Requirements analysis for automating product testing in aerospace manufacturing

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Abstract

The Aerospace Industry has been undertaking strategic changes towards digital manufacturing. One of the challenges is the lack of rationalisation for a cost-benefit analysis of automating certain manufacturing and assembly processes within a customer order. The rigidness and complexity of aerospace lifecycle, and tight industry restrictions does not leave much room for high risk innovations in manufacturing and production lines. This research addressed this problem by investigating an automation adoption scenario with BAE Systems, Electronic Systems, which is a UK based aeronautical systems integrator. This paper reports findings from the general manufacturing industry via an industrial survey. These findings are compared with original findings from an empirical study carried out with BAE Systems within the New Product Introduction team to automate product transportation logistics in an environmental test facility. The paper describes the challenges particularly related to skills, and labour workforce required to manipulate heavy standing products in and out of a production line and how their requirements can be addressed within an automation solution package. The solution includes key design factors related to intricate handling of aeronautic systems via the gripping interface design, and the rest of the operational issues surrounding the testing objectives such as transportation, and test setup. The findings are presented in the form of a requirements analysis for businesses looking to automate manually-intensive tasks in the future, and provide some insights into the lessons learnt in the development of the solution to benefit UK manufacturing tactics to some similar challenges.

Keywords: Robotics, Automation, Design for Manufacture and Assembly, Aerospace Industry

1. Introduction

An increasing number of system interfaces and variations of aeronautic products and black box technologies are becoming the new norm of New Products Introduction (NPI) activities, in meeting the supply and demand of integrated technologies for use in flight equipment [1]. High value – low volume, is the nature of these systems. Recently this was evolving into a high value, ‘higher volume’ nature of business as companies seek a greater balance between commercial and other applications. Due to the Covid-19 pandemic, commercial markets have weakened, leading to manufacturers requiring a high mix of products for capacity utilisation. The high mix nature causes shared processes, such as environmental testing, to see greater variability of the engineer-to-order products, demanding greater resources to manage the variability and volatile scheduling [2]. Aerospace manufactures are realising the need for a more versatile and flexible approach to their manufacturing operations strategy. It is no longer adequate to ensure strict adherence to safety as well as improve quality in the throughput, via further relying on a limited number of subject matter experts and experienced engineers as the only way. As test protocols have matured over the past decade, an opportunity to automate parts of the environmental testing processes presents itself amidst the issue of resource utilization. A similar challenge is occurring in other sectors of the manufacturing industry, such as civil, electronics, general mechanical, and mechatronics sector [3]. There is a substantial gap in the literature that aims to transform and implement proven automation solutions for manufacturing process innovation [4], particularly into the aerospace domain due to its closed nature.

On the other hand, the automation domain had dramatically increased its industrial research output to address many issues on a case-by-case basis, but are yet to become disseminated across the wider scope in the manufacturing sector that could closely depict this phenomenon of the aerospace product lifecycle. Our industrial survey findings from multiple manufacturing sectors, verify that there is more to be done for the aerospace sector. The findings place much of the limitations on the stringent inflexibility found in aerospace product lifecycle management approaches and the ICT infrastructure around it. With the use of a more open enterprise approach, the empirical study at BAE Systems, Electronics Systems division, in the UK was able to firstly capture the requirements of automating the processes, configurations, and secondly, the needed scenarios to achieve a satisfactory proof of principle for a lights out reliability shakedown test procedure (RST) shown in Fig. 1.

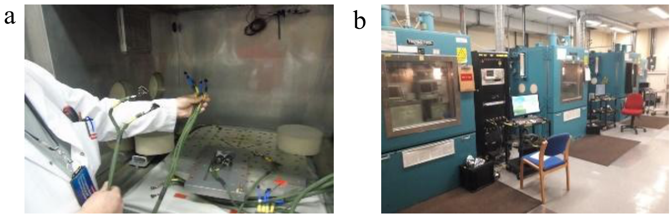

Fig. 1. (a) RST Connections (b) Environmental Chambers in RST procedure.

A requirements analysis is presented that aims to describe a comprehensive viewpoint of the technological capability and dynamic backbone of a flexible knowledge management framework capable of hot-swapping data and information models to feed into the procedure where and when needed and can accommodate more change management approaches. The analysis shows substantial benefits regarding flexible manufacturing and automation integration especially with logistical operations requiring mechatronic handling of products using robots, grippers, and mobile site movement. A discussion of the implications on workforce, and the skills gap is presented to pave way for further justification of cost-benefit valuation for industries with similar challenges.

1.1. Overview of related literature

Manufacturing reference models, architecture international standards such as CIMOSA, GERAM, ISO STEP-NC and Manufacturing ontologies/frameworks [5,6,7,8] have significantly contributed to the development of manufacturing information management practices. Management of robot software for automation had often been developed discreetly, due to the lack of early involvement in Industry 4.0 applications, resulting in issues related to the incorporation and integration of two separate modelling architectures into singled occurrences within, for example, Enterprise Resource Planning (ERP), Product Lifecycle Management (PLM), and Manufacturing Execution Systems (MES) [9].

Unlike the automotive industry, aerospace, and similarly other high value manufacturing sectors, need to place flexibility in their enterprise architecture at the core of their values in the coming decade. Traditional PLM systems simply cannot provide that capability to cope with uncertainty and flexibility as well as Enterprise 2.0 technology could [10]. It is proven that adapting this approach to the industry could provide crucial stepping stones in the way that the design of automation building blocks can be accomplished [11]. Previous research carried out by the authors with BAE Systems tested an experimental approach to manufacturing data integrity to allow creative modelling of defect knowledge to address design challenges. Similarly, an adaptation of this approach can be expanded into this empirical study to allow workflow modelling and versatile ICT infrastructure capability to incorporate robot related technologies deemed crucial to the success of the implementation of the requirements into a manufacturing system. This approach considers all actors in the manufacturing system to be represented in the form of an adequate model, useful enough to be classed as an informational cyber physically enabled system [12].

It is vital to incorporate instructional and feedback design to utilise the correct technologies required in the industrial application. Standardised modelling definitions can provide the backbone of the data structure to be used in applications, via semantic control [13] as proven by previous research. To build on this, new models concerning the workplace and environmental factors have to be taken into account when trying to automate the level of complexities within an RST logistics scenario. The capability of each actor requires populating in a database as structured information. In such case, robotic equipment have to be modelled considering additional layers of their interactivity aspects and not just the multi-movement of their built-in axis of rotation [14]. Identifying and implementing world-class high-quality communications and network protocols such as in building information modelling, would be at utmost importance to bring the vision of 24-hour operations of the RST procedure to life similar to a smart factory context. A raft of technological innovation will be needed to enhance the operating aspects of robots in automation and production lines. Modelling Cyber Physical Systems using tracking sensors, and marker feedback triggers allows dynamic monitoring of human-machine interfaces [15] in almost real-time. In our research, node taxonomies have been used to represent operating modes of the manufacturing process functionalities [16] which was known at the time of the empirical study.

2. Requirements capture

An industrial survey [17] reached out to 35 Small to Medium Enterprise (SMEs) in the general manufacturing sector operating within the British France channel, highlighting barriers to automation to include cashflow, production stoppage, manual intricacy, speed of delivery, and low volumes. Mobility and displacements within the shop floor was highlighted to be of significant influence on decision making. In comparison, the aerospace industry differed in our findings. The scale of the issues surrounding cashflow, production stoppage, and low volumes, are less critical. Although the findings of the follow up discussions of industrial survey, with our Aerospace collaborator BAE Systems, identified Smart Manufacturing concepts (including automations) as a better way to drive costs down where there was a clear indication of a low volume high mix environment of operations. The finding described that this environment requires a significant amount of manual effort to manage movement and manipulation of material by human workers as a pressing matter. Our discussions with the strategic team members recognized that human intervention is advantageous in improving the control of complex and varied tasks due to greater ability of dealing with variability and unprecedented scenarios, the kind of conditions a batch size-one environment would create.

Through further empirical studies with BAE Systems, it was observed that products were manually moved between departments, often by highly skilled engineers. Quantifying the amount of time goods were in transit was measured via asset tracking devices within the building architecture, making it possible to track the motion of all tagged goods, including the trollies that moved them. The results showed that some products would travel up to a mile throughout the production process and total time elapsed could equal a significant proportion of a highly skilled worker's schedule work time. The need for a flexible automated process for moving goods between departments that also fits with the production pull system that BAE Systems operates under, is crucial to debate, for industries with similar challenges.

2.1. Methodology

Capturing the parameters of the event in which RST automation is required was carried out, to represent the future state model. The observations in this study were carried out by two independent researcher engineers with no prior apprehension of any solutions discussed, overseen by BAE Systems Chief Engineer, and the corresponding author as the coordinator. They were given the task of elicitation of the requirements for transformation of manual tasks to automation enhanced tasks via instructional design. The observation resulted in capturing seven micro-phases specifically concerned with the BAE Systems environmental testing facility and are summarized below:

- Scenario design by manual imitation of the movement, and manoeuvrability steps.
- Digital, geometric modelling of key product, machine (RST configurator), robotic (base + arm + grippers) touch points in the scenarios.
- UML (Unified Modelling Language) representation of the work path decision points.
- An extensive IF algorithm of decisions variations when made.
- Isolating information models to enable discrete knowledge management.
- Allocation of subordinate modelling tasks to the engineering team.
- Programming a comprehensive virtual simulation in solid works for mechatronic factors and gazebo for dynamic factors shown in Fig. 2.

The numerical models were captured into Excel and tested in Drupal as information content to validate as part of an Operations ICT tool.

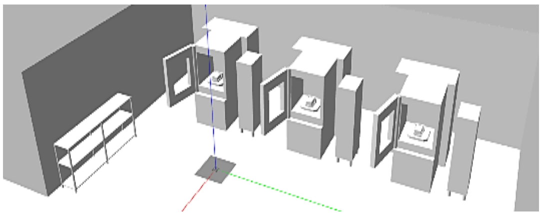

Fig. 2. Gazebo Layout Model of the environmental test facility

Key characteristics of the layout used were isolated in the model for elicitation of the dynamics with the pick and placement was replicated. Similarly, the test system setup jig was mechanically replicated via reverse engineering methods, and its information model made explicit. The key touch points included threaded holes, Teflon base, an ARINC (a type of rack and panel) connector, and a self-guiding screw to design a clamping mechanism shown in Fig 3b. Furthermore, the test chamber in which most of the effort is undertaken intricately was semi-simulated to reduce modelling of unused information whilst capturing critical mechanical factors. This included accurately measuring the height from the ground depending on the type of chamber used. Other significant dimensions such as depth markers, mechanical clamping mechanisms, and electrical cable pathways were included in the modelling efforts.

Transportation data from an existing on-site RFID (Radio Frequency Identification) asset tracking system was transferred into Excel showing the trolley name, date, time, and location over a calculated average use case. The data was broken down to define journeys of which there were over 350, with repeating data sets being defined as routes shown in Fig. 3.

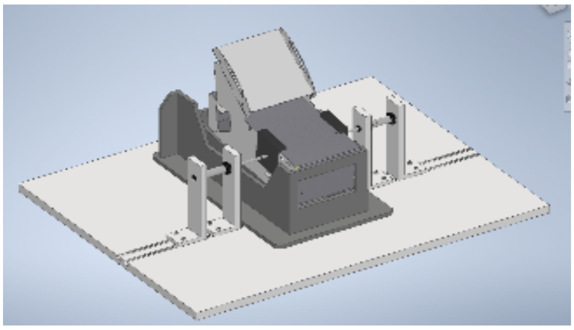

Fig. 3. Clamping Mechanism Design.

The total travel time elapsed during the period of one week, was 53 hours 42 minutes. These figures, along with other factors formed a significant part of the cost-benefit justification and provided employees at BAE Systems a strong rationale for innovating in mobile autonomous robot domain area. Where BAE Systems differs from typical manufacturing sites that already use autonomous mobile robots (AMR's) is its high occupancy, meaning any proposed project involving AMR's would need to emphasise the safety of the system and its ability to detect site operators and not impede occupants in a call for evacuation as well as reliability of the system proposed as a whole.

2.2. Case Study

In this apparatus, a repeater HUD (head up display) with a 25kg mass, was replicated as shown in Fig. 4. The repeater HUD was used as the case study example to drive the development of the digital and physical models. Both models were used simultaneously to model different aspects of the dynamic placement of this product in the testing chamber. The CAD model was used to elicit and structure details related to the geometry, whereas the physical model was used to observe and understand the gripper's intricate handling operations in terms of touch points within the products aesthetical touch points.

Fig. 4. Repeater HUD Model

The case study as a whole used the specific information obtained from the industrial collaborator. However, the purpose of the case study was to provide a repeatable and flexible means in which any given product with certain constraints can be used. Similarly, the case study ensured that any testing chamber could be used within the limitations of the space and environment given. The case study, used on this product is planned to replace products, and test chambers to allow for this flexibility in future development of the research.

3. Analysis of the requirements

The first step in the analysis is modelling the dispersed manufacturing activities and identifying the data required to be reused from the PLM, and ERP system to carry out the required robot tasks. In the event of process planning, the data required would be the production line layout, and process information, the product design data for robot handling, and logistical aspects such as sources of parts, warehousing, and scheduling.

The next step is sourcing the data and creating the appropriate relationships between the robotic system. For example, from the layout data of the production line, appropriating the free manoeuvrability space from the limited spaces is essential when using manoeuvring robots picking up products and placing them into each of the required manufacturing process space.

The third step is the integration of the information model with the robot program which was be created based on the robot capabilities depending on the robot used or planned for use, i.e. the arm for picking up and placing, and its subsequent integration with the production cell information model that specifies the geometry centres for placement and so on.

The fourth step is generating a pathway based on product variations of the complete scenarios from first to last step, regarding a robot achieving a particular operation or assembly task, whether in manufacturing, testing, distribution and so on. This information is then be centralized and managed through a knowledge management system and supported by a knowledge base for the fifth step to be completed.

The fifth step would be the adaptability of the generated knowledge for accomplishing certain tasks on other types of robots, or production environments, with built-in inputs for variabilities from the PLM data sourced initially for step one. This is to effectively reuse the generated knowledge to carry out similar tasks or identical tasks using different robots, different scenarios or products, followed by repeating the steps for generating new knowledge within the new context. The analysis of the captured requirements was formulised as the framework represented in Fig. 4.

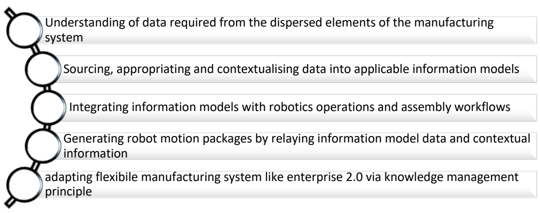

Fig. 4. Representation of Analysis Requirement Framework in 5 steps.

The next part of the work, had not been completed but a proposed plan to use knowledge agents for service applications of the RST automation scenario is proposed below:

In order to physically implement the framework, seven knowledge domains were built as a result of the analysis, but results are to be disseminated in future publications. The purpose of the knowledge domains is to store and manage the variable data within the domain information models. Such data consists of the different types of end of arm tool models in the robot knowledge domain, different types of assembly stations in the process knowledge domain, different clamping machine controls in the test equipment domain and so on. The products themselves are yet to be modelled to represent the variation of products used in the RST procedure as information models under the product knowledge domain. Likewise, the robots in use, such as an ABB arm, or a different type of arm with other parameters, would be configured in the robot knowledge domain and so on.

These domains are attributed as standalone elements towards knowledge agent use as a service. The knowledge agent for service, considers the relationships between the domains, via constituting a PHP query that pulls and pushes data via the Drupal interface. The data itself is then used to generate a unique path knowledge configuration and associated with the different user's profile for storage. They act as functional agents that compare the data inputs and validate them against the capability. For example, the product height beyond 200mm would not return a successful PHP validation operation if a smaller chamber was used, and so a larger chamber would be required in the agent's operation to be replaced for the analysis to return successful results.

4. Discussions and conclusions

The analysis framework for requirements was based on an empirical study for adopters of automation in the aerospace industry. The framework's benefits are clear, yet the work presented do not fully measure the impact of the work on businesses at its current stages but will do in our future publications. However, to bring the benefits of the work to the context of industry, it is important to acknowledge the significance of a requirements analysis, from a business interpretation point of view.

Businesses seeking new and innovative solutions, might see robotic automation as a means of stability in what is otherwise a very unstable time. In the light of the recent pandemic, it's important for industries to realise that robotic operations, and automation lines will not be affected by it. Thus, meeting the throughput performance of manufacturing if managed carefully. With employees dramatically reducing and skilled workforce with experience legislated to strictly remain at home, the disruptive effects of the event call for more leverage of the efficacy of automation applications towards a cost-benefit analysis.

The initial investment for robots can be substantial as their procurement is normally justified as a proportion to that of the number of tasks you wish to automate. But this, should not be the only way forward. With the utilization of versatile, flexible enterprise hosting, and a diversification strategy, then robots multi-use scenarios can be more effective.

Risks can and should be mitigated by working jointly on a collaboration with academia and manufacturing centre who may supplement research resources and can provide a viable means to predict and enhance company performance outputs via hypothesis.

Nonspecific benefits to the technology also present themselves by unencumbering workers from monotonous and time-consuming tasks. Although the amount of time saved is quantifiable when using a robot for a task, what has yet to be measured through our study is the productivity gains made by workers. Through discussions with workers, it is believed that a large amount of time spared from manual labour, could lead to an increase in manufacturing quality. Another lesson learnt in progress, has also been observed with larger companies. Those that make an initial investment with a high risk, tend to expand and make further lower risk investments due to return on investment provided by their initial decision. With the cost of an autonomous collaborative robot base being around £30K per unit at the time of the research, and the cost of a collaborative flexible robot arm (lifting capacity 10kg) being around £35K then a single piece of equipment can be justified as an average of £65K in the first year. Additional costs such as maintenance, software, service plans and dedicated robotics engineers can also raise the cost significantly in the first and subsequent years. Cost benefit analysis within a low volume high mix-manufacturing environment needs to consider utilisation of the autonomous system across multiple product lines to be economically feasible. Furthermore, creating better employability prospects in the long-term human head growth strategy of the company. Offsetting this by taking advantage of a stronger human workforce, continuous running times and higher work output on aggregate, automation could be worthwhile for some, especially for business' that foresee an unfulfillable growing demand due to lack of talent pools in the economy.

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