A Reconfigurable Robot Workcell in the Automotive Industry

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***Abstract –** The main objective of the work is to present the design and implementation of a new kind of a reconfigurable robot workcell – ReconCell, which is attractive not only for large production lines but also for few-of-a-kind production, which often takes place in SMEs. The presented workcell is based on novel technologies for programming, monitoring and executing assembly operations in an autonomous way. Innovative reconfiguration technologies enable the workcell to be automatically reconfigured to execute new assembly tasks efficiently, precisely, and in an economically viable way with a minimum amount of human intervention. On the business side, our ambition and vision is to bring the reconfigurable robot workcell system to the market. Our strategy is to develop solutions for real life industrial use cases to demonstrate the advantages and capabilities of the developed robot workcell. Our ambitions also include preparation of the post-project commercial phase, with a focus on the development of a business roadmap, as well as involvement of investors for setting up a commercially sustainable enterprise. The ReconCell can subsequently be implemented and scaled as a new product and business for the world market with a product and distribution philosophy that enables a global uptake of the technology/production companies.*

1 Introduction

Rapid changes in market demands lead to decreasing product life cycle times as well as more frequent product launches. This trend is especially critical for small and medium sized enterprises (SMEs). An enterprise has to react quickly, efficiently, and in an economically justified way to market changes. More frequent changeovers in product type or in a number of required products demand new engineering and production methodologies and machinery equipment to enable shorter set-up times of production environments. Robots have been successfully utilized in many industrial production processes as highly flexible devices. Industrial robots can be applied to execute complex repetitive tasks, often faster, more reliably, and more precisely than human workers. SMEs are still reluctant to employ robots or many types of tasks, e.g. for assembly tasks. The main hindrances are complexities involved in setting up robotic–based automated assembly solutions because these usually require expert knowledge and significant time for testing and fine-tuning. Since SMEs usually do not have that knowledge capacity, they avoid introducing such solutions, even when they are economically justifiable. Looking at robotic systems in more detail, we can recognise that these problems are due to the time duration needed to re-configure and re-programme a robot workcell for a new assembly task (as well as for ongoing maintenance), which are often too long to make the application of robots profitable. Set-up times for automated assembly solutions are still quite long for a number of reasons:

- Robot solutions often require assuring that the position and orientation of objects are predetermined with a high degree of precision. High accuracy requires specific machinery for precise positioning, causes additional hardware costs, and also requires some engineering knowledge on the end-user side in order to integrate such systems. This is still economically viable for larger lot sizes. However, in variable, small-scale production, which is typical for the manufacturing processes in SMEs, this is often too expensive to be profitable.
- If new assembly operations are needed, they can only be implemented by an expert who typically needs a lot of time to program the desired robotic skill. Such a skilled expert is usually not permanently in-place (hired) by a typical SME and "just-in-time" hiring is very expensive.
- Due to the need for monitoring and quality measuring capabilities required for error recovery and/or adaptation to deviations within product tolerances, robots cannot operate autonomously and often require human intervention, which further increases costs, require repairs, and increases the number of faulty products.

There have been a number of surveys documenting the development of reconfigurable robotic systems, both in research and in industry [1–3]. Chen [4-5], placed a specific emphasis on finding optimal module assembly configurations from a given set of module components for a specific task. His work on the design of a reconfigurable robotic workcell for rapid response manufacturing [6] is of particular relevance with respect to the workcell proposed in this paper. However, while that work involved the development of a workcell containing hardware elements that can be rapidly reconfigured manually, our proposed workcell for the automotive industry focuses on introducing hardware elements that can be rapidly reconfigured automatically by the system itself when switching between the assembly of different types of headlamp products.

2 Challenge for Automatization

Manual work and quality depends on workers’ qualifications, skills and their knowledge of the product and assembly process. Customers expect that the supplier company is very flexible with optimized and efficient manual work in assembly sections. Companies therefore strive to reach the specified cycle time for every task and further improve it with various optimizations. Assembly tasks can be simple or complex. Simple tasks should be automated as much as possible. On the other hand, complex tasks still involve manual work. Consequently, production quality and cycle times often vary due to differing skills of workers. Besides the reduction in costs, increased automation can also lead to more constant quality and objective business decisions.

3 Expected Benefits from Automatization

ELVEZ’s use case originates in the automotive light industry, where each light requires its own unique assembly device, which is typically very large and cumbersome. When the subcontractor company stops producing the parts to match the regular demand, assembly devices must not be discarded as they are required such that the supplier company is able to produce spare parts for at least the next 15 years. This means that the assembly devices are stored at the company. The suppliers therefore require a significant amount of storage space just to house these assembly devices since, given that they produce many different types of parts, the assembly devices begin to accumulate. Production of spare parts is a low quantity piece production scenario and usually occurs only a few times per year. This poses a problem because the large, cumbersome assembly devices must be swapped into the production process in order to cover the demand for the spare parts. This process is highly inefficient given such low-quantity, low-frequency situations. It would therefore be extremely useful for suppliers to have a single robot cell available which is capable of assembling many different types of lights, while also being rapidly reconfigurable for alternating production scenarios.

4 Use Case Description

Automotive lights (headlamp and backlamp) are made up of typical structural elements such as housing, actuators, bulb holders, adjustable screws, heat shields, wires, etc. The purpose of this experiment is to show that we can use one reconfigurable robot workcell for many different assembly projects. Using the same injection moulding machine, ELVEZ will be making different headlight housings with the typical structural elements for five different projects (some examples are shown in Figure 1). In the future, we will test the universality of the reconfigurable robot workcell with new projects that will come our way.

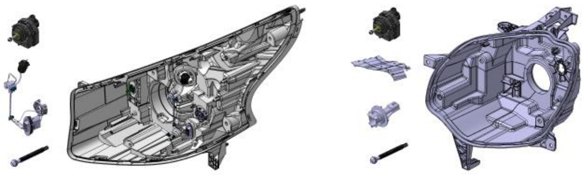

Figure 1. Headlamp assembly components for light housing

5 3D Simulation System

The 3D simulation system VEROSIM [7] was used to plan, test and verify assembly operations. A requirement for these applications was the setup of a Virtual Testbed that can be equipped with a variety of components like actuators, fixtures and single parts for the assembly process. In order to be able to address the manifold of assembly scenarios in SMEs, the underlying data model had to be freely adaptable to new components and products.

Figure 2 shows the integration of the simulation system into the workflow of commissioning new assembly processes. The principles of this workflow were implemented. With respect to the project, CAD models and information about the assembly tasks were provided for a desired product (1). The geometric data for the two parts was processed during the implementation and was placed in a model library for easy access in the 3D simulation system. With the help of the model library, it was easily possible to create an initial workcell configuration that also allows for reconfiguration (2), if the production workflow needs adaptation. Given the cell layout and a description about the assembly sequence, the 3D simulation system provided tools and functionality to visually program the tasks to be carried out during the production process by creating ActionBlock networks (3).

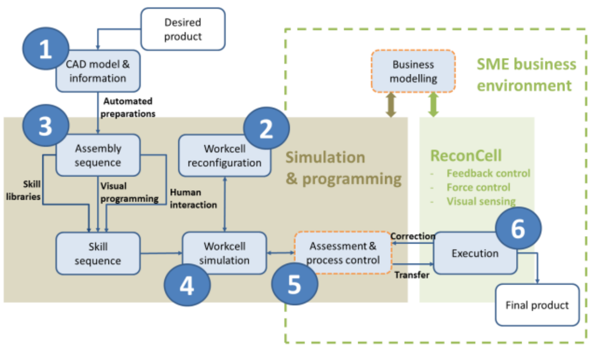

Figure 2. Workflow applied during the modelling

ActionBlocks build upon the paradigm of discrete event simulation, which is applied to the workcell simulation (4). They define discrete events in the simulation system, e.g. “Robot moved” or “Gripper closed”, between which actuator motion or other specific actions occur. The workcell simulation thus allows for the assessment of the assembly sequence during cell development in simulation by providing means of controlling the assembly process (5). It builds the foundation for the task of visual programming and process control in a project by providing information that can be used to refine the cell design. The described workflow was successfully applied to the design of the presented project. Figure 3 illustrates the corresponding workcell configuration in the Virtual Testbed (left) and the physical workcell (right) for the ELVEZ use case. Depicted in Figure 4 is a render of the 3D CAD model of an early workcell layout, which was specifically prepared for the presented use case.

Figure 3. Virtual Testbed (left) of the test workcell (right)

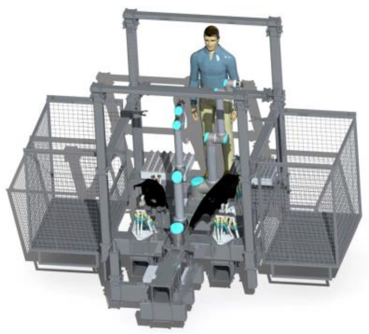

Figure 4. An early render of the workcell for evaluation.

6 Experiment

As mentioned previously, automotive lights (headlamps) are made up of a number of typical structural elements that need to be assembled into a single unit. In the developed experiment, “Jožef Stefan” Institute (JSI) and ELVEZ demonstrated that the developed reconfigurable robot workcell provides the much-needed flexibility and fast setup characteristics for automated assembly processes in the context of automotive lights. We were able to show that the proposed workcell can be automatically reconfigured for the successful assembly of different car headlamps, two of them shown in Figure 1.

The production process occurs as follows:

- Before the start of the production of a new light housing model, the reconfigurable fixtures must be placed in the appropriate configuration such that they can accommodate the initial workpiece, which is the housing (main body of the headlamp) that comes directly from an injection molding machine. This step happens only once per production scenario and needs not be repeated during the production of a single type of headlamp.
- In the next step, one of the robots equips itself with a gripper with which it will pick up the housing and insert it into the fixtures. During this time, the other robot equips itself with a double-headed gripper designed for picking up multiple parts that need to be inserted into the housing later on and proceeds to pick up the relevant bulb holder and small motor parts one after another. Following this, pneumatic clamps mounted on the hexapods close to ensure the proper fastening.
- The robot holding the bulb holder and small motor parts proceeds to insert them into the mounted housing one by one. At the same time, the other robot swaps its tool with a magnetic tool necessary to pick up a metal heat shield and proceeds to pick up the heat shield and inserts it into the housing.
- Finally, this same robot swaps its tool again with the housing gripper tool and after the pneumatic clamps have been opened, proceeds to remove the housing from the fixtures, before moving it on to the next step of the production process. After this, the cycle is complete and can be repeated if desired.

This process has been fully implemented by JSI and the ELVEZ company.

7 Visual Quality Control

As is typical for all industries, quality control is very important. For this reason several quality checks were implemented for the presented use case. In the first example, the shape of a part is analysed. The shape was assessed using the Hough transform algorithm for circle detection [8]. The top circles are detected both in the template and the region of interest (ROI) images. If the distance between the circle centres and differences between the radii are greater than a user-defined threshold, the part is considered to be damaged. For the intensity analysis, the template and the ROI images are converted to the HSV color space [9] and the absolute differences between the intensity values are computed. The total number of pixels, where the difference value is greater than a user defined threshold, is evaluated.

In Figure 5, an example of the ROI extracted from image is shown. Since the circular part of the housing is damaged, the Hough transform fails to detect the circle in the ROI, and the expected circle location is marked red. The parts, where the differences with the template image are significant are marked white. As it can be observed, most of the differences are located in the damaged region.

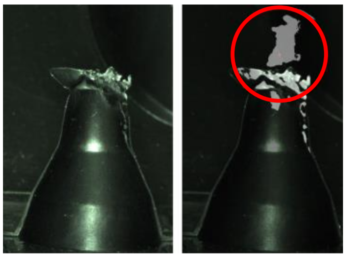

Figure 5. The extracted ROI (left) and the overlaid detection result (right). The circle detection failed and the expected circle location is marked red. Most of the intensity differences are concentrated in the damaged region (marked white).

In the second example, a screw base was selected as a suitable template (see Figure 6). When the template is detected, the appropriate image window is extracted. Finally, Otsu thresholding [10] is applied to the image. From the thresholding result the two largest connected components are extracted and their total height is measured. If the measured height of the screw is not within a predefined range, the part must be rejected.

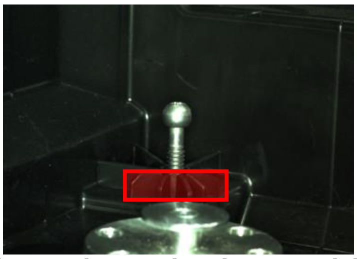

Figure 6. The screw base is selected as ROI and shown red in an overlaid manner.

Six measurement points have been identified for the quality control in total. One of the points had to be excluded because the measurement is not accessible due to the physical constraints of the robot arm and the camera. For the remaining points, quality checks were developed in 60% of the cases as a binary task, while the rest of the cases required angle and distance measurements.

8 Conclusion and Future Work

In this paper, a new reconfigurable robot workcell for the assembly of automotive light housings was presented. The robot workcell will, in the future, assist the manufacturing industry with many small production batches or even spare part production, where changes of tools occur frequently. Different kinds of technologies are used to assemble the presented reconfigurable workcell. These technologies allow the robot workcell to be reconfigured very rapidly. For reconfiguration, no human intervention is needed. In the presented work it was shown that the fixtures are adaptable enough to firmly mount at least two fairly different automotive light housings [11].

To demonstrate the benefit of using such a workcell in a real automotive industrial scenario, a case study was developed in collaboration with a scientific partner. With the applied use case, the applicability for industry was demonstrated.

In the future, we will test the reconfigurability of the robotic workcell by testing the assembly with a variety of different light housings. As well as that, the logistics and supply of the workcell will be analysed. Measuring the repeatability of the assembly process will also be performed. Repeating the experiments using a measuring method with better spatial resolution would also be beneficial. Measuring a stress-deformation characteristic in parts during assembly would also be interesting as it would help us to determine the forces used for the assembly of a part.

Acknowledgment

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