Parts Presentation and Handling for Packaging – Case Study: Conceptualisation and Prototyping of a Flexible Mechanism for the Placing of Plastic Valves into Pouches

Michael A. Saliba[1*], Andrea Amato[2], Jonathan C. Borg[1] and Kevin Alamango[2,3]

[1]Department of Industrial and Manufacturing Engineering
University of Malta
Msida, MSD 2080, Malta

[2] Baxter Malta Ltd.
Marsa, MRS 3000, Malta

[3] *presently at*
Engineria Ltd.
1115 KBIC, Kordin, Malta

Abstract

The concepts of Agile and Lean Manufacturing require a company to have the ability to quickly reconfigure its production facilities to meet a varying production demand, while at the same time eliminating all kinds of waste including the time taken to reconfigure the production line. In an automated environment this requires the development of automated production systems that can be easily reconfigured to process a mix of products that have similar geometric and production requirements i.e. a product family. In the case study presented here, we report on the development of a flexible parts presentation and handling system for the packaging of plastic valves into multi-compartment pouches. The system is intended to be applicable to various valves that, although irregularly shaped and different, have common features that can be exploited by the system. This paper presents the results of the 'lean and agile design' approach adopted in designing the reconfigurable automation system, the decisions made and the tools/methods used to objectively support such important decision making.

1. Introduction

The design and development of effective and reliable parts presentation and handling systems remains one of the main problems that must be addressed in any discrete manufacturing automation system. While the recent push towards the incorporation of part design guidelines that facilitate automated manufacturing and handling, i.e. the "design for manufacture" and "design for automation" principles, have served to alleviate these problems to some extent in some industries, many manufacturers have been slow to embrace these concepts, particularly when migrating from a manual to an automated production system. There can be various reasons for this. The costs associated with making the part design changes (e.g. development of new moulds) could be prohibitive. The time frames involved in implementing the design changes (e.g. re-design, re-test, re-certify the part etc.) could be too long. The manufacturer's client might simply refuse to accept such design changes. In many cases, particularly when the part to be manufactured is complex and/or highly specialised, it may also be technically or economically unfeasible to implement any design changes that would not adversely affect the functionality of the specialised part.

Thus in these cases, in order to satisfy the market demand for high production at low cost, the manufacturer must implement automation on the *unmodified* complex part. While this implementation is normally already a very challenging task, it becomes more difficult when there is a degree of variety in the parts produced. In these situations, the manufacturer is not only forced to implement automation of a difficult task, but also has the additional requirement for that automation to be applicable to the manufacture and/or handling of batches of *distinct* complex parts, with minimum reconfiguration effort. The manufacturer must therefore look for relevant similarities in the features of the already-designed, distinct complex parts, and exploit these similarities to develop a flexible automation system that satisfies the production requirements.

* Corresponding author: Tel.: (356) 2340-2924; Fax: (356) 2134-3577; E-mail: michael.saliba@um.edu.mt

The case study that is reported here involves the implementation of flexible / reconfigurable automation for packaging, under circumstances of this nature. Baxter Malta Ltd. manufactures consumable medical equipment such as intravenous administration sets, burette sets, and dialysis sets. In particular, they produce plastic fluid control valves of the types shown in Figure 1. The smaller of the two valves in the figure (the stopcock) is packaged in sets of seven units, while the larger of the valves (the medistop) is packaged in sets of six. In order to maintain sterility all units within a packaged set must be isolated from each other, and for this reason they are packaged in a plastic strip that contains separate pouches to take the individual valves. The moulds that are used to make the pouch strips for the two types of valve are shown in Figure 2. After the valves have been loaded into the pouches, the pouch strip is sealed with paper from above at high heat, to isolate the pouches from each other and from the environment.

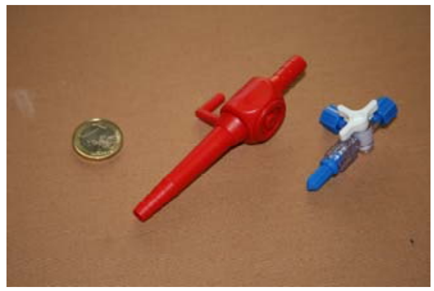
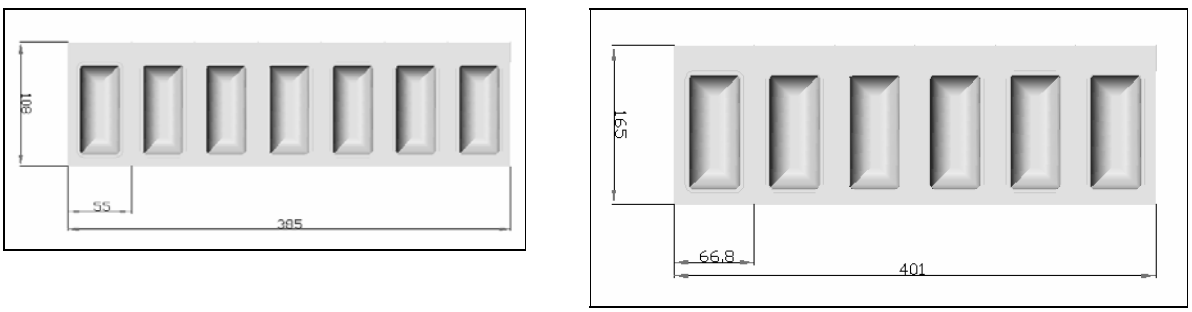


Figure 1: The medistop (left) and stopcock valves



(a) *(b)*

Figure 2: Pouch moulds for (a) the stopcock, and (b) the medistop. Dimensions in mm.

Manufacture and sealing of the pouch strips is carried out automatically by means of a Multivac® form, fill and seal machine. The valves presently arrive for packaging in an unstructured manner, and a number of human operators load the valves manually into the pouches prior to the automated sealing process. It is required to automate the parts presentation and loading of the valves, using a system that can be easily reconfigured to handle the different valves.

2. Related Work

The fundamental issues involved in this work are those of similarity identification in members of a part family; development of effective parts presentation and parts transfer systems that exploit these similarities; and the general issue of reconfigurability of the automation.

Group technology is a manufacturing approach in which parts that have common design features or that are manufactured in closely similar ways are grouped together so that their similarities can be exploited during the manufacturing process. One of the major tasks that must be carried out prior to the implementation of a group technology approach is the identification of part families [1]. A common way of identifying similarities between parts, when the number of parts is small, is through visual inspection [2].

The importance of effective parts feeding for any automation system is emphasised in many standard texts [3], [4]. Flexible feeding of complex mechanical parts is often carried out with the aid of a machine vision system, e.g.

[5]. This alternative may be difficult to implement, and very often requires the use of an industrial robot, therefore increasing the cost of the solution. A less costly approach that is often satisfactory is that of sensorless orientation of parts, where positioning and/or orientation of the parts is carried out by passive mechanical compliance [6].

Parts transfer is generally a necessary function in any manufacturing process, and its automation is very often crucial for the attainment of target productivity levels in a competitive environment. A number of studies have been carried out to develop guidelines for optimal gripper design, e.g. [7], [8]. Where there is product variety, the issue of flexible, or at least reconfigurable, gripper design becomes important (e.g. [9], [10]).

In general, the requirement for agile manufacturing usually calls for the use of flexible and/or reconfigurable automation [11]. Reconfigurability in manufacturing refers to the use of systems that can be easily adjusted to handle different products or circumstances [12], [13]. Flexibility is a broader concept that may even include the ability of a manufacturing system to handle different products without adjustment. Various categories and definitions of flexibility have been put forward [14], [15]. In particular, Sethi and Sethi [14] relate *process* flexibility to the set of parts that can be produced without a major set-up.

3. Basic Considerations

3.1. *Development Strategy*

When a manufacturer of various high-complexity parts needs to migrate from a manual to an automated production system, a specific sequence of stages needs to be followed. At each stage, critical decisions need to be taken regarding the production process, and these decisions are reached with the aid of specific tools. In Figure 3 we give a representative model that illustrates this sequence of stages for a project of this nature, and the tools used to instigate the decisions involved at each development stage. The design, development, and decision processes implemented throughout this case study are based on this model.

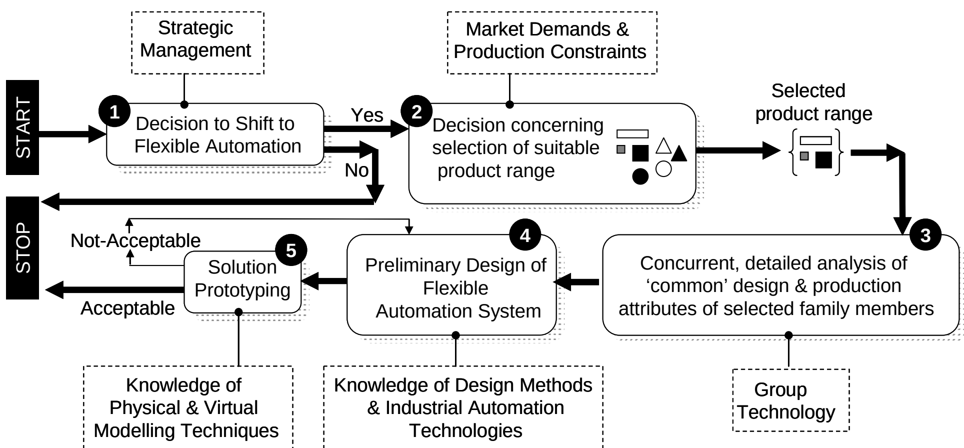
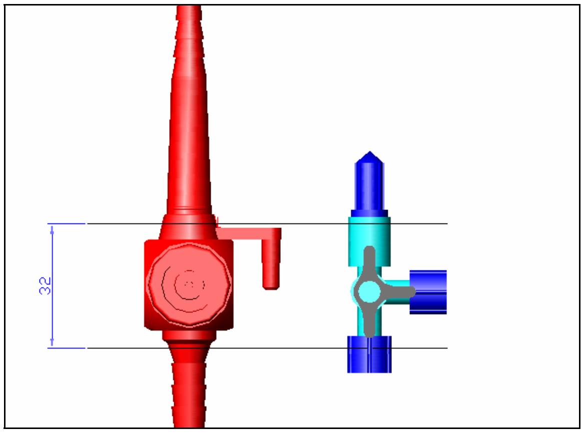


Figure 3: Decision stages, and supporting tools, for migration from manual processing to flexible automation

3.2. *Dimensional and Geometric Similarities*

In this work, the main objective was to develop a conceptual solution for a pilot, reconfigurable automation system for the packaging of the two valves shown in Figure 1. To this end, the two valves were *constrained* to belong to the same part family, and an exercise was carried out to identify similarities between the parts that could be exploited for the automation project. These two valve models in fact are extreme representatives of a larger set of valves, such that the identified solution would eventually be extended to the larger population.

Two main features were identified, that were both geometrically and dimensionally similar for the two valves. These are (i) a common dimension between two cylindrical sections of the valves having similar diameters, and (ii) a dimensional similarity between the cylindrical ends of the components. These two features are shown in Figure 4.



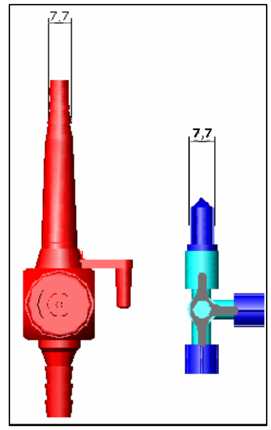


Figure 4: Dimensional similarities between the two components (dimensions in mm)

3.3. General Parts Presentation and Handling Issues

The boundary conditions of the problem required the valves to be converted from an initial state where they were randomly placed on a conveyor to a final state where they were placed in the individual compartments inside the pouch strips. The solution was required to be applicable to both valves with minimum reconfiguration effort between the two types. Any particular batch to be processed would consist of only one type of valve.

A number of high level conceptual approaches were considered:

(i) A wholly flexible system using a vision sensor to locate the position and orientation of the randomly placed valves, and an industrial robot having a minimum of four degrees of freedom to pick up the valves and place them into the respective compartments in the pouch. This solution would require the development of a gripper that would be capable of handling both parts, and that would handle one valve at a time.

(ii) An approach utilizing sensorless orientation of the valves, such that the valves would then be presented to a transfer device in an ordered fashion. This solution would require the use of a three degree of freedom transfer device, and the development of a gripper that would be capable of handling both parts, and that would handle the valves one at a time.

(iii) An approach utilizing sensorless orientation of the valves, such that the valves would then be presented to a transfer device in an ordered fashion, but where all valves to be packaged in the same pouch strip would be transferred to the strip simultaneously. This approach would likely require the development of a multiple gripper capable of transferring six or seven parts simultaneously, and reconfigurable to handle the two types of valve. This approach would also require the solution of the secondary problem of *spacing* the valves by the correct distance for packaging into the strip.

General approach (iii) was selected on the basis of minimum cost and minimum cycle time.

3.4. Process Model

A “to-be” process model was drawn up, to illustrate the transformations that were required to move from the initial state to the desired final state, and the inputs and outputs for each transformation. This is shown in Figure 5.

4. Morphological Chart and Concept Generation

A morphological chart of candidate subsystems that could perform each of the functions of the process model was drawn up. Initial ordering of the valves could be carried out using either a vibratory bowl feeder or a system of conveyors and passive orienting parts. Alternatively the valves could be stored in a magazine cartridge from the previous operation. Spacing of the valves could be achieved through a number of different approaches, shown in Figure 6. These include the use of an intermittent barrier as the valves moved along a rail; the use of a conveyor with correctly spaced mechanical protrusions that would detach the valves from the rail and hold them; or the use of a compound mechanical sliding rail system where a number of mechanical protrusions and notches on the sliding rail would collect the valves from the fixed rail at the correct intervals. Grasping and handling of the valves could be achieved using either pivoting or parallel-type two-jaw grippers, or vacuum, adhesive, or scoop-type grippers. Transport of the held parts could be affected using either a system of pneumatic cylinders or a system of electric linear actuators. An alternative to the grasping, handling and transport concepts would be to drop the spaced valves directly into the pouches in a gripperless system.

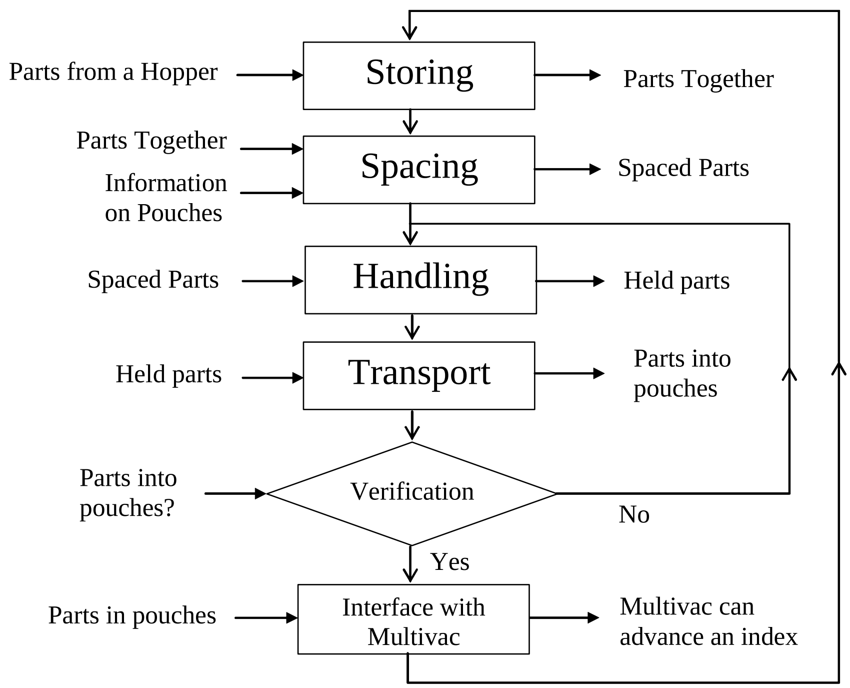


Figure 5: Process model

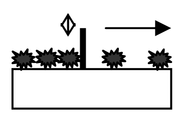
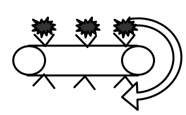
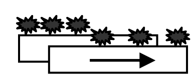
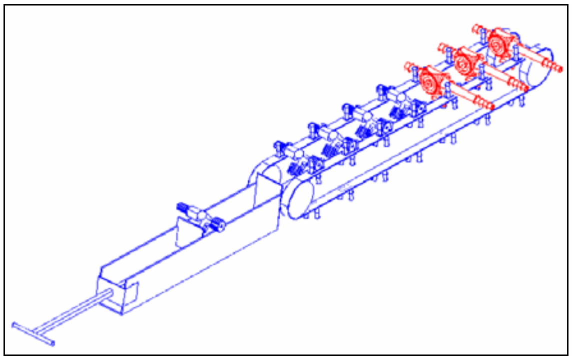
Sub-process	**Option 1**	**Option 2**	**Option 3**
Spacing of Parts	*Intermittent Barrier* 	*Conveyor* 	*Sliding rail* 

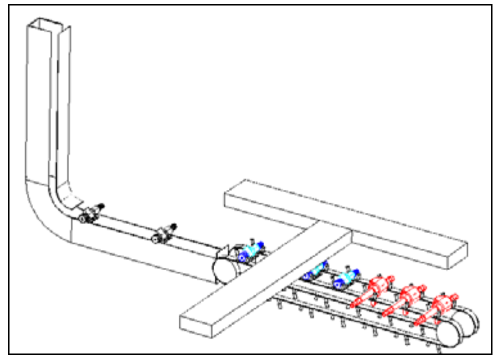
Figure 6: A section of the morphological part: candidate subsystems for the spacing function

A number of alternative concepts were generated for each element in the morphological chart. A number of these are shown in Figure 7.

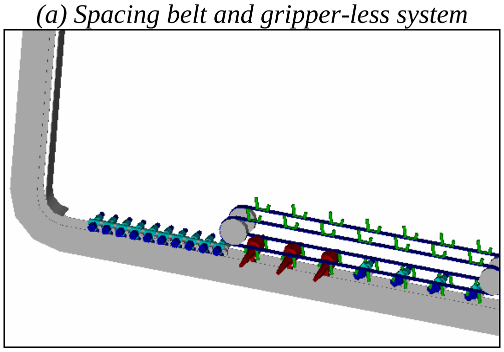
In Figure 7(a), the spacing belts lift and hold the valves off the feeding rail at the correct spacing. When the correct number of valves are held, the belts separate dropping the valves into the pouch strip below (not shown). In Figure 7(b) handling and transport of the valves is carried out by a multiple gripper system. In Figure 7(c) the spacing principle is similar to that of the spacing belts, however in this case the belt is on top of the feeding rail. Figure 7(d) is a variation of a one-gripper concept (not shown here) where the processing speed is doubled by using two rails and a double gripper which feeds two pouch strips simultaneously. Figure 7(e) shows the spacing rail concept, while Figure 7(f) shows the multiple gripper concept which can be used in conjunction with either a spacing belt or a spacing rail.



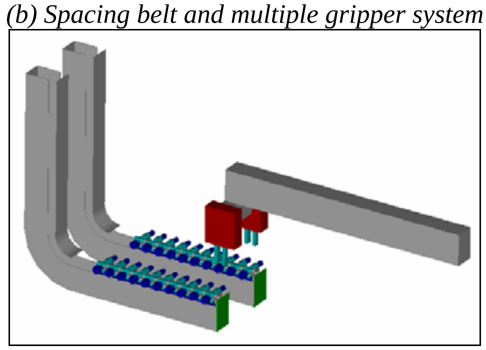
(a) Spacing belt and gripper-less system



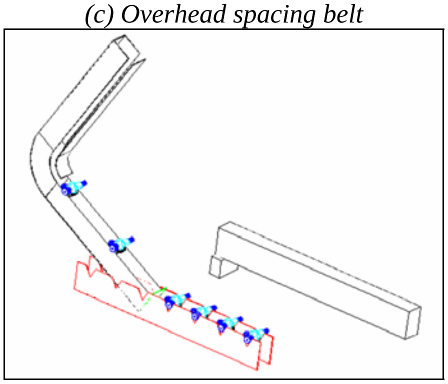
(b) Spacing belt and multiple gripper system



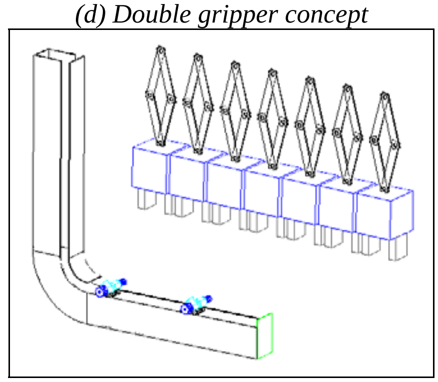
(c) Overhead spacing belt



(d) Double gripper concept



(e) Spacing rail and gripper



(f) Multiple gripper concept

Figure 7: Some of the generated concepts

5. CONCEPT EVALUATION AND SELECTION

The various concepts were evaluated using a decision matrix. The first step in constructing this matrix was to identify and list the specific objectives that needed to be addressed by the solution, and to give a weighting value to each of these objectives reflecting its importance to the manufacturer. Each concept was then evaluated against these objectives, and given a partial score to reflect how well it satisfied each objective. For each concept, the partial scores were then weighted accordingly and added up to give a total score for the concept, reflecting its relative suitability to solving the problem at hand.

The list of objectives and their weighting values were determined from detailed discussions with the manufacturer. For each concept, the partial scores against each objective were determined from a qualitative evaluation of the extent to which the concept was expected to satisfy the objective.

The selected solution involved the use of a vertical magazine that would be loaded from the previous operation; the use of a spacing rail; and the use of a multiple two-jaw gripper to grasp, transfer and load the valves simultaneously into the pouch strip. A pneumatic actuation system controlled by a programmable logic controller (PLC) was proposed for the eventual final solution. The design objectives and their respective weightings, as well as the raw scores obtained by the *selected* solution against each objective (prior to weighting), are given in Table 1.

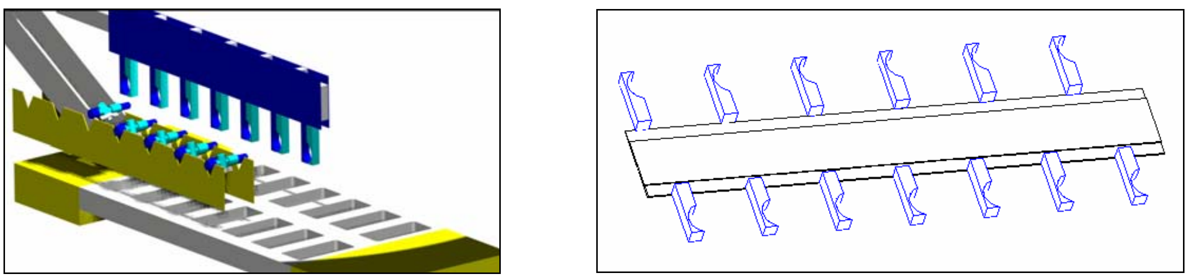
Table 1: Objectives used to construct the decision matrix

Objective	Weighting	Scores for selected solution
Reliable spacing and loading of parts	10	8
Cycle time	8	9
Ease of reconfiguration	7	6
Design simplicity	5	8
Interface with Multivac	3	10
Ease of manufacture	3	9

6. Simulation, Prototyping and Testing

Simulation models and partial prototypes to test the selected solution were developed concurrently. In this manner, the interim results from the simulation as it was being developed could guide the development of the prototypes, while experimental results obtained using the prototypes could be fed back into the simulation program to correct its function and to validate its output.

Figure 8(a) shows the output from an early version of the simulation and serves to illustrate the selected concept in more detail. The valves slide down an inclined rail, and are collected in the correctly spaced notches within the horizontal rail as it slides to the right. When the correct number of valves have been collected, the sliding rail comes to rest beneath the multiple gripper. The multiple gripper consists of the correct number of two-jaw grippers, each consisting of a fixed and a moving jaw. All of the moving jaws are rigidly fixed to each other, so that the entire gripping system consists of only one moving part, thus minimizing design complexity. Reconfigurability of the gripper between the two parts could be enhanced using a “double multiple gripper concept”, shown in Figure 8(b).



(a) *(b)*

Figure 8: (a) The spacing rail and multiple gripper concept, (b) the reconfigurable multiple gripper concept

Testing of the first prototypes showed that there were two problems with the initial design. Firstly, the valves did not always fall into the slots of the moving spacing rail in an orderly manner. Secondly, variations in gripper and valve dimensions resulted in the gripper not achieving a secure grasp of all the valves that were being picked simultaneously. The first problem was solved by adding mechanical stops and protrusions to the inclined and spacing rails as shown in Figure 9. The specially designed features allow the valves to be collected one by one from the feeder rail and then held on notches that are separated by the required distances. The second problem was solved by installing compliant foam fittings to the gripper jaws. Further details on this case study can be found in [16].

7. Conclusion

The conceptual solution developed and described above has been shown, by experimental validation, to address successfully the numerous issues associated with this automation problem. The required flexibility is obtained through a reconfigurable design, where the gripper and the spacing rail are the only two components that need to be replaced in order to process different members of the same part family. The solution can be further improved by implementing the reconfigurable gripper concept suggested in section 6. This case study illustrates the application of a general model for the migration from manual processing to flexible automation in the presence of both complexity and variety in the part to be manufactured.

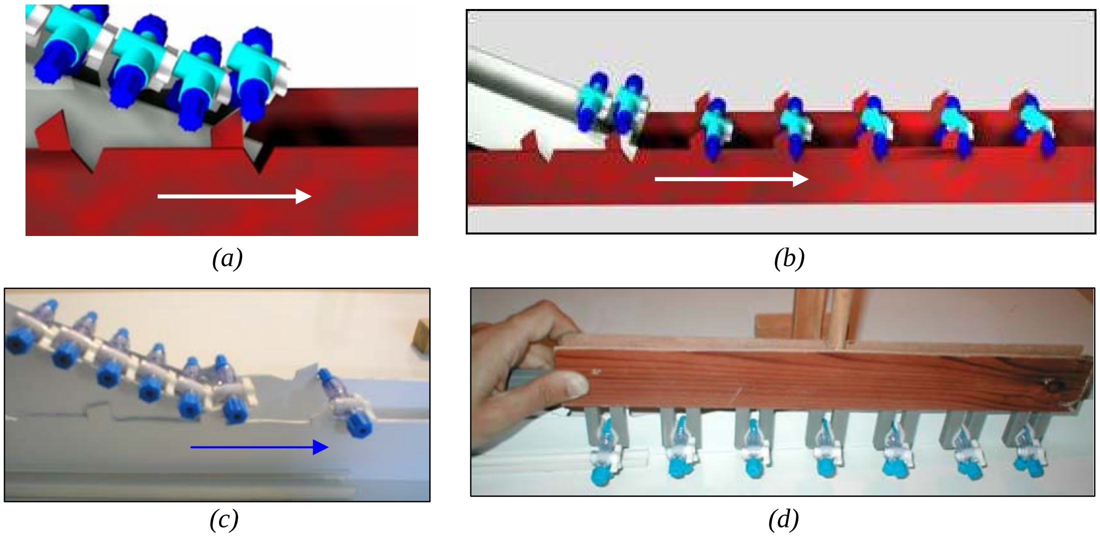


Figure 9: Final designs and prototypes - (a) the inclined and spacing rails, (b) collection and spacing of valves, (c) modified prototype spacing system, (d) modified prototype gripper

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