system verification and validation, and system acceptance (based on technical integrity and performance). This systems model (or suite of models) can be executed to stimulate systems that support trade studies and design decisions. In the *Microcosm* program, the objective is to maximise (for the purpose of characterising) the appropriate use of models in the systems engineering life cycle as well as use these models to serve as the knowledge repository for systems engineering artefacts.

It is planned that *Microcosm* will be used as a focus for collaborations with pertinent programs nationally and internationally. It is the intention to engage with similar practiced based SE&SI programmes such as the Systems Engineering Innovation Centre (SEIC), at Loughborough University in the UK. SEIC has established a similar environment as part of its ConSERT[1] program. As a result, DSTO, UniSA and the SEIC are discussing opportunities to share environments, research initiatives and potentially collaborative system engineering and system integration programs.

[1] http://www.seic-loughborough.com/AllPages.html?Page=360

2. *The Microcosm Program*

Microcosm is a program that explores systems engineering practices within an environment that utilises autonomous systems operating and interacting with humans and the physical and/or simulated environment. It offers a facility in which systems engineering practices may be developed and extended in a both a research and teaching environment. Essentially, it provides a *'SE&SI sandpit'* to be used by stakeholders as an avenue to stage demonstrations, conduct experiments, train staff, and to evaluate systems configuration and operation. *Microcosm* is intended as an evolutionary facility and will expand in capability to meet the wider and longer-term aims of its stakeholders.

The program is a collaborative activity between DSTO and UniSA, forming the flagship program of the Centre of Expertise in Systems Integration (CoESI). *Microcosm* will be used by staff and students to support the development of their systems engineering skills and their understanding of systems engineering concepts through course work, experiment based practice and research. This also provides an ideal foundation to explore the SE&SI challenges of:

1. capability driven technology insertion (including architecting open systems),
2. network centric warfare,
3. integrated logistic support (life-cycle costing and technology refresh), and
4. test and acceptance (including verification and validation of MBSE artefacts).

In addition, *Microcosm* will support operational scenarios that complex military systems would be expected to support in the real-world; be composed of components with open interface definitions that may be used to emulate considerations relevant to commercial off-the-shelf (COTS) product integration; provide a synthetic environment where research can be safely conducted; support full instrumentation so that data may be readily collected during an experiment; and maintain a historic database of systems engineering data.

2.1 *Microcosm* Use Cases

The development of *Microcosm* offers an opportunity to grow individuals' capability and to provide a larger engineering and research base in technologies important to future systems engineering projects. It is intended to be a fully '*instrumented*' facility, in that it will be possible to extract quantitative information about system components, their properties, their states and their configurations, in support of the following 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. This facilitates analysis of systems behaviour in different scenarios using either physical hardware, software models or a mixture of real systems and simulated models.
- ***Human-Agent-Based Modelling for Systems Engineering:*** Provide an environment where human operators can be replaced by configurable intelligent agents. This facilitates investigation of: human-machine interface, agent teaming, human replacement agent and socio-technical models.
- ***Education Activities:*** Use Microcosm to support postgraduate programs (e.g., PhD & MEng) and to facilitate professional training. The scope of which will encompass systems engineering process, systems modelling, human-computer interaction, integrated logistics support; and the development of professional

capability in systems engineering, cross-discipline domains and project management.

- ***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.
- ***Systems Engineering Approach to Model Development:*** Foster model-based systems engineering research and development to support system engineering processes, where system information is stored in executable models and objects instead of piles of documents.
- ***Systems Enhancement Research:*** Provide tools for system analysis including; system parameterization, optimization, system enhancement and algorithm development.

2.2 A Microcosm of the Capability Life Cycle

Within the *Microcosm* project, we explore the application of MBSE across the capability life cycle (needs, requirements, acquisition, in-service, and disposal), with a focus on a spiral development systems engineering paradigm. Specifically, we have defined a five phase process: requirements, design, build, test and evaluation, and technology insertion. These phases are pictorially outlined in

Figure 1 and detailed below.

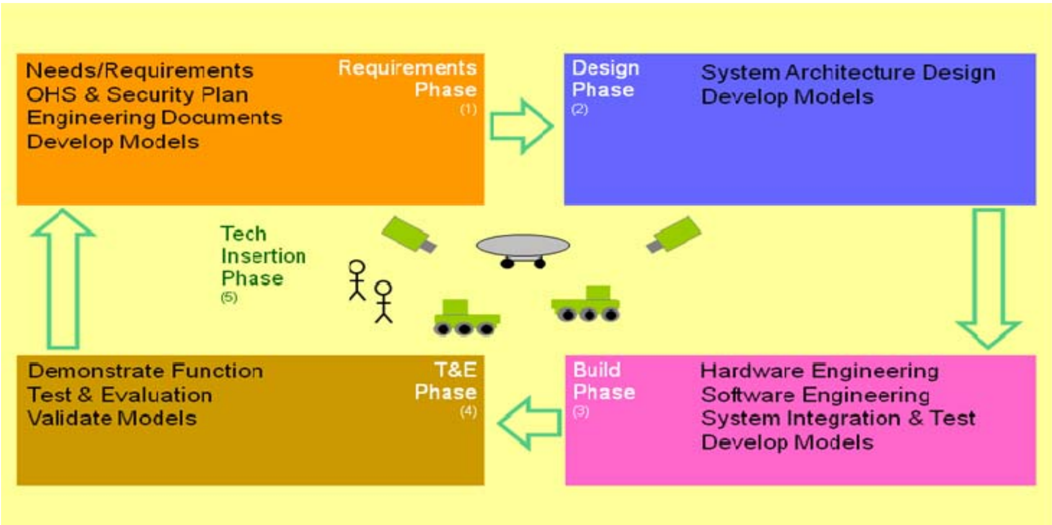

Figure 1 - *Microcosm* spiral development phases.

Phase 1 – Requirements phase: In this phase, the initial project requirements are specified; concept of operations, top level requirements, Enterprise plans, Occupational Health and Safety (OH&S) plans and Security plans are developed; and high level system models developed. This phase also includes the procurement of the preliminary hardware and software sets to support concept exploration. The deliverables from this phase consist of:

1. Operational and support scenario descriptions.
2. Project needs.
3. System requirements.
4. Project plans (including Enterprise Plan, OH&S plan, Security plan).
5. System documentation.
6. System-of-system models.
7. System models.

Phase 2 – Design phase: In this phase, the System Architectural Design is defined allowing requirements to be allocated to key subsystems, and these subsystems and the environment to be modelled. Subsystems are characterised by the functions they perform and are modelled as low-level entities, include sensors, internal interfaces, information manipulation, decision logic, and effectors. When integrated these subsystem models characterise the performance and behaviour of the system within predetermined (and agreed) scenarios. The deliverables from this phase consist of:

1. System architectural design
2. System architectural model
3. System architecture design simulation
4. Sensor, command & control and effectors models
5. System requirements (updated)

Phase 3 – Build phase: In this phase, the sensors and platforms are procured, control systems are coded, and unit level testing conducted. The total system-of-systems is then integrated to enable test readiness reviews in the *sandpit*. Throughout this process the modelling environment is used to support design implementation and to assess capability impact of engineering decisions. For example, in *Microcosm* stage 1, integrated live and virtual (modelled) systems are used to support trade-off studies. The deliverables from this phase consist of:

1. Hardware engineering artefacts
2. Software engineering artefacts
3. Procured/developed equipment and software
4. Integrated platforms
5. Integrated systems
6. Simulation environment
7. Model refinement
8. Sensor, command & control and effectors simulations
9. Platform simulations

Phase 4 – Test and Evaluation phase: In this phase, the total integrated capability represented by the systems-of-systems are tested and evaluated against the original requirements of the *Microcosm* program as determined in Phase 1. In addition, a series of controlled scenarios will be executed to validate the models developed during Phases 1 and 2 and then refined through phase 3. This allows the modelling environment to be employed to validate system performance against scenarios that can not be executed live. In line with the training and education goals of the *Microcosm* program, the project management and applied systems engineering processes will be reviewed for effectiveness. The deliverables from this phase consist of:

1. Test reports
2. System models (updated and validated)
3. System requirements (updated)

Phase 5 – Technology Insertion phase: This phase utilises the MBSE environment to characterise capability deficiencies and explore potential capability improvements. The modelling and analysis can then be used to explore capability investment decisions leading back to Phase 1.

After completing a capability cycle, the *Microcosm* team will critically evaluate the performance and capability of the *Microcosm* program and capability provided by the *Microcosm sand-pit*. Post execution of an experiment, a lessons-learnt database/Wiki will be updated. The deliverables from this phase consist of:

1. Project report (i.e., lessons learnt)
2. Project Management Plan (updated), for the next *Microcosm* spiral (eg; Microcosm Stage 2)
3. Systems Engineering process update.

3. *A Systems Engineering and Systems Integration Sandpit*

Microcosm is a fully "instrumented" open-system that employs a customised systems engineering process based on the Defence Capability Development Cycle utilising the Spiral development model to foster model-based systems engineering (MBSE) research and education. This is achieved by establishing a Systems Engineering and Systems Integration (SE&SI) "*Sandpit*" to be used by stakeholders as a facility to stage demonstrations, conduct research in MBSE, evaluate systems configuration and operation, and investigate process improvement (Cook et al. 2008). The facility is intended to be evolutionary and expand in capability to meet the wider and longer-term aims of its stakeholders, where quantitative information about system components, their properties, their states and configurations are extracted, stored and updated onto a central repository. Thus, it captures details of project requirements, design interfaces, standards, configurations, components, systems implementation, test and evaluation, lessons-learnt and other related information. These are made available to developers and potential users for ease of adding new system's components to meet specific stakeholder requirements for an experiment or demonstration.

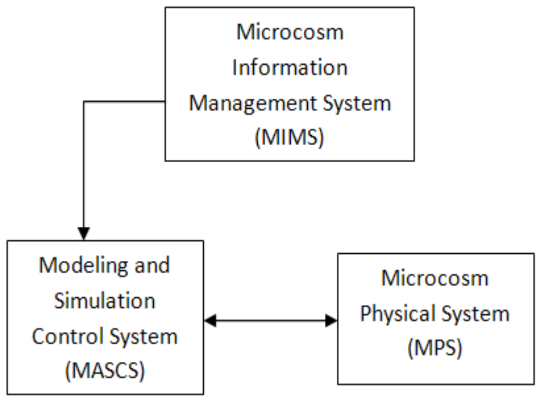

Figure 2. Microcosm High-Level Architecture.

The *Microcosm* high-level architecture has three sub-systems: Microcosm Information Management System (MIMS), Modelling and Simulation Control System (MASCS), and Microcosm Physical System (MPS) as depicted in Figure 2. The former is an integrated information management system that stores all the systems engineering products associated with the project through each spiral-development cycle. The SE products of the previous stage, especially the lessons-learnt, and system's capabilities vs constraints are critical for the *Microcosm* facility to evolve to meet Defence's demand for systems integration and MBSE research and development. The MASCS is a simulation and control sub-system that contains synthetic models of *Microcosm's* components including environment models, simulated autonomous vehicles, and a suit of onboard and off-board sensors. Control algorithms are also being developed to provide simulation capabilities of various defence operational scenarios, where aspects of *Microcosm's* performance improvement due a sensor or subsystem upgrade can be investigated. The system also provides the capability for hardware-in-the-loop (HIL) simulation through the use of a common interface between simulated and physical components that provides seamless interactions between these components in a given operational scenario. Finally, the MPS consists of all the physical components of the Microcosm facility, consisting of autonomous mobile robotic vehicles and wall-fixed sensors. Each robot has a suite of sensors that includes laser and ultrasonic rangefinders, vision, wheel odometers, a magnetic compass, and an Ultra-Wide Band (UWB) position location system.

3.1 Microcosm Modelling and Simulation Environment

The *Microcosm* modelling and simulation environment is being designed and developed to allow the easy interchange of software modules (Models) representing the components of *Microcosm*, with the software that is actually used to run those components. In some cases the software driving the components already exist, and can be used with minor modification, while in others the complete models have to be built. In this way *Microcosm* will mimic the situation that arises in real projects, albeit at a much more complex level, where the need for the integration of subsystems within large systems-of-systems projects remains problematic because there is no effective way of testing the whole system until very late in the build process. The *Microcosm* environment allows the stimulation of the real components as described above by the simulation, and also allows the stimulation of the simulation by the real components.

The conceptual design of the *Microcosm* is shown in Figure 3. In the figure the largest box represents the "physical" environment within which the real components of *Microcosm* act. The robot, sensor and effector objects can each be instantiated as real objects in the *Microcosm* domain. The environment object will either be the specification of the real environment – locations of walls, obstacles and beacons, etc. – or a model of some other environment as called for by other scenarios. Such a scenario might then have the robots and sensors perceiving that they are acting on a sea surface, rather than a concrete floor. Finally, the ad hoc controller object can be instantiated either by a real person, or by an agent based model of a person. The objects, real robot, real sensor and real effector, are instantiated in the simulation system either as software that is supplied with the physical equipment or as bespoke software that has been written by the *Microcosm* project team. *Microcosm* is designed to run in an autonomous mode with the human acting as an observer, or as an observer who can issue instructions to the robots, sensors or effectors in response to the signals received from them. The corresponding agent-based model will be built to respond to the same information.

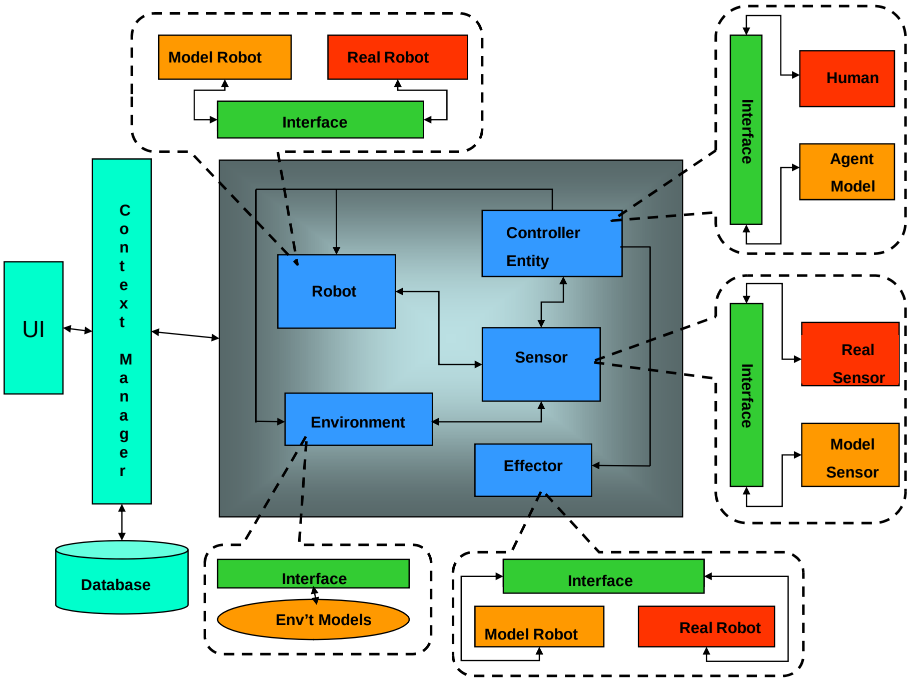

Figure 3. Microcosm Conceptual Architecture.

The user interface runs the *Microcosm* environment through a context manager object. The context manager is a rule-based component which allows a user to select the various options that go to comprise a scenario and makes the necessary connections between the components, while at the same time preventing connections that are not supported. For example, a user will be able to select which real components and which simulated components are to be used for a given run of the *Microcosm* system and the software will then automatically assemble and connect all the required components. Information about all aspects of the system is assembled and held in the database. The context manager will contain the meta-information needed to allow rapid assembly of the environment according to user choices and is essential to support the rapid setup of different scenarios to meet both teaching/learning and research needs. Finally, the interface objects allow the "*plug-and-play*" of either the models of the system components or the "real" software modules managing actual data from the hardware.

The software modules for controlling the robots and other real components are being developed using either MatLab or Microsoft Robotic Development Studio (MRDS) so that we can demonstrate the ability to interface with models written by different sources. The simulation software will be developed using the open-source agent-based modelling environment Repast[2]. Repast interfaces with MatLab models and also provide the tools to allow us to interface to software developed in MRDS. Repast will be used to provide a flexible, easy to use, agent-based model development environment with the capability to use many third party tools, one of the most important of which is the open-source Geotools[3] package for spatial representation.

This agent-based modelling method was selected as it supports the object-oriented programming paradigm, which is ideal for this type of application where there is a need to easily replace one model with another. The *Microcosm* software is being built to:

- Provide a flexible object-oriented environment with well specified interfaces that allows a user to instantiate either real or simulated objects into a seamless simulation that will support the initial *Microcosm* use cases described in section 2.1.
- Facilitate easy and rapid construction of scenarios to support single user or group learning simulations through the use of a rule-based context manager.
- Facilitate easy and rapid construction of scenarios to support research into various aspects of model-based systems engineering. In particular, the modelling and simulation environment is planned to aid investigation of architectural design features that will better support more intensive use of modelling and simulation in complex system engineering.
- Provide a platform for investigating the development and validation of agent based models of human operators "*in-the-loop*" by supporting a comparison between real humans interfaced with *Microcosm* and agent models.

A further advantage of a simulation architecture that supports easy replacement of models is that it provides a platform for investigating the issue of necessary model fidelity for the implementation of a model-based systems engineering (MBSE) environment. Clearly, it is not expected that the human-agent model will replicate the full performance of a real human. However, the intention is to include a human element in the developed MBSE environment to investigate and understand what level of fidelity in the representation will render the agent fit for a specific purpose, where that purpose might well differ across different scenarios. Similar but less complex issues also exist for the models that represent the physical behaviour of the real components. Although this latter is a much better understood problem, our simulation system will provide a convenient way to both teach and research all these issues.

3.2 Microcosm Stage One – Delivered Capability

The *Microcosm* facility is being developed to explore innovative approaches to Systems Engineering and Systems Integration (SE&SI) practice through the emulation of real-world military activities such as target acquisition, target tracking, intelligence surveillance and reconnaissance (ISR), and search and rescue. The *Microcosm* stage one operational scenario consists of two unmanned ground vehicles (Pioneer 3DXs), and two fixed global external sensors: vision and a SICK LMS 291 laser sensor. The OV1 view of the operation scenario is depicted in Figure 4.

[2] http://repast.sourceforge.net/
[3] http://geotools.codehaus.org/

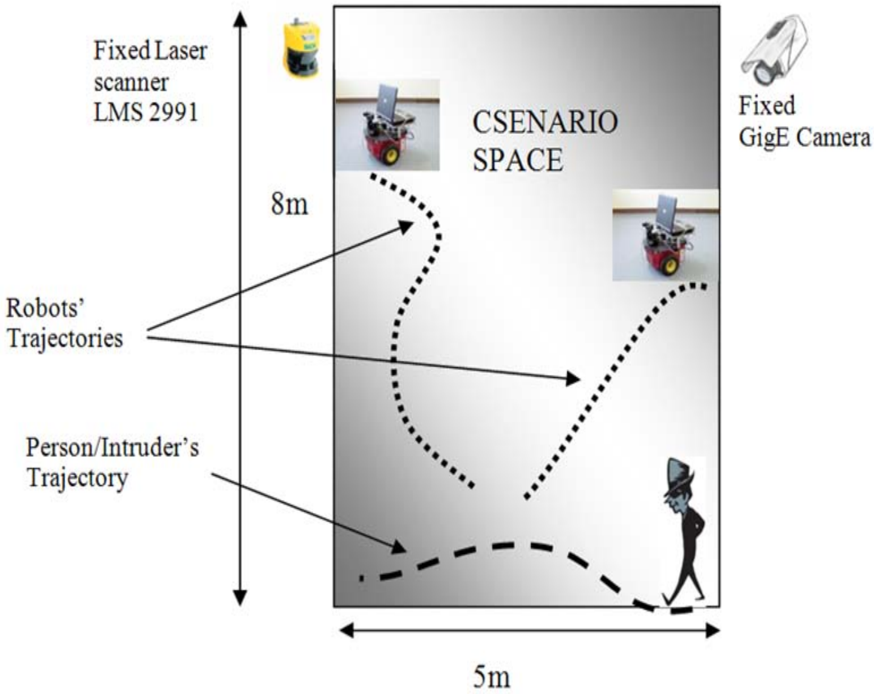

Figure 4. Microcosm Stage One – Operational Scenario.

The operational scenario is further expressed using the OV2 diagram, shown in Figure 5 that illustrates the relationships between different nodes in the system. This is further depicted in Figure 6.

The two fixed sensors (vision and laser) are used for intruder detection (i.e. a person), and after detection the Ground Station sends notification to the two P3DX robots to intercept, assess, perform threat mitigation or naturalise the intruder. Nodes in the OV2 diagram are further decomposed as illustrated in Figure 6 where each robot has an onboard microcontroller that communicates to an ultrasonic sensor, wheel odometers and an onboard laptop via a RS232 serial interface. A sensor suite is connected to the laptop including a Procillica Gige camera, URG laser rangefinder, OS5000 compass, separate wireless network for video transmission and Bluetooth communication between the robots. The ground station consists of a desktop computer and a laptop computer that together provide a graphical user interface (GUI) and accommodate the image processing algorithms for intruder detection and tracking respectively.

The software decomposition of the OV2 diagram on the other hand is shown in Figure 7. The control architecture is implemented based on the Decentralised Software Service (DSS), Coordination Concurrent Runtime (CCR), and the .NET framework within the Microsoft Robotic Development Studio[4]. Under this framework, functions are implemented as loosely coupled services, and systems and sub-systems are created by orchestrating a collection of services. These services are interconnected and communicated to one another concurrently via an intranet (which can be expanded to the

[4] http://msdn.microsoft.com/en-us/robotics/cc470040.aspx

Internet) using REST (Representation State Transfer) and SOAP (Simple Object Access Protocol).

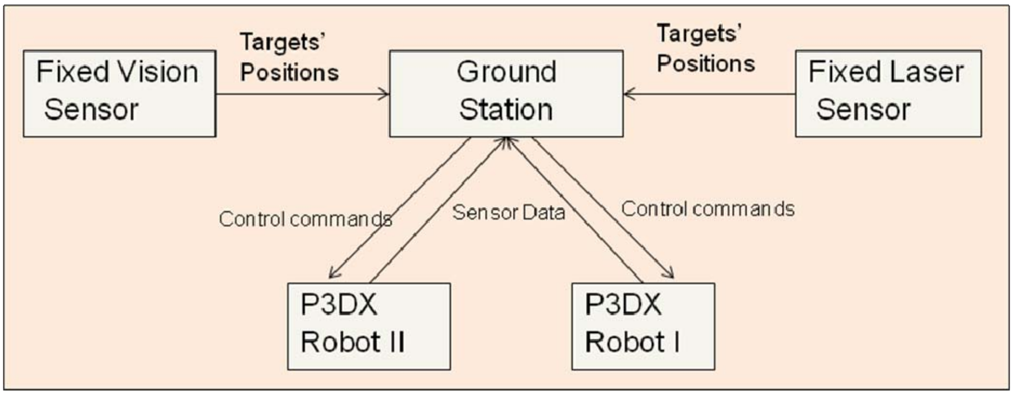

Figure 5. OV2 Diagram – relationships between different nodes in the operational scenario.

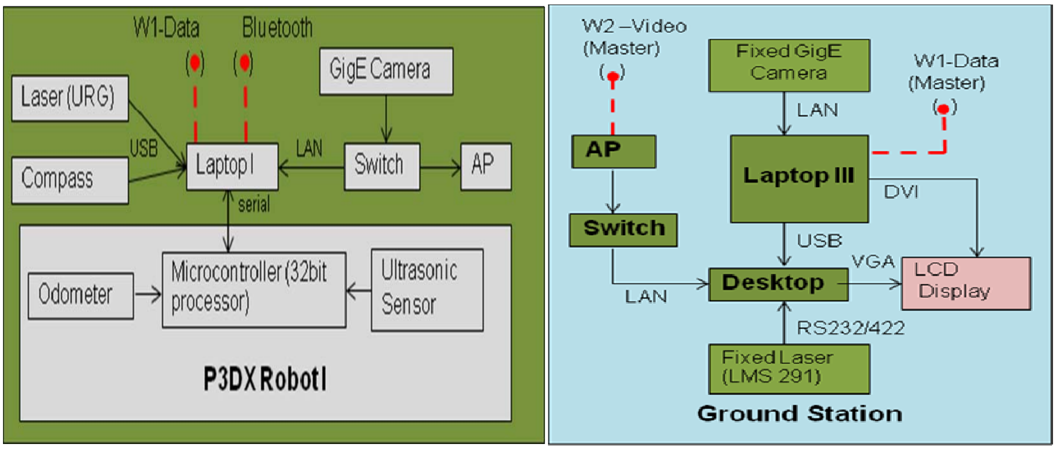

Figure 6. Hardware decomposition of the OV2 diagram.

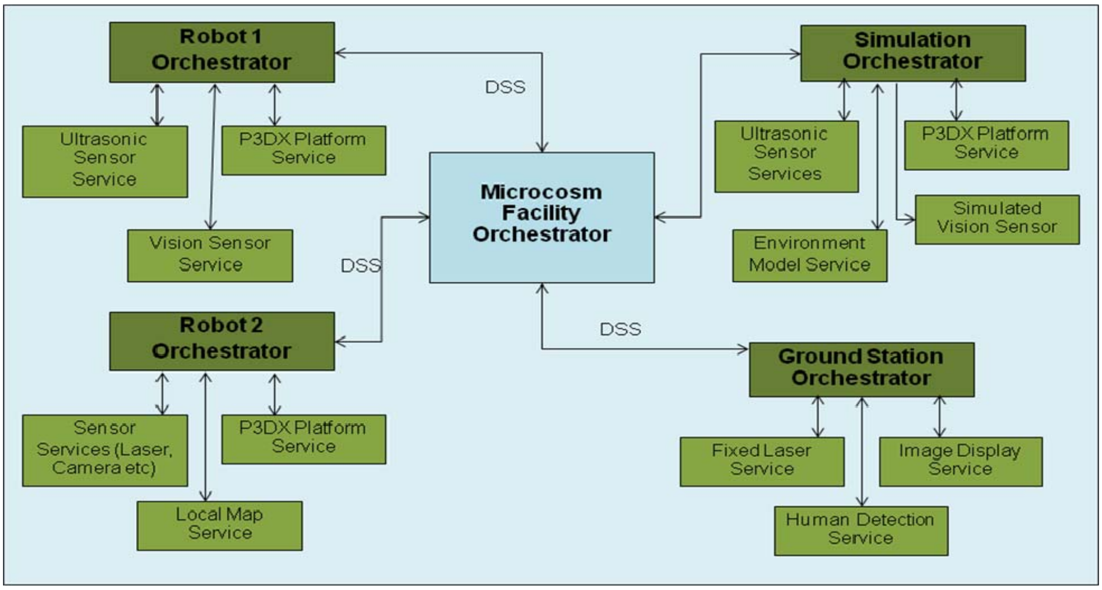

Figure 7. Software decomposition of the OV2 diagram.

3.3 Microcosm Stage Two – Program Planning

Planning of the *Microcosm* Stage 2 program is currently being executed by DSTO and UniSA, in consultation with key stakeholders. The first step is the generation of an "aspirations list" followed by a more detailed needs analysis against the following *Microcosm* program objectives:

1. *Microcosm* as an education and training environment.
2. *Microcosm* as an SE&SI research environment.
3. *Microcosm* as a collection of systems (platforms, sensors, etc) that can be integrated to execute representative military operations.

Academic research activity tends to be funded piecemeal, so in conjunction with top-down planning, funding is being sought to extend the physical infrastructure to include additional autonomous platforms (including an airborne vehicle), integration of additional sensors and actuators and more capable control. Funding is also being sought to enable geographically dispersed interaction to occur with similar educational laboratories overseas. Thus in common with the real world, the trajectory of *Microcosm's* development will, to a fair extent, follow funding!

3.4 Microcosm Information Management System

The Microcosm Information Management System (MIMS) captures all data pertinent to the system engineering process of the *Microcosm* spiral development model. Through each stage, system engineering products are collected and stored in the MIMS-wiki, which has been implemented using Wikipedia and 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 learned spread across the entire project life cycle, promoting the "*learn-by-reflection*" methodology. Consider an example of a lesson-learned in the microcosm project named, *commercial-of-the-shelf (COTS) product integration*. This lesson related to one of the requirements for the *Microcosm* stage one operational scenario.

> *"The sensor shall detect a person entering the Microcosm facility (8mx5m) and report their position in less than 1 second after the intrusion."*

The sensor selected for this mission was the SICK (LMS-291 2006) laser scanner. This sensor provides a fast scan of an 180^{o} sector at a rate of 50Hz and in a range of up to 80 meters. Initially the sensors arrived with an RS232 communication cable and manufacturer's software running at 9600 baud rate, which provides a scanning rate of less than 1 Hz. Although the laser sensor is capable of operating at a faster baud rate (up to 38400) the manufacturer's software could not change to the higher baud rates. As a result, customized code was developed to change the baud rate, and to read and display the sensor's data.

The LMS-291 datasheet indicates that the laser sensor can operate at a maximum baud rate of 500kps using RS422 communication. Since, the sensor uses non standard socket and pin configurations, a customized RS422 compatible cable was created, and a RS422-to-USB converter was purchased to interface with the sensor. Unfortunately, this did not work correctly as the sensor operates at a non-standard baud rate (500kps). Therefore, an additional PCI RS422 interface card and the relevant software were purchased to configure the sensor to operate at the 500kps baud rate suggested by the supplier. Once again, the manufacturer's software failed to change the baud rate to 500kps. Regrettably, in-house software had to be developed to provide RS422 communications with the LMS-291 laser sensor at 500kps baud rate and a second interface device purchased before full functionality was achieved.

The MIMS records this sequence and associates it with the frequently learned lesson that detailed technical knowledge of products and their interfaces is essential to ensure straightforward integration. We would not be the first to learn that the performance and interfacing of COTS products is not entirely consistent with their data sheets and manuals!

4. Future Research

Microcosm is intended to be an evolving environment which will serve as a laboratory for SE&SI research well into the future. In addition to the Use Cases described in Section 3.1, the project team envisions a number of research efforts which could be conducted within future evolutions of the *Microcosm* environment.

One such research activity involves the application of agent-based modelling approaches to describe the role of the human observers/actors that directly interact with the system. Tests within the simulation environment of *Microcosm* could be used to conduct validation investigations to determine what level of fidelity is necessary for the agent model to provide an accurate representation of the human-system interactions. This could be accomplished by constructing a simple object tracking scenario and judging agent-based simulations against human-in-the-loop simulations of the scenario to validate the model.

Another research activity under consideration is using *Microcosm* to analyse and describe the level of model fidelity required to support the different phases of the capability life cycle. This activity may then be extended to characterise the MBSE deliverables that could be used to relace traditional document-centric systems engineering deliverables.

As outlined in Sections 1 and 3, one goal of *Microcosm* is to support research into model-based systems engineering, particularly in demonstrating how the paradigm enhances the systems engineering process. A future research activity envisaged involves the elaboration and formalization of the changes to systems engineering and project management resulting from the employment of model-based systems engineering practices, using *Microcosm* as a case study.

The range of SE&SI research applications in which *Microcosm* could serve as a laboratory is broad and it is expected that this list of possible future research activities will grow with the evolving capabilities of *Microcosm*.

5. Summary

A major challenge confronting Australian defence today is systems integration of complex military systems. Large Australian defence projects generally require procurement of pre-existing, 'best-of-breed' equipments from a variety of manufacturers and the integration and tailoring of these to form large-scale, complex systems to meet Australian Defence requirements. System integration issues are notoriously difficult to identify early in a project but education, training and industrial experience can and does make a difference. As an investment in addressing SE&SI challenges, DSTO established the Centre of Expertise in Systems Integration (CoESI) with the University of South Australia (UniSA). The CoESI focuses national resources on system integration and an initial emphasis has been on building a SE&SI '*sandpit*'.

The *Microcosm* facility described in this paper is designed to accelerate systems engineering and systems integration (SE&SI) education, research and development, and foster good SE&SI practice. It is also intended to explore the use of model-based systems engineering and the extent to which this paradigm can improve SE&SI outcomes. *Microcosm* provides the infrastructure and flexibility necessary to support these activities using the concept of a SE&SI *sandpit*. The *sandpit* consists of a collection of physical robotic systems, external sensors and actuators, and synthetic models and an information environment that evolves continuously to expand the capability of *Microcosm*. These synthetic models and physical systems support the concept of '*plug-and-play*' and open architectures through the use of the publish-and-subscribe paradigm. *Microcosm* is intended to be configurable via a context manager to address a wide range of scenarios to meet the needs of our stakeholders and partners to support the investigation and education of various aspects of SE&SI.

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