# Integrated Modular Systems for Maglev Vehicle Control

No. 96

Peter Hubbard, Prof Roger Goodall and Dr Roger Dixon
*Loughborough University, Ashbey Road, Loughborough, Leicestershire, UK, LE11 3TU*
P.D.Hubbard@lboro.ac.uk, R.M.Goodall@lboro.ac.uk, R.Dixon@lboro.ac.uk

Matthew Mapleston
*BAE Systems, Systems Engineering Innovation Centre, Holywell Park, Loughbrough University, Leicestershire, LE11 3TU*
M.Mapleston@lboro.ac.uk

ABSTRACT: Integrated Module Systems (IMS) have over the last 10 years become a viable direction for the future of complex avionics systems as they have the potential to provide a solution to the issue of increasing product complexity and improving operation performance whilst driving down the system's lifecycle costs. In addition control architectures of commercial Maglev vehicles have similarities to the requirements of avionics systems in that they are required to meet stringent safety specifications. This paper will introduce a project commissioned to test an IMS upon a Maglev test rig, and highlight how the field of Maglev can benefit from this development in the aerospace industry.

## 1 INTRODUCTION

The avionics industry for a number of years has been progressing from the well understood and well used concept of a federated systems architecture to an Integrated Modular Systems (IMS) approach. The drivers for this next generation of military avionics are to reduce lifecycle cost and improve operational performance in terms of maintaining high levels of redundancy and availability of safety critical functions, such as flight control systems, even in the presence of faults.

One of the main areas still to be addressed in the field of IMS is the full authority management of faults throughout the system (Nicholson 2005). The Integrated Modular Processing for high Performance high Integrity Control (IMMPIC) project has been commissioned as part of a PhD that is jointly funded by BAE Systems and the Engineering and Physical Sciences Research Council (EPSRC) of the UK government, and is based in the Systems Engineering Innovation Centre (SEIC), a partnership between Loughborough University, BAE Systems and the East Midlands Development Agency. The output of the project is to be a tangible demonstration of systems management concepts within IMS and the successful response of the system to the injection of a fault. A fundamental concept of IMS is that it should be platform independent, in that the same hardware and software components can be relocated from say a car to a train, and with minor changes be used to perform operational tasks. Therefore a Maglev test rig has been used as a demonstration platform and the results generated valid for interpretation by the aerospace industry.

Blomerius (Blomerius 2000) and Joachim, (Joachim 1995) discuss that Maglev systems need to meet safety requirements laid out by transport agencies for operation. The problem of providing reliable operation of complex systems to certifiable requirements is one that has been increasingly evident in the aerospace industry since the introduction of safety critical, complex technology such as fly-by-wire. It is therefore evident that commercial Maglev systems can benefit from the lessons learned and the development of technology in the aerospace industry, such as IMS.

This paper intends to outline the concept of IMS in section 2 and introduce the Maglev test rig in section 3. Section 4 will go into more detail about the implementation of IMS with commercial off the shelf components and the use of IMS for safety critical control of the rig is discussed in section 5.

## 2 OVERVIEW OF IMS

Systems based on an IMS architecture feature standard (in form, fit, function and interface) hardware modules connected both to each other and to various sensors and actuators by flexible communication networks. Upon each hardware module, a layered software architecture is incorporated to facilitate the simultaneous execution of multiple, independent software components known as applications. The layered architecture used is known commonly as the Three Layer Stack and is shown in figure 1.

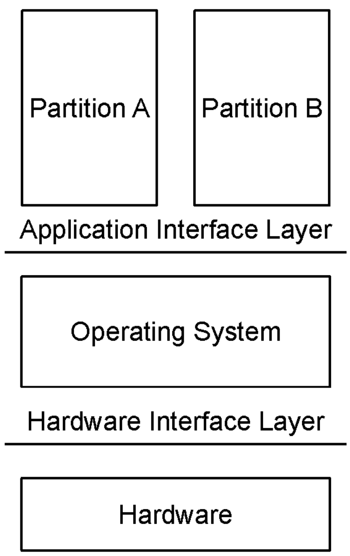


Figure 1: Three Layer Stack

The main feature of the three layer stack is that standard services, e.g. processing time, memory, communications, etc, are provided to the applications, independent of the underlying hardware.

A communications bus (e.g. ARINC 629 or MIL-STD 1553 (Moir 2001)) can link a large number of modules in a flexible manner, as shown in Figure 2.

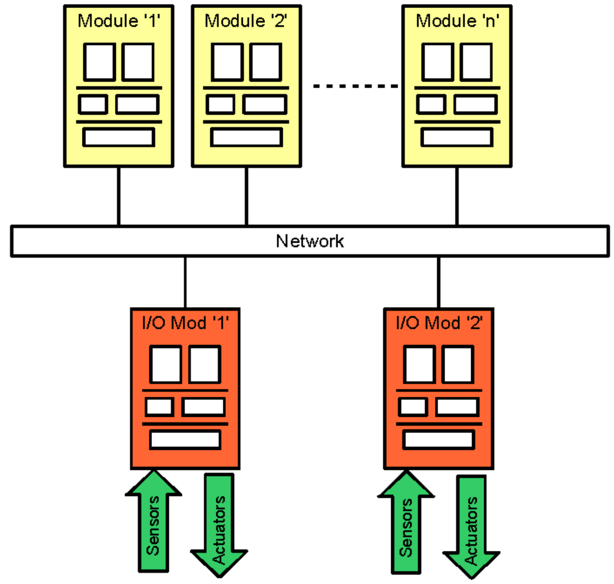


Figure 2: Concept network of IMS modules

Application software processes are run on physical resources and configured according to a systems blueprint, under the control of a distributed systems management scheme. Systems management, together with the inherent flexibility of systems using an IMS architecture, enables automatic system reconfiguration in response to events in order to optimize system functionality, resource usage and dependability under different circumstances.

In summary an IMS is a distributed, hard real-time control system with the capacity to reconfigure in order to continue to provide service and high levels of redundancy in the presence of faults. The loose coupling between software components and hardware allows for easy upgrade or replacement of one or more modular components, without the need for a full system re-design.

## 3 APPLICATION FOR MAGLEV

There is a large amount of work been undertaken on the Transrapid Maglev TR07 regarding certification of a commercial vehicle (Blomerius 2000, Joachim 1995, Ellmann 1995). The main issue identified within these papers is the fundamental requirement to maintain magnetic suspension. This is highlighted as a critical point with regard to safe egress of passengers on an overhead track, where there will only be a discrete number of safe stop and exit locations. The fundamental requirement of continued levitation in the face of all possibilities feeds down into stringent requirements in the design of the car body, the secondary suspension system, the on-board energy systems and the levitation and guidance system. These papers go on to suggest control strategies with standard methods of redundancy included within the designs in order to meet the levels of reliability required for certification of the system.

These requirements echo issues identified in the aerospace industry. However, a further major item that occurs in aerospace literature is the problem of maintaining the levels of redundancy and the system throughout a full product lifecycle where components of the system may become outmoded and difficult to source.

With this in mind, it becomes evident that the concept of IMS could be generally beneficial as a control strategy for Maglev systems.

Interestingly, although the application of IMS theoretically provides an increased level of reliability, the issue of certification still remains an issue (Conmy, McDermid 2001). Although active research is underway in this field, it is not the intention of this paper to address this issue.

## 4 RIG DESCRIPTION

The Maglev rig used for this project is a 200kg rig with four magnets.

Figue 3: Maglev test rig

The magnets have dual wound coils fitted around a single core, and duplicated flux sensors. This arrangement provides dual lane redundancy that can be exploited at later stages in the project for fault accommodation.

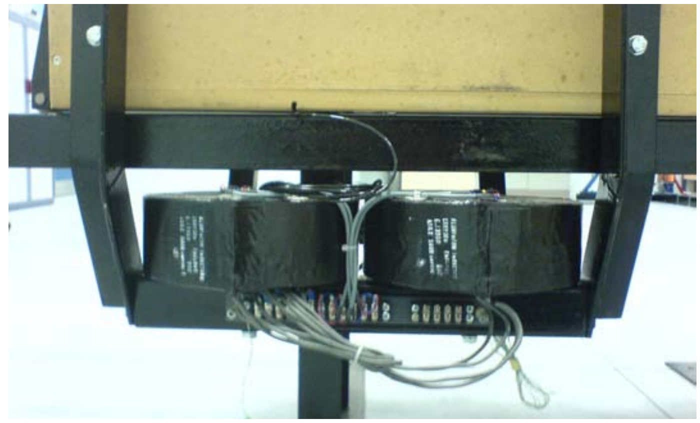

Figure 4: Photo of magnet with dual wound coils

Figure 5 shows the schematic for the dual coil assemblies. Each magnet pole has one of these dual coil assemblies to form a U-shape pole-wound electro-magnet. On each poleface there are two search coils installed to measure flux density, the signals from which are integrated by self-zeroing integrators in order to provide the flux measurements.

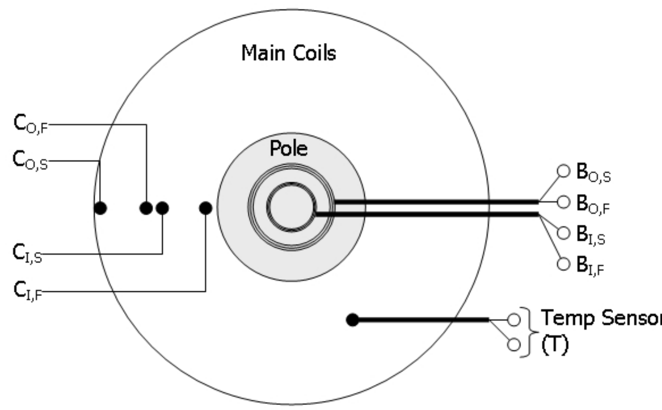


Figure 5: Schematic of coil windings

The control scheme to be used for levitation of the rig is taken from existing work done (Goodall 2000, Goodall 2004). The derived control structure for this particular rig consists of parallel flux loops at a bandwidth of 66Hz, nested in 4 airgap control loops at a bandwidth of 13Hz. Temperature sensors provide a basic health monitoring of the coils and current is also measured for performance analysis purposes.

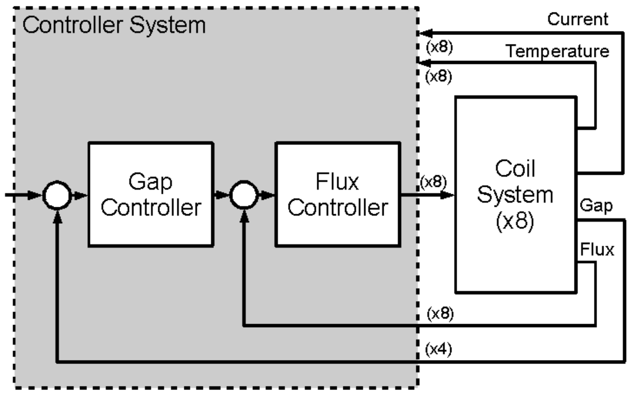


Figure 6: Control structure of Maglev test rig

## 5 IMPLEMENTATION OF IMS

Implementation of a full specification IMS as a development facility was beyond the scope and time frame of the project. As such, a representative IMS solution has been implemented with Commercial Off-The-Shelf (COTS) devices that provide the key components required for testing, and will meet the demands of the control structure outlined in the above section.

The IMS has been developed around a standard PC motherboard using a LabVIEW real time solution as the operating system. This format allows the easy integration of input/output (I/O) in the form of National Instruments Data Acquisition (DAQ) cards and provides the necessary drivers to interface with communications systems such as Ethernet.

The LabVIEW real time operating system (RTOS) is not designed as an IMS "middleware" solution and is therefore augmented by custom code designed to mimic the IMS systems management facility. Figure 7 below shows how the LabVIEW structure is analogous to the standard three layer stack structure in Figure 1, in which the LabVIEW "System Management.vi" function in combination with the RTOS provide the IMS middleware.

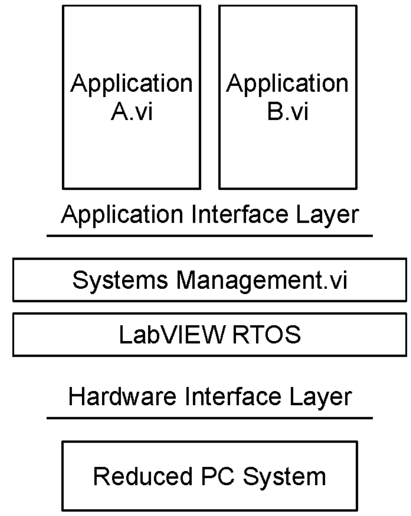


Figure 7: LabVIEW implementation of Three Layer Stack

The next challenge from this stage is to arrange for the autonomous configuration of the system by logically assigning applications to available resources.

There are a number of schools of thought as to how applications can be physically transferred to the appropriate hardware modules. It is possible via a high speed data network that a configuration is decided and then applications are downloaded onto the appropriate module. This approach has the possibility of causing an overload in bus traffic if a reconfiguration is required during run time. For simplicity, in this circumstance, each module will have pre-installed all existing applications and it will be the responsibility of the system manger to start and stop the appropriate applications in the correct place. Although not an ideal solution for a full scale avionics type system, it will suffice for the purposes of the project and provide appropriate results for the system management component of the system.

It is important at this stage to realise the assignment specification that has to be defined for each application at the design stage to ensure that the requirements for independent redundancy channels are not jeopardised. It is necessary to declare for each function the following assignment criteria:

- Inputs
- Outputs
- Type of module required (e.g. I/O module
- Applications that cannot exist on same module
- Criticality level

The system designer therefore needs to map out the functionality of the system in a logical way using an appropriate functional requirements capture technique such as IDEF0 in order to identify these specifications in full.

These assignment criteria are recorded by the system blueprint and are used in the process of logically assigning applications to resources. Figure 8 below shows a simplified flow diagram of how the systems manager uses the available information to create a configuration.

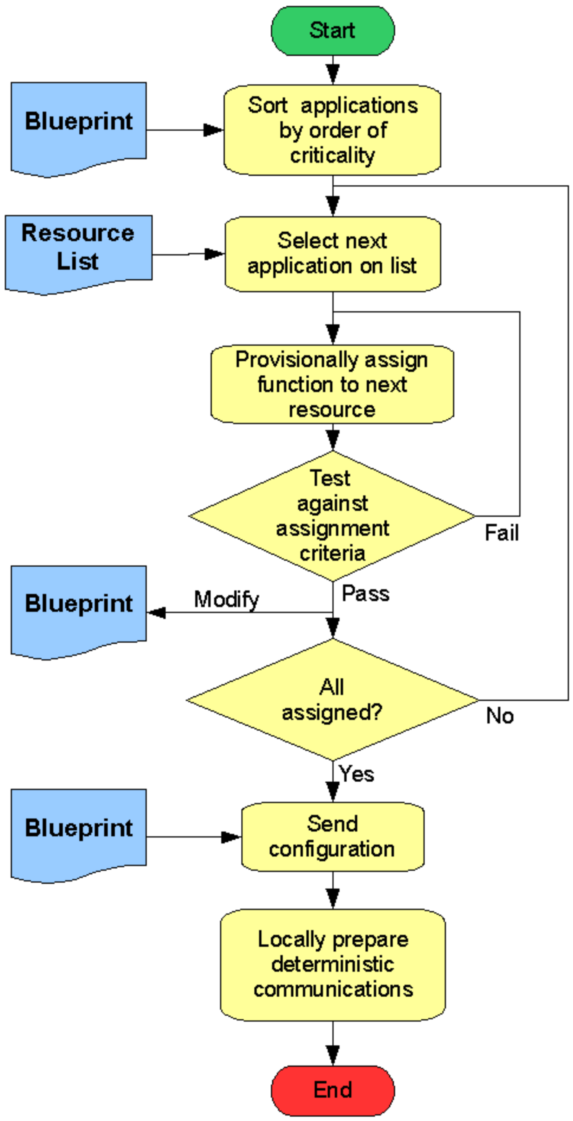


Figure 8: Flow diagram of system configuration

Due to the logical capture of assignment criteria, finding a solution to an acceptable configuration is similar to solving a combination problem, in that only a finite number of solutions exist out of a large number of possible configurations. Rather than using a 'brute force' method by generating all possible combinations and selecting the most compatible, the system works through a logical method in order to assign applications to resources whilst satisfying real-time requirements.

As shown in figure 8, the functions are ordered in terms of criticality, such that the most important functions can be placed first. At each attempted placement, the system checks against the assignment criteria specified at design and against other aspects such as available processor time on each module, and availability of the network for outputs. The least critical functions are placed in the available slots of processing time and network availability The output of the systems configuration is an updated blueprint that not only details the assignment of each module, but contains the timing within the discrete time frame that each application can execute and send/receive data.

Consider the following simplified diagram describing the control functions required to maintain a constant airgap. The flux controllers are split into two sets of 4, such that there is a redundant channel that can control the whole rig. Likewise, the gap controller is split into two sets of 4, again so that there is full channel of redundancy across the vehicle. Each flux controller set receives data from both gap controllers, and each gap controller receives data from each sensor set. The sensor sets are linked with the flux controller set to form a flux-servo loop, thus an assignment criteria exists where sensor set A must be placed on the same I/O module as flux controller set A and likewise for sets B.

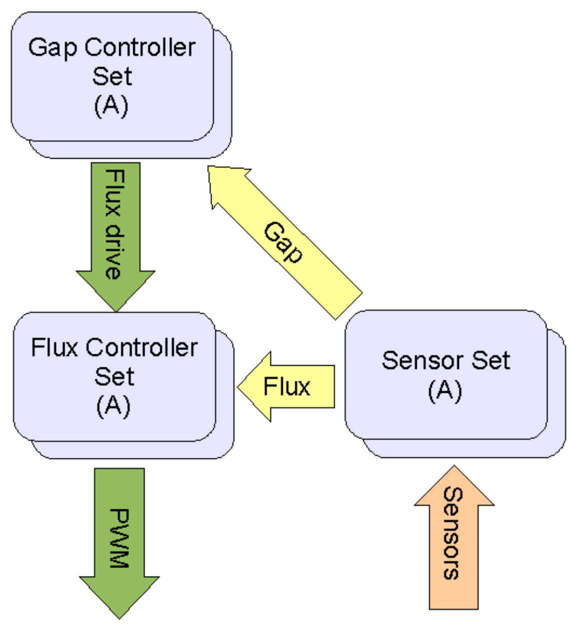


Figure 9: Example functional flow diagram for Rig control

Each function and interaction is defined and recorded in a function specification in order for the system manager to interrogate to extract the assignment criteria.

By installing these functional applications on the system and running the configuration method to an IMS hardware architecture consisting of 3 generic modules and 2 I/O modules, the following assignment configuration is realized:

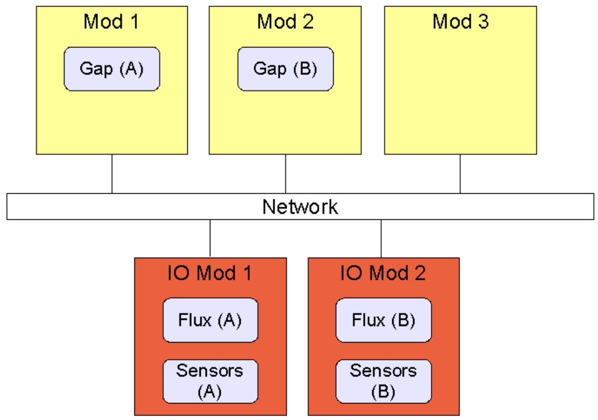


Figure 10: assigned functions

As well as configuration, the system manager outputs the required start time within the frame of each application, and the time at which each application can send data across the network.

## 6 FAULT MANAGEMENT

This section will discuss how the example system designed and configured in the above section has the capacity to cope with failure by utilizing classic static redundancy and dynamic reconfiguration.

Consider the functional description of the diagram in figure 9. It can be seen that the system has been designed with a duplex redundancy method in mind. Therefore, if there is a failure in a sensor, actuator, or any individual processing component, the redundant lane can be utilised to maintain service, albeit at a lower level of reliability.

In addition to this the IMS provides the capacity to cope with failure beyond standard multi-channel redundancy. By utilising redundant processing resources it is possible to exploit the flexible assignment of functions in order to reconfigure the system and restore higher levels of redundancy during operation.

Figure 10 highlights a possible configuration of applications to resources. Consider the case of a failure in the processing module named Mod 1. In the short term, the service of the system will be maintained by the use of Gap Controller Set B. However, as mentioned previously, the system is now operating at a lower level of reliability. Because of the flexibility of IMS, it is possible in this case to restore the system back to near-full levels by dynamically reconfiguring the system. It is possible to identify that Mod 1 has failed and that this has resulted in the loss of the Gap Controller Set (A) function. From here, the system can then re-assign this function dynamically to the redundant processing module, Mod 3, thus restoring the full duplex system.

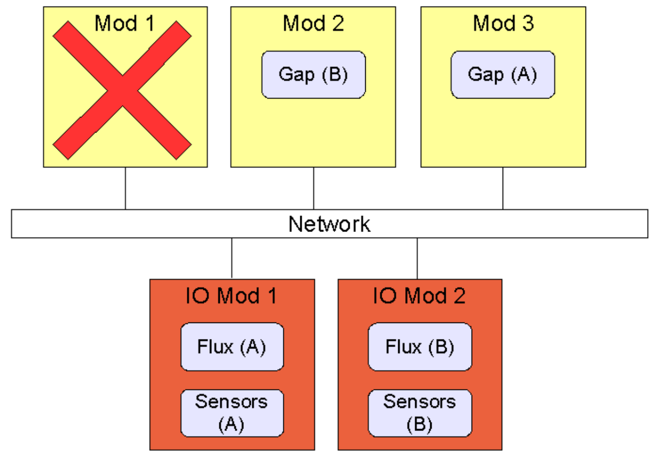


Figure 11: Example of Reconfiguration

Although this does not actively repair the original problem, it masks the effects of the failure. However, this reconfiguration may provide a solution that still meets the levels of reliability required for operation and it is not essential that the system is repaired by maintenance staff immediately. This extended time between service reduces maintenance costs as the system can be repaired at planned intervals, rather than creating immediate down time.

Obviously this is a simple example showing one reconfiguration option. With more complex systems it may be that a perfect reconfiguration solution cannot be found, so less critical functions or redundant channels are sacrificed. The system has the capacity to constantly reconfigure itself to find an optimum solution based on the availability of resources, until it is not possible to create a configuration that meets the specification of the designed system

## 7 CONCLUSION

Although IMS is not yet a fully used concept, its potential benefits to the field of avionics is staggering. In turn, it is possible for future commercial Maglev vehicles to use this concept of IMS in order to reap the benefits of improved operational reliability specifications and the reduction of overall lifecycle costs. The project in this paper has not only been used to test an IMS systems manager, but has proven that IMS can be used as a modular solution for the control of a large, complex commercial system.

## 8 REFERENCES


Blomerius, J. 2000, "Safety of High Speed Maglev Trains of the Transrapid Type", *16th International Conference on Magnetically Levitated Systems*.

Conmy, P. & McDermid, J. 2001, "High level failure analysis for Integrated Modular Avionics", *Sixth Australian workshop on Safety critical systems and software - Volume 3* Australian Computer Society, Inc, Darlinghurst, Australia, pp. 13.

Ellmann, D.I. 1995, "The Levitation of the Superspeed Maglev System TRANSRAPID", *14th International Conference on Magnetically Levitated Systems*Die Deutsche Bibliothek, Berlin, pp. 63.

Goodall, R.M. 2004, "Dynamics and Control Requirements for EMS Maglev Suspensions", .

Goodall, R.M. 2000, "On the Robustness of Flux Feedback Control for Electro-magnetic Maglev Controllers", *Proceedings of Maglev 2000*, pp. 197.

Joachim, B. 1995, "Status of the Safety Certification Process of the TRANSRAPID System", *14th International Conference on Magnetically Levitated Systems* Die Deutsche Bibliothek, Berlin, pp. 95.

Moir, I. 2001, *Aircraft Systems,* 2nd edn, Professional Engineering, Bury St Edmunds.

Nicholson, D.M. 2005, "Health Monitoring for Reconfigurable Integrated Control Systems", .