

An Intersectoral Reconfigurable Manufacturing Automation Testbed: Preliminary Design Considerations

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Abstract— *This paper presents the preliminary work towards the development of a generic manufacturing automation testbed intended for application to a range of different manufacturing sectors. This study is part of an academia-industry collaborative project aimed at increasing the competitiveness of a relatively large cluster of diverse manufacturing firms which are operating in a small and geographically isolated economy. Following an in-depth investigation of the target industry, various disadvantages to competitiveness are identified. To aid these manufacturing companies, this work aims to develop a generic intersectoral automation testbed, on which various unrelated manufacturing solutions will be developed, with a focus on implementing automated modular reconfigurable manufacturing systems. The testbed itself must be modular and reconfigurable since it must be capable of providing a large variety of different solutions to clients coming from various manufacturing sectors. The design and developmental considerations, approaches and guidelines for this intersectoral testbed, and the nature of subsequent manufacturing solutions, are discussed in this work.*

Index Terms—Reconfigurable Manufacture

1. INTRODUCTION

Over the years, the manufacturing industry has evolved and adapted to the numerous challenges imposed on it through various factors. Back at the beginning of the 20th century, the primary target for competitiveness was to provide customers with cheap and affordable products. This led to the development of Dedicated Manufacturing Systems (DMSs) which were developed around a single product, and thus were capable of mass producing high quality products at low cost. With the progress of time, and the advancement of technology, product variants were being gradually introduced. Programmable manufacturing systems and subsequently Flexible Manufacturing Systems (FMSs) were

developed so as to cater for this increase in product variety. However, FMSs have a number of disadvantages. Employing the philosophy of “buy it just in case it may one day be needed” [1], often results in a high investment cost. In addition, due to the mentality of equipping a flexible system with a vast amount of inbuilt capabilities, FMSs often result in equipment lying idle on the shopfloor. In the worst cases, certain capabilities of the FMS would never be used at all.

In the 1990s and early 21st century, a new paradigm of a reconfigurable manufacturing approach was developed. Various authors discussed Reconfigurable Manufacturing Systems (RMSs) [1]-[3], Reconfigurable Machine Tools (RMTs) [2], [4]-[6] and Reconfigurable Manufacturing Equipment (RME) [7]. Such systems bridge the gap between DMSs and FMSs, and combine the advantages of both approaches. Reconfigurable systems are built around a part family, or part families, allowing product variants within the same part family/families to be manufactured. The approach is that these reconfigurable systems are built out of separate modules, both hardware and software, so that product variety is catered for through the potential of substituting, exchanging, adding, removing, and/or modifying modules to change an existing RMS configuration into a new configuration with different capabilities.

A reconfigurable system is conventionally developed in a series of steps, such as per the guidelines discussed in [4]. First, the customer’s needs and the required reconfigurations are analysed. A set of functional steps are identified, with the reconfiguration functions clearly distinguished from the fixed functions. Developing separate modules for the reconfiguration functions will equip the system with the potential to be configured for different products or part families. Clearly, the level of abstraction into modules will depend on the level of expected variability. Developing a system to cater for only a single reconfiguration does not

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necessitate that the system be highly abstracted into various separate modules. However, having a large amount of variability would necessitate that the system be highly abstracted into various modules to give a high reconfigurable potential to the overall system.

The manufacturing industry today is experiencing more stringent challenges. Firstly, customers are demanding a much larger amount of product variants. Secondly, as time passes, there is continuous progress in technology, and as a result, products are constantly evolving so as to incorporate new technologies. Manufacturing systems and processes are also being directly affected by this advancement of technology due to the development of new techniques, processes and equipment. The introduction of regulations is also leaving an affect on the manufacturing industry. New regulations have affected manufacturing both directly and indirectly. Examples of direct consequences of these are the introduction of new regulations affecting specific manufacturing processes, such as the shift to use lead-free solder in recent years. Indirect consequences on manufacturing systems may be due to regulations that affect the product, such as safety regulations which then require the redevelopment of a particular product, or else recycling regulations which limit the presence of a particular material. Another existing challenge concerns the shift to an ever-expanding globalised market. Manufacturing companies today no longer have to compete against local companies only, but have to compete against distant and/or foreign companies as well. All these factors together have resulted in the current market situation being extremely volatile and unpredictable.

In this work, we focus on the specific challenges experienced by manufacturing companies operating in a small, geographically isolated economy. Such an economy would have inherent disadvantages, such as the limitations on the availability of high-level manufacturing automation solution providers, or the lack of easy exposure to new manufacturing technologies. As a case study, the local current situation in the Maltese Islands has been taken. The general objective of our research is to suggest and develop a systematic approach to increase the competitiveness of the individual companies within such an economy, particularly through effective use of reconfigurable manufacturing automation systems. Part of this approach, and the subject of this paper, involves the development of a generic resource to facilitate the development and implementation of more effective production and automation technologies and methodologies, within a bounded but diverse manufacturing sector.

2. SITUATION ANALYSIS

An essential part of this study relates to investigating in detail the actual manufacturing scene that is to be addressed. Detailed surveys, interviews and discussions have been conducted with thirty local manufacturing companies from across the range of manufacturing sectors, and physical tours have been taken of the facilities of most of the companies

interviewed. From this investigation, it has been identified that although the manufacturing scene is operating in a small and geographically isolated economy, there is still a very diverse manufacturing sector, with a focus on high value-added manufacturing. A high percentage of the companies fall into the following manufacturing sectors: plastics, electronics, food and beverage, assembly, furniture, textiles, chemical, metalwork, and mechanical component manufacturing (which generally combines multiple sectors from among the previously listed sectors). Although in all of these sectors, companies vary a lot in size and employment figures, most of the companies fall within the definition of Small and Medium-Sized Enterprises (SMEs). Even companies that locally are regarded to be relatively large would still be quite small by international standards. Due to the existing manufacturing situation highlighted in Section 1 above, most of these companies manufacture a very large amount of small volume batches. The challenges discussed above are also resulting in these companies finding it increasingly difficult to stay competitive.

From our investigation, some key problems have emerged with regards to manufacturing in an economy of this nature. With many companies consisting of only a small number of people in total and with many other routine mundane non-manufacturing related tasks that continuously require to be done, manufacturers often do not have the time and resources to delve into investigating potential improvements in their manufacturing strategy. As a consequence, a high percentage of these companies make use of relatively extensive human labour. From the study, it was identified that in fact these companies do show the wish to actually analyse ways of improving competitiveness in manufacturing; however they often do not act on this wish. These expressed desires include improvements in their existing process, upgrades in their manufacturing systems and equipment, and the embarkation on new projects, for example to develop a modified/new product together with the required production system. However, being small, these manufacturing companies cannot afford to employ personnel who would be dedicated to such issues. In addition, due to the small and relatively isolated geographical area and lack of manufacturing resources, certain manufacturers are not aware of the possibilities present nowadays with regards to manufacturing systems and new technologies, approaches and methodologies, sometimes even with automated approaches never having been investigated for implementation.

Our overall study aims to aid local manufacturing companies experiencing the mentioned problems that stem out of this lack of local resources. This has led to the concept of the development of a generic intersectoral manufacturing automation testbed to facilitate the development and implementation of manufacturing solutions as required by manufacturing companies within the geographically isolated economy. The testbed will focus primarily on providing the required instigation for the implementation of reconfigurable automation systems in the

local industry, with the ultimate aim being to increase the competitiveness of the manufacturing companies.

3. OBJECTIVES OF THE GENERIC INTERSECTORAL MANUFACTURING TESTBED

The sharing of resources through physical manufacturing testbeds is not in itself a new approach. Various other manufacturing testbeds have been developed as initiatives by government entities, universities, individual companies, or even the cooperation of a multiple of these bodies, with some of these initiatives outlined in [8]-[15]. These testbeds were generally developed to target a specific manufacturing sector, such as the automotive industry or the shoe industry.

In our work, the testbed is aimed at being available to a wide range of local manufacturing industries and to offer solutions related to manufacturing from various sectors. This would be analogous to directly giving the possibility to a particular company to actually employ relevant experienced personnel together with other development resources for specific manufacturing projects. On the testbed, solutions for various manufacturing companies can be developed, physically built, and tested, and this provides relevant companies with the commodity of analysing a particular solution thoroughly before actually taking the plunge and investing in new equipment and other resources.

The detailed objectives, and the subsequent developmental guidelines, of the intersectoral testbed have to be in line with the current manufacturing scenario that it is intended to cater for. From the manufacturing investigation discussed in Section 2 above, certain objectives of the generic intersectoral testbed and of the approach to manufacturing solutions can be drawn up:

There must be the potential to develop distinct, unrelated manufacturing systems within diverse manufacturing sectors. The testbed is required to reproduce manufacturing situations from a wide range of companies, from various different sectors. The development of the required capabilities and functionalities for each individual solution would stem from this same testbed. The intersectoral testbed therefore has to have the potential to develop various unrelated manufacturing solutions that deviate significantly from each other.

Developed solutions can either be dedicated/fixed or reconfigurable systems. Although the new paradigm of manufacturing is that of RMSs, DMSs are still very applicable in situations of mass production of a particular product. In view of this, the intersectoral testbed requires to have the potential to develop RMSs as well as DMSs.

There must be a rapid response. A fast and rapid response to develop a particular manufacturing solution is beneficial both to the manufacturing company *per se*, as well as to the intersectoral testbed. Through rapid response and fast development, a larger number of manufacturing solutions can be undertaken on the intersectoral testbed every year.

The testbed must provide both turnkey solutions and conceptual but effective solutions. As identified through the

detailed analysis performed, there exist two main situations which the testbed has to cater for so as to be an effective facilitator for the implementation of automated manufacturing systems in the target industry. The intersectoral testbed should develop manufacturing systems which companies can then make direct use of, or else replicate, on their respective shop floors. However, the same testbed also has to be able to provide conceptual solutions for companies that would prefer simply an investigation into the advantages of automating a particular process.

The testbed must operate at an economical cost. In order to be sustainable, the testbed must operate at an economical cost at all times. Unfortunately, lowering of cost comes at the expense of various other advantageous factors, such as the utilization of a wide diversity of equipment so as to cater for a wider range of companies more rapidly. Trade-offs will therefore inevitably be required to be made.

Specific solutions should be achieved through continuous client collaboration. Developed solutions are envisaged to be highly unrelated, and targeted towards various different products. Therefore, it is essential to develop each particular solution in parallel with discussions with the client. In this way, past manufacturing experience of the client on the product, or on similar products, and of the particular process, are conveyed and clearly understood. This also ensures that the solution developed is always in line with the client's expectations. Client collaboration throughout solution development is also useful when it comes to the equipment selection. During the various discussions with manufacturing personnel in the local companies discussed in Section 2, some of the respondents pointed out that automation solution providers should allow the clients to choose their own preferred brand of manufacturing equipment and components.

4. PRELIMINARY DESIGN AND SYSTEM DEVELOPMENTAL CONSIDERATIONS

Many choices in the design, set-up and development approaches of the intersectoral testbed have implications for its usability and achievement of its objectives. Taking such considerations from the initial stages will facilitate the implementation of automation solutions by the testbed to various manufacturing companies, without necessitating high-investment and time-consuming actions for each and every subsequent solution generation that occurs throughout the operation life of the testbed.

4.1. Intersectoral testbed architecture

As outlined in Section 3 above, the solutions should be in line with the manufacturing needs, and it therefore results that quite significant unrelated manufacturing solutions, as required by the industry, are to be developed. The intersectoral testbed can be regarded to consist of two levels; the overall *testbed level*, and the *system level* as illustrated in Figure 1. The testbed level is the topmost general level, and consists of the separate resources that make up the testbed, for example an inventory of various components. On their

own at the testbed level, these components do not make up a specific manufacturing system, but rather, the various manufacturing systems and processes need to be developed out of these separate resources. The system level is where the various manufacturing system solutions are to be developed, through the selection, utilization and interaction of various different components, with the potential to develop a multitude of various distinct unrelated solutions stemming from the testbed level. This is illustrated in Figure 1, with different manufacturing systems being developed at the system level. The scenario illustrated in Figure 1 depicts the development of distinct unrelated systems over a period of time. First, a RMS is developed to manufacture Part Family A for Company I. Once this is completed, a DMS is developed from the same generic testbed to manufacture Product B for Company II. Upon completion of this DMS, another RMS is developed from the testbed, this time to cater for two part families, Part Family C and Part Family D for Company III.

4.2. Intersectoral testbed reconfigurations

The core potential of the test-bed is the ability to allow ease of change. Changes at the system level will occur continuously, with such changes envisaged to be highly unpredictable, unrelated and of varying extent. System development changes may include:

- slight modifications of an already developed set-up to change certain characteristics, arising from several factors such as input from the customer, quality issues etc.;

- reconfigurations of a particular set-up to change certain capabilities, for example to manufacture a similar product and/or part family; and
- more extensive reconfiguration, or redevelopment, of the testbed to develop a completely distinct “new” set-up.

The first two situations above are limited to changes on an already existing manufacturing system at the system level, with reconfiguration usually being a higher form of change than modification. In these changes, the core of the existing manufacturing system remains unchanged, with minor modifications and/or reconfigurations being done on specific sections only. However, the third situation of redevelopment is at a higher level, with redevelopment representing a higher form of change than the conventional reconfiguration outlined in the second situation. Whereas in conventional reconfiguration, a certain level of functional similarity is present between the new and previous systems, in the present approach, the new system may be significantly different and distinct than the previous one. The variations having to be catered for by such a generic testbed are not limited to variations of a product, or even those present in a part family, but they are of a higher level and highly unpredictable in having to cater for completely different manufacturing situations arising from different manufacturing sectors. The testbed will therefore experience various forms of reconfiguration, ranging from minor reconfigurations of a particular function, up to reconfiguration of the total existing setup to develop a distinct new system.

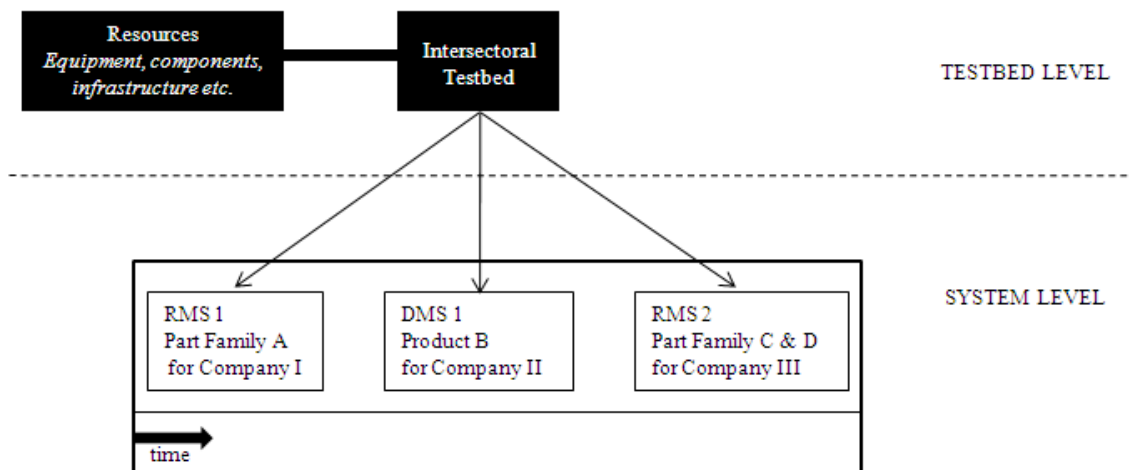


Fig. 1. Architecture of the generic intersectoral reconfigurable manufacturing testbed

4.3. Solution developmental guidelines

The need to develop a multitude of systems from the same overall testbed necessitates the identification of indirect relationships between the different systems to be developed. This means that the development of each manufacturing system using the intersectoral testbed has to follow an approach that is somewhat different from that used conventionally. However, one should not deviate from the conventional approaches applicable to the various classes of manufacturing systems. Developing a DMS still entails the building of a system solely around a particular product resulting in a relatively low cost solution and a high quality product. If on the other hand a RMS is being developed, the relevant applicable guidelines of developing the system around a part family still apply, with the requirement to analyse all the potential existing and future reconfigurations of the solution, and with the need to equip the reconfigurable solution with the necessary capabilities and functionalities to cater for these expected reconfigurations. However, in both these cases, the systems are developed for already known causes (products) - a specific product or a part family respectively. As previously discussed, in the case of the intersectoral testbed, the nature and extent of future reconfigurations are unknown. For this reason, each system developed out of the intersectoral testbed must take into consideration the reusability of the overall testbed.

To maximise the reusability of the testbed for unrelated manufacturing solutions, a set of guidelines for the development of manufacturing solutions at the system level has been drawn up. The steps to be taken in the development of each manufacturing solution on the intersectoral testbed are discussed below:

Step 1. The conventional guidelines as applied to DMS and RMS should first be applied. This stage entails in actually outlining approaches on how to achieve a manufacturing solution using already established methods. In the case of a DMS, the system is built around a particular product only, with the system composed out of the required functions. If on the other hand the system is developed on the lines of a reconfigurable solution, the conventional principle of segmenting the overall function into modules containing a variety of sub-functions to enable easy reconfiguration still applies.

Step 2. The conceptual solution is then analysed and functions are examined in detail so as to identify whether they can actually be broken down into more specific sub-functions. This would result in the system being segmented into lower level single, specific functions.

Step 3. For each specific function, a technical solution is selected.

Step 4. The final step is to attain the various technical solutions out of various physical and software components. The reuse of equipment from previous developed solutions is encouraged, this being facilitated due to the system having been segmented into very low level single and specific functions. In the situation where new equipment needs to be bought, the manufacturing system is built up from the

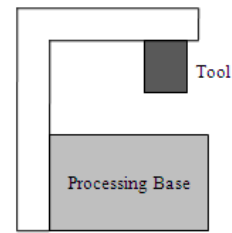


Fig. 2. L-shaped structure (unshaded) to process a part from above

identified single functions. Although the system is segmented into singular functions, if previously used equipment (for a past manufacturing solution) can perform a multitude of presently required functions together, such conjoining of functions is encouraged since it will minimize the number of interactions between the separate components and their respective functions in the present solution, and thus the overall complexity of the solution development. However, if no previously used equipment can be implemented for certain functions, such functions should not be conjoined in a way that would prohibit their respective components from being implemented individually for subsequent solutions. The exception arises when certain functions are generated together due to the nature of the component/element (e.g. a pneumatic cylinder resulting in both relative part-tool movement along a particular axis, and an acting force along the same axis).

A simple example to illustrate this system developmental approach can be given, taking the commonly occurring scenario of processing/assembling a part from above. One approach might be to design an L-shaped structure as illustrated by the unshaded region in Figure 2.

Such an L-shaped structure, having been developed solely around the existing requirements, is most probably applicable only to the current situation. Such an approach might easily result in this L-shaped structure becoming obsolete once the testbed needs to be redeveloped into an unrelated manufacturing system. Examining this L-shaped structure in more detail, it can be determined that it actually caters for two separate simple functions. These are

- (i) provide an elevation; and
- (ii) to provide a lateral shift to pace the relevant tool over the part to be processed/assembled.

An alternative approach therefore would be to design two separate structures, with each structure dedicated solely to a single function, which can then be joined together to result in the same L-shaped structure, as illustrated by Structures A and B in Figure 3. The degree of elevation and of lateral shift would be adjustable. Such an approach will still build up the L-shaped structure, but in the future both elements can be separated from each other and more easily applied in other redevelopments.

It is emphasized that when the client finally implements the solution on their shop floor, they may still opt to build this L-shaped structure as one complete unit. The critical point being demonstrated here is that in the testbed, the use of lower level sub-components is preferred.

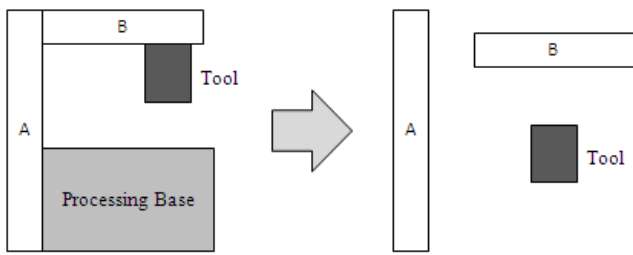


Fig. 3. Independence between components to facilitate reusability of each component

5. RESOURCE REQUIREMENTS OF THE INTERSECTORAL TESTBED

The potential for these different levels of reconfiguration, to develop a multitude of manufacturing solutions at the system level, stems from four basic elements of the overall intersectoral testbed; these being:

- the physical facility together with any required infrastructure (such as an adequate supply of compressed air and electrical points);
- equipment and components;
- system developmental guidelines; and
- relevant personnel, so as to set up and make use of the above three resource categories to develop a wide range of different manufacturing solutions.

The reconfiguration potential of the intersectoral testbed arises from the effective combination of the mentioned four resource categories. Obviously, certain limitations, and boundaries, can be foreseen. For example, the physical dimensional size of the intersectoral testbed will be limited by the available space. As a result, systems above a certain size would not be able to be developed. The product size may also limit the systems that can be developed.

The approach towards the setting up of the manufacturing equipment and components in the physical facility available, and the approach through which such equipment is actually implemented in the various solutions, affects the potential of the intersectoral testbed to satisfy the above discussed objectives. With the inventory of components analogous to the separate building blocks of a LEGO set, the larger the component choice, the more the contribution is towards some primary targets of the testbed; e.g. the vast number of different systems that can be developed, and the rapid response in developing new manufacturing systems. However, various issues hinder the setting up of a vast amount of different components for such an inventory, mainly the investment cost and the physical space available. A balance is required, with trade-offs being a clear necessity, so as to maximise the reconfigurability potential of the generic testbed, whilst minimizing the economic cost and redeployment time for each different set-up. Four different types of equipment/component resources

have been identified as being necessary to attain the objectives of the testbed, these being

- off-the-shelf components,
- reconfigurable components,
- flexible components, and
- specialized equipment.

5.1. Instantly purchasable off-the-shelf components

Readily available and instantly purchasable off-the-shelf components shall not be initially physically included in the component inventory of the intersectoral testbed. Such required components may include various actuators, sensors, and other standard peripheral devices. For these types of components, an up-to-date library of component catalogues from local suppliers would however be necessary. Depending on what is required to develop a new system, components are bought on a *buy what is necessary, when necessary* philosophy. After physically building a new manufacturing system, the components are then either implemented on the actual shop-floor by the relevant client, or else the components are added to the equipment inventory of the testbed for possible future use.

5.2. Reconfigurable and flexible components

To reduce the response time of the testbed, components that are relatively time-consuming to develop, both hardware and software, shall be added to the inventory from the initial stages. This requires an investigation of the core equipment that should be included in the generic testbed. In this regard, two separate approaches are fundamentally required; reconfigurability and flexibility.

5.2.1. Reconfigurable Components: Reconfigurable components enable reuse, system reconfiguration, and even testbed reconfiguration. Examples of such possible reconfigurable equipment include a reconfigurable conveyor, and reconfigurable gantry-type support structures. Such reconfigurable equipment should be developed out of modular components to allow for further lower-level reconfiguration if this is required. Although reconfigurable equipment may be implemented in the development of manufacturing systems, it does not necessarily signify that such equipment is going to be reconfigured within the application of a specific system solution. In this case, the reconfigurable equipment would simply be used to build the single required configuration for the developed solution.

5.2.2 Flexible Components: Flexible components can be applied to a wider range of processes. These type of components usually have a relatively high-investment cost. Therefore it is highly important to clearly justify the inclusion of such flexible components in the intersectoral testbed. The results of the investigation detailed in Section 2 above, indicated that the general flexible components to be included among the testbed equipment should be industrial robots (6-axis revolute and SCARA configurations), machine vision systems, computers, programmable logic

controllers (PLCs) etc. Such flexible components have the potential to be utilized in various manufacturing companies, and can also be potentially applied to a wide range of processes across various sectors such as machining, assembly, control, inspection, soldering applications, and welding.

The approach to be implemented in selecting between reconfigurable and flexible equipment for a specific solution depends on several factors. Apart from the feasibility analysis required for each solution, the client has also to be consulted on the selection of the approach. For a client requiring a precise and turnkey solution, reconfigurable equipment may provide more satisfying results. For example, taking the case of requiring a fixed gantry-type structure in the development of a particular solution, opting for reconfigurable equipment (in this case the implementation of a reconfigurable gantry structure) may result in the gantry structure being configured to cater for the particular solution, but then for the solution in question to remain fixed throughout. The solution given to the client then is that of the fixed gantry structure, and the client would later build a non-reconfigurable version of the equipment to implement the solution. However, taking the case of developing a conceptual system to analyse the benefits on production of automating a particular process, the implementation of flexible equipment may be preferred from the perspective of the testbed. This is due to the fact that generally, flexible equipment is equipped with a high number of capabilities that are relatively easy to implement. Some examples are inspection with a smart camera by making use of a particular algorithm embedded in the machine vision system, or else the implementation of an industrial SCARA robot arm for pick-and-place applications.

5.3. Specialized equipment

Specialised equipment refers to equipment that is used only for a particular field and/or application, thus limiting the potential for the equipment to be utilized for other applications. In such a case where the equipment is required only for the development of a particular solution, the investment is clearly not justified from the point of view of the testbed since the equipment will not be able to be reused for subsequent unrelated solutions. If the client already possesses the equipment, there is the possibility of two approaches. Either the rest of the system, if applicable, would still be developed to interact with such equipment but without physically implementing the particular equipment, or else the equipment is transferred from the client to the intersectoral testbed for the solution development. If on the other hand the client does not already possess the equipment, the client is either requested to buy the equipment early during the solution development exercise, or else a physical non-functional model of the equipment is built, with the rest of the system developed around this model.

6. PRELIMINARY EVALUATION OF THE CONCEPT

In this section, a brief demonstration is given of how the discussed preliminary design guidelines can be implemented for the development of unrelated manufacturing systems on the intersectoral testbed. To evaluate this overall concept, together with the suitability and applicability of the design considerations, three case studies from different local manufacturing sectors are in the stage of being addressed.

6.1. Case studies from unrelated manufacturing sectors

6.1.1. Case study 1

The first case study concerns a mechanical component manufacturing company seeking to improve a punching process. A wide range of discs, of varying materials, require to be punched in various diameters. The punched discs are then required to be placed in their relevant storage bins. Currently the process is being done manually due to the high flexibility of human labour to cater for the wide range of variations, however the company wants to investigate any advantages that might arise in automating this production process.

6.1.2. Case study 2

The second case study arises from a relatively small electronics company. The company wishes to automate a soldering process. Currently this soldering process is being done manually. Different printed circuit boards require having their connections soldered to the product casing for electrical connectivity and physical placement issues.

6.1.3. Case study 3

The third case study relates to a handling and inspection process in a plastics component manufacturing company. Various incoming different products that are arriving at random poses on a flat belt conveyor require to be inspected for defects, with the correct ones requiring stacking in the relevant container, and the faulty ones being discarded. Various potential defects require to be inspected, ranging from physical defects, up to the colouring and printing on the product. Variations therefore include the actual product that is on the manufacturing line, together with the various possible defects each product may have.

6.2. Reusability of equipment between unrelated case studies

All three of these case studies are completely unrelated in their overall function, and in fact each case study stems from a different manufacturing sector. Each solution development will obviously require the design of a completely new solution. Still, as outlined in the system developmental design guidelines, similarities should be investigated to minimize the reconfiguration time of the testbed as well as the investment cost required for each single solution development, through the re-use of the same equipment and components. Some possible similarities shall now be outlined.

6.2.1. The transfer of discrete products

Two of the solutions (Case Studies 2 and 3) involve the transfer of individual components to a processing station. Case Study 2 involves the transfer of the overall product casing, onto which the printed circuit boards are soldered. Case Study 3 involves the transfer of plastic products to the inspection stage. In Case Study 2, it is required that the product is transferred to the processing station always in the same pose. The approach that may be taken is that the product casing is supported between two separate conveyor belts which are synchronised together as illustrated in Figure 4(a). The product casing (unshaded region) has two overhangs that are placed on the conveyor tracks (shaded region), with the casing hanging in between the void between these opposite tracks. The end result is that the product casing is constrained from any excessive lateral movements whilst being transferred to the soldering station. Case Study 3 does not require the products to always arrive at the same pose, and a normal flat belt conveyor is used as illustrated in Figure 4(b).

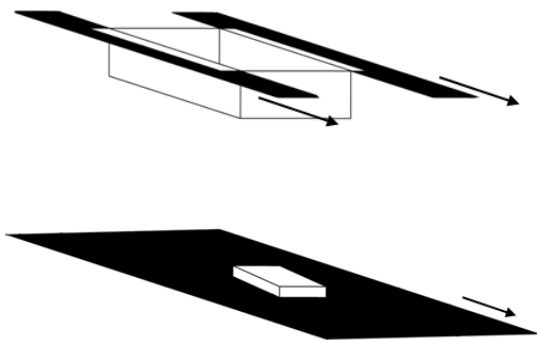


Fig. 4. (a) Top: product transfer for Case Study 2

(b) Bottom: product transfer for Case Study 3

Through an analysis of these processes, the actual product transfer of Case Study 2 can in fact be broken down into simpler general sub-functions: the direct product movement, as well as the constraining of the product pose. The overall conveying methods of these two case studies are different from each other, but similarities do exist, the main one being that the discrete product movement is along the same path of motion. Through a reconfigurable conveyor that has the potential to reconfigure the conveying belt means, both solutions can be achieved on the same basic equipment. For Case Study 2, the belt means implemented would be of the two separate tracks onto which the product casing hangs, whilst for Case Study 3, the conveying means is configured to a single flat belt. Through such an approach, although the initial investment cost and time to develop such a reconfigurable conveyor from the point of view of the testbed are higher, the overall investment cost and redevelopment time of the whole intersectoral testbed over a number of solutions are minimized.

6.2.2. Pick-and-place mechanisms

Case Studies 1 and 3 both require pick-and-place mechanisms. In Case Study 1, the punched discs require to be picked up and stacked onto each other in the relevant bins, whilst in Case Study 3, the inspected products need to be picked up and stacked in their relevant containers. Taking the case of conventional solution developments, when developing a system for Case Study 1, a reconfigurable or flexible gripper solution is developed to cater only for the required range of different discs. The same would have been done for Case Study 3. However, the relatively simple pick-and-place mechanisms for both test-cases require some common functions, these basically being:

Common function 1: Lowering the gripper to the component/product.

Common function 2: After gripping the product, pulling the gripped product back up.

Common function 3: A lateral motion of the gripped product.

Common function 4: Lowering the product once more inside the relevant bin followed by the release of the product.

One particular approach would be to develop a pick-and-place mechanism, possibly by utilising a reconfigurable gantry structure allowing traversal motion along a horizontal plane carrying an actuator that itself allows motion perpendicular to this plane. The actual gripping device, mounted onto this actuator, would be independent of these common functions. Implementing such a reconfigurable approach would result in equipment being able to be used for both applications just by modifying the parameters of the structure, and swapping the actual gripping device between the case studies. Another overall feasible approach would be to utilize a flexible unit, such as an industrial robot arm. By changing the gripping device of the industrial robot, both situations in the mentioned case studies can be achieved.

These examples discuss how the intersectoral testbed can be applied to the solution of unrelated manufacturing problems. Although all of the mentioned case studies are taken from different manufacturing sectors having unrelated products, through the extraction of existing common functions in the process, these unrelated manufacturing processes are implemented on the testbed through equipment reuse.

7. CONCLUSION

In this study, we have identified the objectives of a generic, intersectoral, reconfigurable, manufacturing automation testbed aimed at improving the competitiveness of industrial manufacturing companies operating in a small and geographically isolated economy. The testbed is aimed at being a readily available resource to these companies for the study and development of manufacturing systems and approaches, as well as manufacturing automation investigations. Manufacturing systems developed on this testbed are envisaged to include both dedicated as well as reconfigurable systems. However, the conventional approaches of developing DMSs and RMSs would not allow

for the overall reconfiguration of the testbed to cater for various unrelated manufacturing solutions. Thus, new guidelines for the development of the intersectoral testbed, as well as for the development of manufacturing systems on this testbed, have been drawn up. In continuing work, the solution developmental guidelines are to be physically evaluated on the testbed, by applying them to the three case studies under consideration.

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