Platform Intelligence and Control – What Does the Future Look Like?

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Synopsis

Throughout the years since the advent of the electronic computer, the speed of processing and availability of memory have increased at a consistent rate in line with the perception of 'Moore's Law', that the number of transistors on a microchip doubles every two years though the cost of computers is halved.

As this availability of computing power has increased, as has the desire of engineers to monitor, record and analyse increasing aspects of equipment. This desire has led to increasingly complex monitoring and recording systems, with increasingly complex control system to attempt to analyse and present this information in a useful manner.

The systems that perform this function have become increasingly complex, and with the complexity come cost, and programme risk, with these systems now approaching or on the critical path. These systems now combine many functions including: providing indication to an operator, recording data for incident analysis, tracking data for maintainers, providing condition assessments, automated control of functions, and now approaching full automated control of the entire platform.

With the relentless progression towards ever bigger data, what should the intelligence and control system of the future look like? This paper seeks to explore the options that may be, or become, available in regard to how the hardware is selected and configured: how data is collected, sorted and prioritised: how security and integrity of data is embedded; how the requirements of data integrity and security are met without imposing the most demanding requirements on all elements.

While a definitive answer is unlikely to exist, the issues are becoming more well-known and the impacts keenly felt across our industry.

Keywords: Control Systems, Intelligence, Data, Information Systems

Caveat

The views and opinions in this paper are those of the authors and should not to be construed as the official views of the wider maritime community.

1. Introduction

When discussing the future of the Maritime control industry, key customer desires must be considered. As ever, cost reduction is the foremost goal. Many of the techniques and tools discussed in this paper pave the way for this to occur. Open system architectures and modular designs can maximise re-use from other industries. Artificial intelligence can speed up the design process.

A reduction in costs can be achieved by a reduction in manning – another trending desire of customers. By removing manning, many of the current systems and challenges go away (a majority of platform systems are required purely to serve people). To achieve this goal there needs to be a transition where automation increases and human interaction becomes more observatory, allowing a transition to the removal of people.

The advances in bigger data also bring increased levels of threat from cyber warfare as data is potentially exposed to cyber threats. This can however also be counteracted by taking Cyber protection to the next level with automated systems detecting threat behaviour.

2. Big Data

As the use of computing power has increased in industrial applications the volume of data collected and stored has progressed to the position where it can only be described as comparable to 'Big Data.' A definition of Big Data is:

> *very large sets of data that are produced by people using the internet, and that can only be stored, understood, and used with the help of special tools and methods:*[1]

[1] Cambridge University Press, Cambridge Dictionary

Big data can be discussed efficiently when looking at more specific industrial examples.

2.1. Wind Turbine Example

A modern wind turbine farm provides an excellent way to understand the mechanics of a big data platform. At the edge of the platform the wind turbine is augmented with multiple sensors and control loops with data sampled at different rates. These edge processors (which are located in the nacelle) are at a point where a first level of real-time analysis is performed. The turbine controllers collate data with respect to the turbine propeller pitch in an onboard historian (a database optimised for time-series data or streaming process). The pitch data is stored at two data points every 40 ms to optimise the pitch of the turbine blades; the conversion of rotational energy into electricity; and the determination of local battery storage or grid transmission.

A second level of analysis occurs at the farm level. A farm controller receives more than 30 signals from each turbine at approximately 160ms intervals. The farm monitoring software processes 200 tags (a tag is a raw sensor data point or calculated value with various associated properties including name, value, time stamp, data quality) from each turbine at a one-second interval from each turbine a second.

A remote monitoring station provides the third level of analytics at one second intervals. The data scientists at this station are able to analyse individual turbines and whole farm diagnostics. A high-performance computing cluster can be used to analyse years of data from a multitude of farms and data points with the aim of optimising the full generation and distribution chain.

2.2. Aerospace Example

Within the aerospace industry fuel efficiency means everything to operators because of its direct influence on profitability. Integrated flight data and analytics provide insights to identify and implement sustainable fuel efficiency opportunities: measure and track savings, before and after, at fleet level; drill down per phase of flight. Analytics and reporting are able to drive insights for further saving opportunities.

Aerospace utilises big data to further other benefits.

- Removal scheduling
  - Using Life Limited Parts (LLP) and tracking their deployment
  - condition monitoring and fleet projections to manage shop loads for efficient utilisation of spares holdings.
- Prognostics / Diagnostics
  - Using global fleet data to predict and solve fleet issues before disruption occurs.
  - Configuration tracking – Accurate fleet records that are essential for proper maintenance planning

2.3. Naval Controls

Modern naval control platforms contain a multitude of controllers from different providers of equipment. These multitudes of differing controllers are then integrated to form a single coherent system. An integrated system such as this requires extensive interfacing of codes and protocols. As such modern platforms and control systems involve more and more data provided by a multitude of dedicated serial links. Increasingly high speed Ethernet databus are used to publish and subscribe to ever increasing data. Mochulski & Malina [1] chart the use of multiple databus standards in their open systems paper. The challenge therefore is to provide a commonality of standard to publish, log and analyse data.

Ultimately multiple challenges exist in adoption of these big data techniques, however, essentially these are regarding three major areas.

Storage: An acceptance that the cloud is sufficient for the protection of data loss. Storage on an active vessel requires robust data cartridge or network attached storage with the appropriate data protection.

Analysis: Providing sufficient processing power, data mining and trending techniques can be found (PREDIX etc), using AI techniques to gain inciteful cross-corelated and useful data.

Visualisation: Providing the interpreter of the data suitable infographics that are easily understood. The Royal Navy NELSON project has published methods for visualising data (digital style guides and a front-end toolkit). NELSON's objectives are: To make the Royal Navy's data coherent and accessible, to enable the rapid development and deployment of intelligent applications, and to grow a culture of digital delivery.

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These challenges will need to be overcome to realise the benefits of big data. These are, however, benefits that are available on airframes, where monitoring of a user's performance is common, where the systems are used to focus training needs by highlighting anything not actioned within a given trend of behaviour.

3. Artificial Intelligence

Artificial Intelligence (AI) or machine intelligence is largely uncharted area. Put simply AI is any device that perceives its environment and takes actions that maximise its chance of successfully achieving its goals [2]. Machine learning (ML) forms many texts and a number of methods of building models and training them to exhibit human intelligence are available.

Human Machine Interface's (HMI's) most important role is to reduce user workload - and cut down on the number of instances that the user needs to look away from their surrounding environment and down at their controls. 'Heads out operation' is particularly important in military vehicles. The aerospace industry is at the forefront of crew reduction and automation in the area of HMI. Head-up displays and Hands on Throttle and Stick (HOTAS) systems. Another area of interest is Voice Interface- based on complex tasks or used to support supervisor commands. In turn this should reduce crew workload increasing platform effectiveness.

Direct Voice Input (DVI) technology has been adopted on the Eurofighter platform. Eurofighter DVI allows for voice control of some 26 non-critical systems such as radar mode switching, display switching, navigation tasking, etc. Each aircraft is trained to recognise the voice of its pilot. This task is achieved via a Ground Support Station (GSS) with the data transferred to the Eurofighter's on-board systems via a Mission Data Loader. Combined with hands on throttle-and-stick the DVI removes the need for a pilot to look down at the displays in the majority of situations.

With significant amount of data available the development of a System Advisory based upon previous history (AI learning model) could be a major advantage to the crew.

Digital Twin reference model.

To realise the full potential of Digital Twins, a robust platform is needed for them to live, learn and run at an industrial scale. Existing Digital Twins can run on several industrial Cloud platforms such as AWS and Microsoft Azure. Digital Twins are built with our physical domain expertise at its core, blending digital and physical in a combination of data from the blueprints of physical assets and physical and virtual sensors on the assets themselves. There may be cases where extra sensing is provisioned for within a system to give more insight and fidelity into the model that serves the model only. The twin can be used as a reference for predictive analysis or cyber protection (see below).

Figure 1: Aircraft Engine Digital Twin Concept

To combat the resource hungry development of AI techniques developers of Machine Learning applications are increasingly turning to modern graphical processor technologies. The graphics processor unit (GPU) instruction set has been developed to deal with complex geometrical and vectorised processing. The phrase General Processing on Graphics Processing Units (GPGPU) has been used to describe a concept for using GPUs for general processing tasks.

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4. Simulation and Model Based Development

Development of complex interactive systems can be a resource intensive task. It is commonplace during aerospace design to develop and test electronic control systems (avionics) with simulations and hardware in the loop (HIL) environments before such systems take to the skies. These real-time simulations involve developing a model of the system and controller under consideration. Model Based Development (MBD) and the key attributes of the developed models including the possible consideration for the replacement of written requirements by models.

Auto-code generation (ACG) is a method that involves generating code automatically from a model. Model-Based Development (MBD) is more and more used for projects because it is recognised as an efficient method to develop safety-related software. In the MBD environment, the capture of software requirements is done using graphical tools and graphical notations. Then, to fully benefit from this approach, ACGs can be used to produce the source code.

Some estimation of the cost advantages that could potentially be realised with MBD generation are presented in Figure 2. The figure attempts to put some quantification around the concept that the later in the process a bug is discovered the more costly it is to rectify.

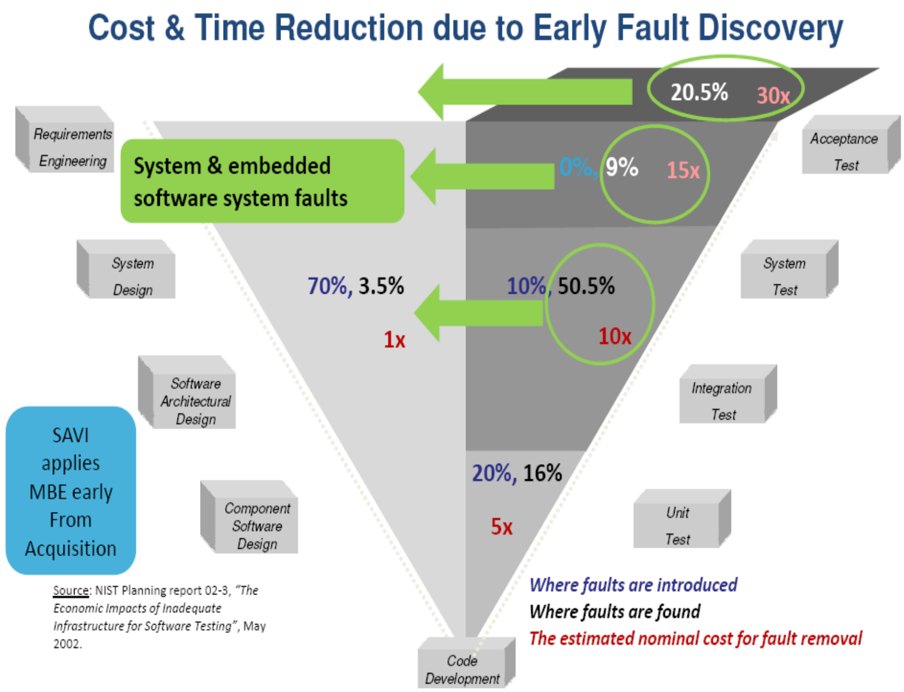

Figure 2: Cost & Time Reduction due to Early Fault Discovery [3]

The case study by Wright and Grazebrook [4] provides a very comprehensive read of the complexities of aircraft fuel control systems. The unique shape of an aircraft is devoted to making the vessels lift coefficient greater than its weight, as such fuel storage and transfer systems of large civil aircraft contain a myriad of fuel tanks valves, pump and sensors. The paper devotes particular attention to real-time simulation of fuel systems for the largest civil airliner the A380. A fluid network model is offered which has been successfully deployed in the core of several hardware-in-the loop integration facilities. Modelling environments and ACGs are referenced and utilised.

The use of tools within aerospace industry are governed by DO178. A tool needs to be qualified for its given development environment. This topic is largely out of scope within this text.

In short simulation and MBD can have the following advantages. The source code is quickly generated and available to show to the customer. The design decision can be investigated quickly prior to long lead hardware availability. It is highly probable that the generated code is free of errors and compliant with the coding standards with qualified or un-qualified auto-code generator. The code is automatically compliant to the model

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for qualified generators. It allows discovery of errors earlier in the project hence lower cost to fix them. Suppression of the risk of traditional project of discovering faults very late in the development life-cycle.
Automatic documentation generation. Overall MBD techniques have the potential to reduce resource intensive sea trials.

The disadvantages that need to be mitigated are creating a model fits reality, ensuring that the model fidelity is sufficient to track the system but not become processing intensive. Before being able to properly use MBD methodologies process, procedure and training will need to be provided. It is not necessarily a magic panacea, especially if a projects schedule risk does not support appropriate training. More effort is required the early development phases of the project (modelling and test case development). There is a high risk that the project team does not have resources in terms of people and time to properly conduct these early tasks. Fitting the automated code into platform service software that deals sufficiently with the real-world interface does need to be considered upfront. The cost of the tool license and training can be CAPEX not easily tolerated by the first project to use them.

5. Open System Architectures

The US Department of Defence (DoD) has been striving to realise the benefits of Open System Architectures (OSAs) since the publication of their OSA framework [5]. A key desire of the Royal Navy digital and data strategy [8] is a common model for infrastructure that promotes open architecture.

OSAs can be characterised by modular designs based on open standards and Commercial Off the Shelf (COTS) components. Nickolas H. Guertin & Dr. Paul Clements [7] define an open architecture as a development methodology that employs published, widely accepted standards for defining key interfaces within a system.

OSAs have already been adopted in many MoD control system projects. Recent control systems for UK Submarines have utilised standards and equipment traditionally associated with industrial control systems such as PROFINET & MODBUS based on COTS industrial controllers.

The latest UK MoD control systems utilise COTS controllers for data acquisition, processing and control. HCI servers use Linux and open architecture SCADA operating systems.

An overview of a generic SCADA system is shown below:-

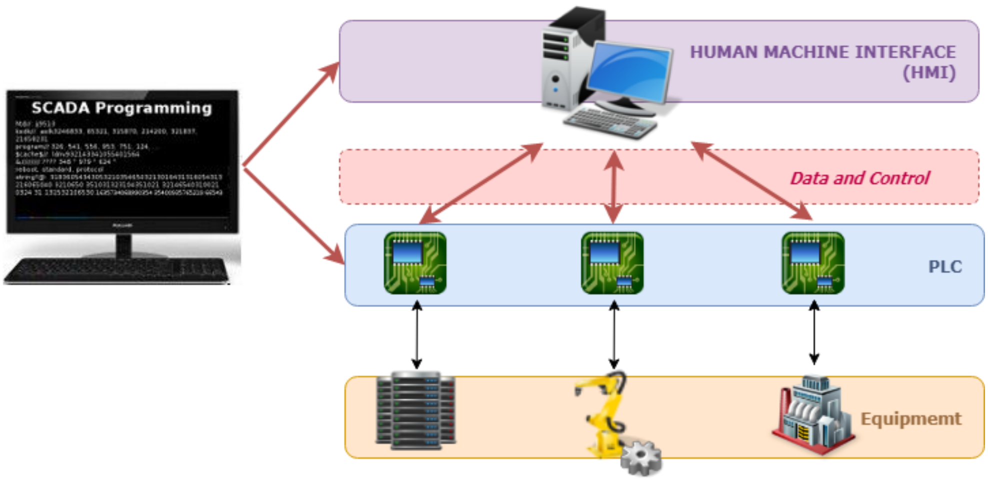

Figure 3 SCADA Systems Overview

Sub-systems under control have also followed the trend of providing standard interfacing protocols. This means more data becomes available to the control system provider.

OSA design patterns have replaced custom solutions based on proprietary hardware and software. Antiquated protocols have either been phased out or abstracted away via middleware products.

There may be a desire for a "Pan Maritime" control system for future platforms across the UK naval fleet. This core solution could be tailored (e.g. additional application specific software) to meet specific ship need such as mine-hunting. OSAs can support this capability by making the solution tailoring as smooth as possible via the use of open protocols and COTS hardware.

The availability of processing at low power and costs means that more processing power is available at lower level of system architectures. This has the potential to move compute and applications up and down the layers to ensure data is acted upon at the most appropriate point.

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Open architectures should equate to lower costs. An open architecture should allow greater competition amongst suppliers due to a more open market. Nickolas H. Guertin & Dr. Paul Clements [7] argue that open architectures have demonstrated:-

- Costs savings (albeit with a lower consistency when compared with product line development).
- Reduction in time to delivery
- Elimination of duplicated effort
- Higher Quality

Significant challenges can be encountered when attempting to gather safety evidence for COTS software components compliant with open standards. As safety standards place emphasis on development process evidence the use of COTS components in OSAs can be problematic when seeking safety evidence. COTS items can sometimes lack development process evidence. The well benefits of COTS need to be balanced against the safety debate when designing architecture.

6. Modular Design

Maritime control system projects can be huge in terms of both cost and programme. Costs can run into £100s of millions in development and have typically spanned 5-10 years in development. The modularisation of this design effort could greatly decrease cost and programme risk by spreading it across smaller modules.

Customers are aiming to move away from proprietary technologies with incumbent provider models, towards a model that can exploit the benefit of open ecosystems and third party software development responding more rapidly and cost-effectively to technology development and evolving threats. This change is philosophy provides opportunities for small to medium enterprises (SMEs) and academia to provide solutions to industries that have been traditionally dominated by a small number or large enterprises.

This operating model has already been exploited by some suppliers to UK Submarines. Systems have been designed using open standards to create a "common infrastructure". This provides the platform of a control network and operating systems running virtual machines. SMEs were then invited to provide "App" style systems that ran on top of this infrastructure. Complexities such as hardware and low level protocols were abstracted away by middleware technologies and the use of virtualisation.

A generic virtualised architecture is depicted below. The complexities of the infrastructure are need not be known by the App.

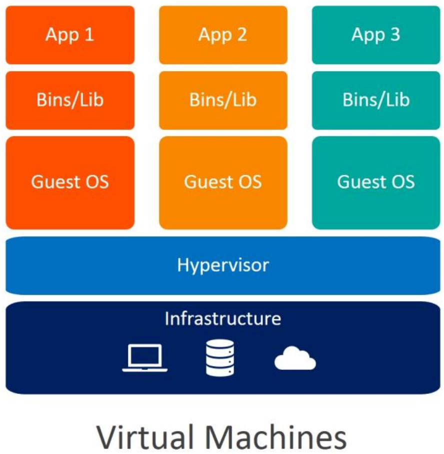

Figure 4 Virtualised architecture

The Royal Navy has begun to support this modular operating model by introducing the NELSON project [9]. Although this project is in its infancy the creation of NELSON standards allows developers to re-use proven code (for example style sheets & functional behaviour).

Modular design has lots of potential benefits to customers:-

- Benefits from cutting edge developments in commercial and academic centres
- Access to a wider range of suppliers, driving competition and cost
- Reduced barriers to entry for suppliers

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- Greater leveraging of COTS components, reducing cost

There are significant barriers to this modular design approach. Safety evidence for a greater number of components can be hard to gain. Lots of software components are not certified when used in a virtualised environment for example. The end-to-end safety functionality can be harder to understand with so many disparate suppliers and components.

7. Automation

As the capability and capacity of processing increases the likelihood of further automation of tasks also increases. Tasks that were once performed by an operator in accordance with operating procedures can now be automated.

The level of automation in Marine Control Systems has evolved from simple systems to remotely controlling and monitoring valves and pumps, through to automation of some tasks. In the submarine domain tasks such as vent state line-ups, trim and compensation operations and some autopilot functions such as depth changes have been automated via the Platform Management System (PMS). However, automated systems in this domain have still remained human centric, with a "man in the loop" for safety critical operations.

While autonomous maritime vessels are a possibility, an autonomous front line warship with autonomy over the power to deploy lethal force is not foreseen by the authors at this stage. There are several examples of unmanned vessels with varying levels of autonomy at various stages of development.

- The US Navy already has unmanned surface vessels. Although these are unmanned they are not truly autonomous. [10]
- Roblin [11] argues unmanned drones may render future submarines obsolete
- HI Sutton [12] discussed the possibility of a fully automated nuclear-powered attack submarine (see below).

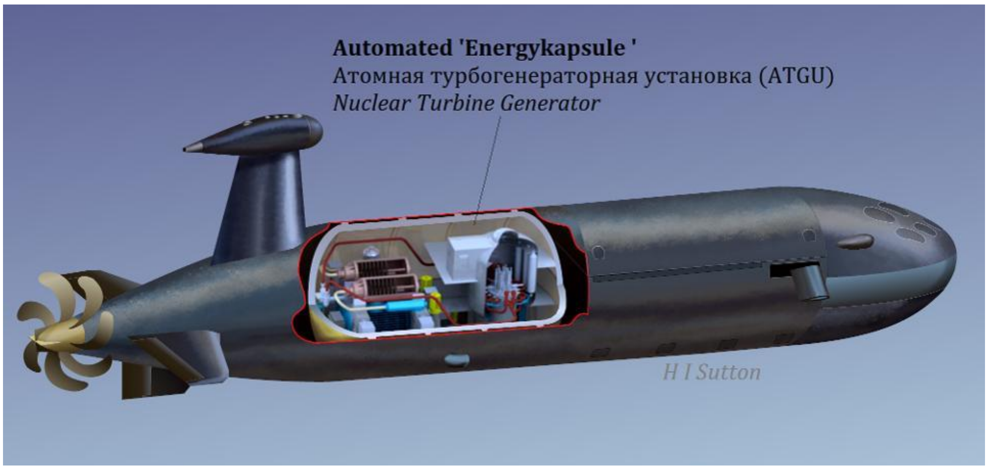

Figure 5: Conceptual illustration of un-crewed nuclear powered attack submarine built around the Russian Automated Nuclear Turbine Generator

Whilst fully autonomous vessels are still some way off, the trend to automation of simple tasks, automated sub-systems and reduction in manning is easy to see.

The obvious benefit of automation is a reduction in manning. However as automation increases and advances it may not relieve operators of tasks, it may simply change the role of the operator and the way they perform tasks.

The ability to automate processes can be limited by human and safety factors as well as processing limitations. If the automation is not trusted by its users, it is not used or misused. If it is trusted too much then this causes other inherent issues. (Schaefer et al. July, 2014). Overreliance of automation of tasks can also have a detrimental effect on the operators understanding of the system – i.e. the mental model.

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8. Cyber Protection Security

As systems become more interconnected cyber security becomes even more paramount. Typical routes to ensuring cyber security set out in classic cybersecurity methodology together with threat vulnerability detection and patching are always playing catch-up with bad actors. With increased computation systems this process can be supplemented with real time analysis.

Taking Cyber protection to the next level with automated systems detecting threat behaviour, reconfiguring the system automatically to protect. The Digital Ghost concept acts above and in addition to common information technology (IT) and operational technology (OT) cybersecurity methods.

Detection: Determines if abnormal operation is occurring which can be caused by a fault or cyber-attack. The detection algorithm combines a Digital Twin model with real-time data from the sensors on the asset and uses algorithms to accurately differentiate normal operation from abnormal.

Localisation: Identifies what is under attack or has faulted, in terms of monitoring nodes (i.e., sensor, actuator or control nodes). It is also intended to provide forecasting (an early warning capability) and critical real-time insights into system operations so that operators can monitor malicious activities, tampering of control system parameters, or the potential onset of a fault.

Forecasting: Provides critical real-time insight into system operations so that operators can monitor malicious activities, tampering of control system parameters, or the potential onset of a fault.

Neutralisation: Maintains a level of system availability without performance degradation by calculating real-time optimal estimations of the attacked sensors.

Blockchain.

The technology utilised to ensure that a ledger of crypto-currency transfer is maintained is commonly referred to as Blockchain. A list of records, called blocks, that are linked using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data.

The Blockchain could be used within the control system environment to create Trusted Networks, Sensors Acquisition, Data distribution, leading to better decision making. Figure 6 depicts the Blockchain Attributes over a distributed, secure mesh of devices.

Utilising basic principles of blockchain will benefit Distributed Consensus. Acting upon real-time data to create chains of network data, application decisions and outputs to ensure unmanned networks are not compromised by bad actors. Blockchain techniques will drive confidence of system integrity due to an agreed ledger across the nodes on the network.

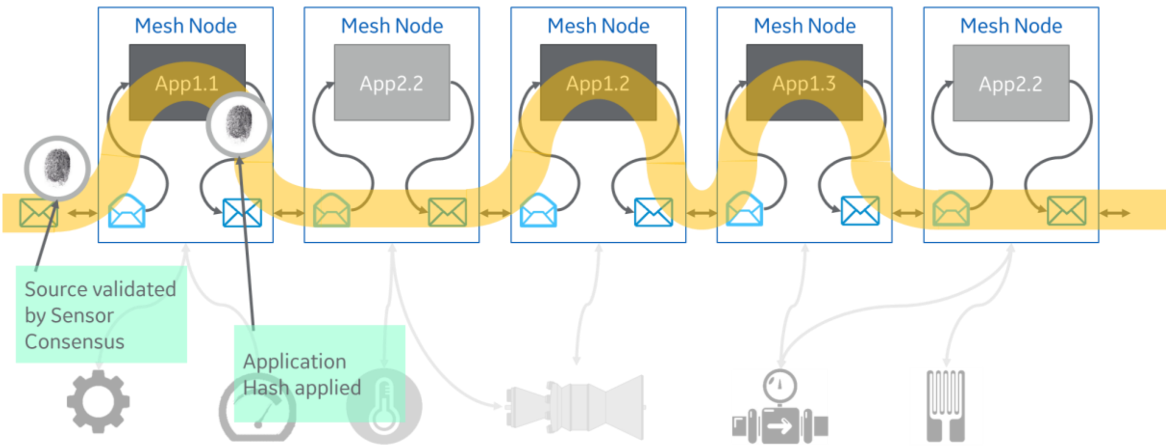

Figure 6: Blockchain for Industrial Network

Each piece of the distributed application adds to the parameter and therefore adds to the ledger. At each stage the node cluster can validate a change. In addition to securing the data transfer blockchain techniques can be used to mitigate Byzantine fault failures of a control system.

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9. Conclusions

This paper has discussed some emerging technologies and how they may link to customer desires.

The adoption of technology must be closely coupled with the application of codes and standards to allow its use and build confidence in the user community. There are methods that can assure security of the system code, the system control and the system data, but these must be designed into the systems from the outset and not considered as optional extras to be added at a later date.

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