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Efficient Use of Human-robot Collaboration in Packaging through Systematic Task Assignment

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Abstract

The ageing workforce in Germany is a major challenge for many companies in the assembly and packaging of high-quality products. Particularly when individual processes require an increased amount of force or precision, the employees can be overstressed over a long period, depending on their physical constitution. One way of supporting employees in these processes is human-robot collaboration, because stressful process steps can be automated in a targeted manner. With conventional automation, this is currently not economically possible for many processes, as human capabilities are required. In order to achieve a balanced cooperation based on partnership, as well as to use additional potentials and to consider restrictions such as process times, it is necessary to ensure a good division of tasks between human and machine. The methodical procedure of allocation presented in this paper is based on the recreation of the process from basic process modules conducted by the process planner. Subsequently, these processes are divided according to the respective capabilities and the underlying process requirements. The company-specific target parameters, such as an improvement in ergonomics, are taken into account. The assignment procedure is described in a practical use case in the packaging of high-quality electronic consumer goods. Furthermore, the use case demonstrates the applicability of the approach. For these purposes, the parameters and requirements of the initial and result state of the workplace are described. The procedure and the decisions of the approach are shown with regard to the achievable goals.

Keywords

Human-robot collaboration; Design method; Task assignment

1. Introduction

In a globalized environment, manufacturing companies are confronted with a dynamic market that is characterized by increasing numbers of variants, simultaneously lower quantities and shorter product life cycles. These developments imply particular challenges to assembly systems in particular since assembly is responsible for up to 70 percent of product costs [1]. On the other hand, assembly processes are difficult to automate due to a high proportion of secondary work steps and peripheral equipment. Full automation can often only be implemented profitably in the area of large-series production since it requires high investments and is associated with a low level of flexibility and transferability to other applications. Considering this, assembly processes are often dominated by manual execution [1]. In addition, companies in the western industrial nations are faced with cost pressure due to high wages in this area. Furthermore, they must react

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to a shortage of skilled workers and demographic changes in order to secure their international competitiveness [2]. These factors force companies to increase the degree of automation in assembly which leads to higher productivity.

Collaborative assembly systems connecting humans and robots are expected to be one way to meet these challenges. They offer a possibility to use automation potentials in the area between manual and fully automated assembly. However, when looking at the market for industrial applications of collaborative robots, it is noticeable that only a small proportion of industrial robots are collaborative and only a few real collaborative applications have been implemented [3]. The high potential that the human-robot collaboration (HRC) offers for modular, flexible and agile production processes is therefore obviously not exhausted yet. The reasons for this are manifold. Often companies state that they have limited experiences in planning and development as well as in the implementation of this comparatively new technology. The relatively long planning and development phases, which are connected with high personnel and financial efforts, represent a significant obstacle for many production companies [4].

In order to counteract the lack of experience and uncertainty, the "SafeMate" research project aims to develop a guideline for the introduction of collaborative systems. This guideline should support companies in planning and development as well as in commissioning of such systems and thus contribute to better exploit the potential of HRC [4]. In this paper, the assignment of tasks between humans and robots is described. The approach is explained using an application case as an example. In this way, the challenges in the implementation of the process become clear.

The article is divided into four sections. We present current approaches to systematic task assignment in HRC. Followed by this, the developed procedure for assigning work contents is explained in the example of a packaging process. In chapter four, the implemented solution and the results gained from it are presented. Finally, the article is briefly summarized.

2. Systematic Task Assignment

In order to simplify the introduction of HRC and thereby advance technical progress, researchers are increasingly working on developing methods that make it easier for companies to plan and implement such systems successfully and reliably. One of the essential steps in the introduction of collaborative systems is the evaluation of suitability for the execution of the manufacturing steps using a robot. This step is often carried out without any quantitative calculation because the decision which step is useful for the robot is based on previous experiences of the employee and process-specific aspects.

In order to systematically select a workplace for the implementation of HRC, several approaches have already been developed. A central decision in the partial automation of a process is to clarify which processes are suitable for HRC and what the task assignment looks like since the success of implementation can be significantly influenced by these facts. Thus, there are developments that try to determine a suitability for HRC based on capabilities [5] or standardized work descriptions [6]. With other approaches, the automation ability of each individual process is considered and transferred to the complete process [3, 7]. In addition, scientists have also developed procedures to allocate the jobs in human-robot interaction. One approach uses mathematical models in combination with a genetic algorithm to find a proper distribution [8]. Another assignment method estimates the time using Methods-Time Measurement to minimize the total production costs [9]. In Tsarouchi et al. the user starts by developing a layout in order to simulate the process [10]. Based on the results the assignment of the tasks is carried out. Pischke et al. use the specifications of the sub-processes to allocate the tasks to the robot and worker [11].

The approach developed in the "SafeMate"-project is based on a two-stage procedure for determining HRC potential. First, we ask a number of questions to determine whether there is general suitability in terms of ergonomical improvements, rationalization possibilities or increased output [3]. The identified questions include topics such as component feeding, the workflow and the necessary cycle time. If this step fails, the user should continue with the evaluation of another workplace instead of going on with this one. Passing leads to the second step in which the user recreates the process with the help of basic process blocks. After that attributes are assigned to the process blocks so that the capability can be assessed. A list was created on the basis of an expert survey to identify capabilities. The expert survey rated different configurations. The scale ranges from 0 (more suitable for humans) to 1 (more suitable for robots). A value close to 0.5 implies that there is no preferred solution.

The sub-processes are then assigned with the help of the predefined capabilities, among other parameters. At first, the sub-processes that are particularly suitable for a resource are assigned [11]. For further assignments, the user has to evaluate if a rescheduling of sub-processes is possible. If it is the case, the user can consider whether the assignment allows building complete process blocks for a resource or an alternating work sequence between the collaborating partners. In this context, a block-building means that several consecutive sub-processes can be carried out one after the other by the same resource without dependence on other process steps. This has the advantage that complete task packages can be performed by one resource without disruption. The product is transferred to the other resource when the task is complete. If the complete blocks of both partners have similar cycle times, the waiting times of each resource can be avoided or at least minimized. Another approach is a sequence in which the partners can work alternately. This allows one partner to prepare components while the other partner works on the product. If it is well coordinated, this approach can also reduce the cycle time. A decision, which system is suitable for the process, can be made on the basis of the cycle time. In many processes, the cycle time is a target specification that can be determined with the help of real measurements or, for example, the MTM analysis.

3. Initial Situation

In addition to economic efficiency and productivity, the ergonomics of workstations are also critical challenges for manufacturing companies. Workplaces with a high potential for improvements in economics and ergonomics are therefore particularly suitable for partial automation with a collaborative robot. Sennheiser electronic GmbH & Co. KG is a company that has already solved such challenges at workplaces with the help of robots capable of collaboration. However, these workplaces can more likely be classified as the so-called coexistence [12]. This means that humans and robots work together without a separating safety fence but no real cooperation takes place. Instead, the human operator just takes over provisioning tasks.

As part of the "SafeMate" research project, a manual packaging workplace for microphones was selected by Sennheiser. The use cases in the project are supposed to implement real cooperation between humans and robots. The following application was selected in close consultation with the production managers and employees based on ergonomic aspects and economic reasons. This application is particularly suitable for HRC, since traditional, hard automation is very difficult to implement or very cost-intensive due to various complicated sub-processes, which are described in the next subsections.

3.1 Current Process

At the selected workstation, two workers pack microphones and the needed equipment manually in a carton box (see Figure 1). The equipment includes several parts, such as the storage bag for the microphone and the instruction manual. During the packaging process, additional cardboard parts are folded so that the microphone fits perfectly into the box. Finally, the carton must be closed. Most of these steps are pick-and-place processes, thus automation is possible. However, some of the remaining sub-processes are difficult to automate due to the properties of the parts (e.g. elasticity, stiffness...) or the process requirements (e.g visual inspection...).

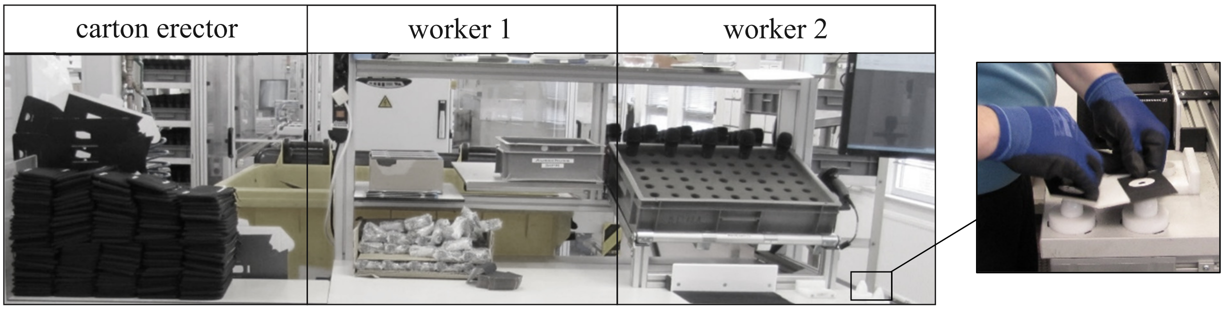


Figure 1: Layout of the presented workplace and the stressful process "wide cuff"

Table 1 shows the individual sub-processes in their sequence, priority and respective process times. The steps performed by worker 1 sum up to a total of 11 s, which the employee can perform in 10 s by parallelizing some steps using both hands. The second employee needs 18 s. A rearrangement of the assembly steps is only possible to a limited extent since the processes are based on each other and the sequence of steps is often predetermined.

Table 1: Process steps with priorities and execution times

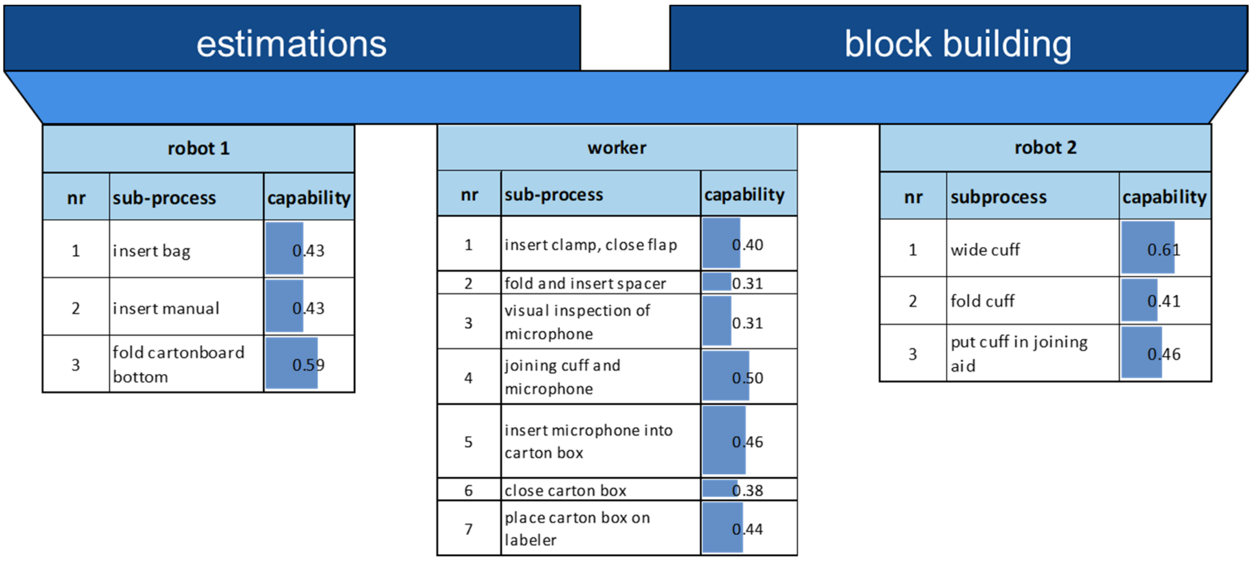
Worker 1			Worker 2		
Priority	Step	Time [s]	Priority	Step	Time [s]
1	take carton	1	1	take carton	1
2	insert bag	2	2	wide cuff	3
2	insert manual	2	3	fold cuff	1
3	fold cardboard bottom	1	4	visual inspection of microphone	5
4	insert clamp, close flap	2	5	joining cuff and microphone	2
4	fold and insert spacer	2	6	insert microphone into carton	4
5	supply carton	1	7	close carton	3
			8	place carton on labeler	2
	∑	11		∑	22
	due to parallelization ∑	10		due to parallelization ∑	18

Based on the manual work steps described in Table 1, an automation concept is being developed in which each sub-process is examined concerning its automatability using a collaborative robot. The main goal is the reduction of the workforce to one employee, maintaining the current cycle time.

3.2 Potential analysis for human-robot collaboration

As stated in the section before, the analysis of the use case presented in this article leads to the conclusion that there is a potential for rationalization and an improvement in ergonomics. There are two main reasons for this assumption. On the one hand, the process contains activities that are difficult to automate. For example, a visual inspection must be carried out where a worker checks the microphone basket for a firm fit. He also checks the microphone for small scratches or other irregularities so that the customer can be provided with a faultless product. This is difficult to achieve with today's automated systems because of varying ambient conditions and the uncertainties in the fault itself. Also, the packaging contains flexible parts so that full automation can only be achieved with considerable effort. Partial automation, on the other hand, makes sense because there are many sub-processes suitable for automation and some of which place huge physical stress on the employee. For example, the "wide cuff" process demands a high force applied by the worker. The openings of the cuff must be widened with a force of 80-100 N on a mandrel, which puts a considerable strain on thumb and shoulder at more than 700 times per shift (see Figure 1). Another goal, which is to be achieved with partial automation, is to increase productivity so that in future one person can carry out the packaging process alone. This is of additional relevance for the company because the demographic change (the proportion of the working population in Germany is continuously declining [13]) makes it difficult to replace employees leaving the company due to retirement.

In order to investigate the packaging process, the assessment process of Pischke et al. [11] is carried out. Therefore, all sub processes defined in Table 1 need to be analyzed. The results show that the processes "fold in inlet" and "wide and fold cuff" offer a high degree of eligibility for the robot (Figure 2). On the one hand, this is because high stresses and strains occur for humans, which must be prevented. On the other hand, only simple movements are required for the process that can easily be taken over by a robot. At the same time, other processes require capabilities that can only be provided poorly by an automated system like the visual inspection mentioned above. Also, there are many processes in which both partners are equally well qualified. Especially with these processes, it is essential to properly evaluate how these can be distributed among the partners.



robot 1

nr	sub-process	capability
1	insert bag	0.43
2	insert manual	0.43
3	fold cartonboard bottom	0.59

worker

nr	sub-process	capability
1	insert clamp, close flap	0.40
2	fold and insert spacer	0.31
3	visual inspection of microphone	0.31
4	joining cuff and microphone	0.50
5	insert microphone into carton box	0.46
6	close carton box	0.38
7	place carton box on labeler	0.44

robot 2

nr	subprocess	capability
1	wide cuff	0.61
2	fold cuff	0.41
3	put cuff in joining aid	0.46

Figure 2: Capabilities and task assignment of the developed workplace

Overall, the evaluation shows that the workstation is suitable for a HRC from a sub-process point of view because it contains processes that utilize the strength of humans and robots. If this is not the case, manual or fully automated assembly can be a better option. Based on this assessment, the entire, semi-automated process including the new workstation layout can then be developed.

3.3 Task Assignment

The division of the sub-processes was first carried out on the basis of the capabilities, whereby first the processes "fold in inlet" and "wide and fold cuff" were assigned to the robot and "insert clamp and close flap", "fold and insert spacer", "microphone visual inspection" and "close carton box" were allocated to the worker. After this assignment and the consideration of the cycle time, the time frame remaining for additional processes of the worker in each cycle is only 6 seconds. This corresponds to about two additional steps. Accordingly, the other processes must be allocated to the robot. After a rough estimation of the cycle times for the robot (e.g. via RTM [14]), it is decided that a second robot is necessary. This is because too many tasks have to be assigned to the robot, which cannot process the tasks in the given cycle time. With regard to the prioritization of the processes and the use of another robot, an alternating sequence is hardly possible in this case because waiting times for all partners would occur. Accordingly, three sub-process blocks are formed, whereby one is done by the worker and two by the robots (see Figure 2).

The first block deals with the preparation of the cardboard box. This block includes the sub-processes “insert bag”, “insert manual” and “fold cardboard bottom”. The second block contains the preparation of the cuff and is also carried out by a robot. The operator is supposed to do the processes “joining cuff and microphone”, “insert microphone into carton” and “place carton on labeler”. The whole process of the worker is as follows. At first, the worker puts the clamp in the carton box. After that he folds and inserts the spacer into the prepared carton. He then carries out a visual inspection of the microphone and, if there are no faults, fits it into the cuff. The microphone is then packed in a carton, the carton is closed and transferred to the labeler. This results in a cycle time of approx. 22 seconds. A cycle time of 18 seconds can be assumed by parallelizing the processes (e.g. inserting the clamp and folding the insert, since the human operator carries out these steps in parallel by working with both hands).

The resulting scheduling must then be investigated in more detail in experiments or simulations, as the times for the robot and the human parallelization are based on an estimate. However, with the example could be shown that a methodical procedure helps to generate an efficient sequence based on partnership.

4. Implemented Process

After a successful investigation of the cycle times, the implementation process of the workplace can proceed with the development of the workplace realization. Taking into account the derived job scheduling and cycle times, a layout needs to be developed. In addition, there are safety standards to be fulfilled, which can result in longer cycle times or even prevent an implementation of HRC workplaces. It is possible that the scheduling has to be adjusted due to safety reasons. In this case, the user needs to switch the relevant sub-processes. In the following part, the developed packaging process as a HRC workplace is described with the emphasis on process times and safety.

4.1 Collaborative Process

As described in the last chapter, the developed packaging process is divided into two automated and one manual processes (Figure 3). In the first process, a bag and an instruction manual are inserted into the carton, the inlet is folded and finally made available to the operator. This process is therefore decoupled from the worker and not in the worker's work area. For this reason, this process can be considered a coexistence. Nevertheless, the safety standards, in particular ISO/TS 15066 [16], must be obeyed. This means that the speed and acceleration of the robot must be limited in order to comply with the force and pressure limits defined in the safety standards. After conducting an experiment on the cycle time, it is found that the desired cycle time cannot be achieved with the intended hardware. Consequently, additional automation is needed in order to maintain a cycle of less than 18 seconds (Table 2). In this application, a friction feeder can carry out the insertion of the operating instructions to save manual process time. Once the instruction manual has been inserted, the robot removes the bag from a magazine and inserts it into the carton. The gripper is executed as a suction pad, as this makes it easy to separate and grasp the pockets. The gripper was specially designed and has rounded edges for the protection of the human collaborator. The gripper also serves as the device to fold in the inlet. Finally, pneumatic cylinders transport the carton into a buffer, thus making it available to the operator in the next step.

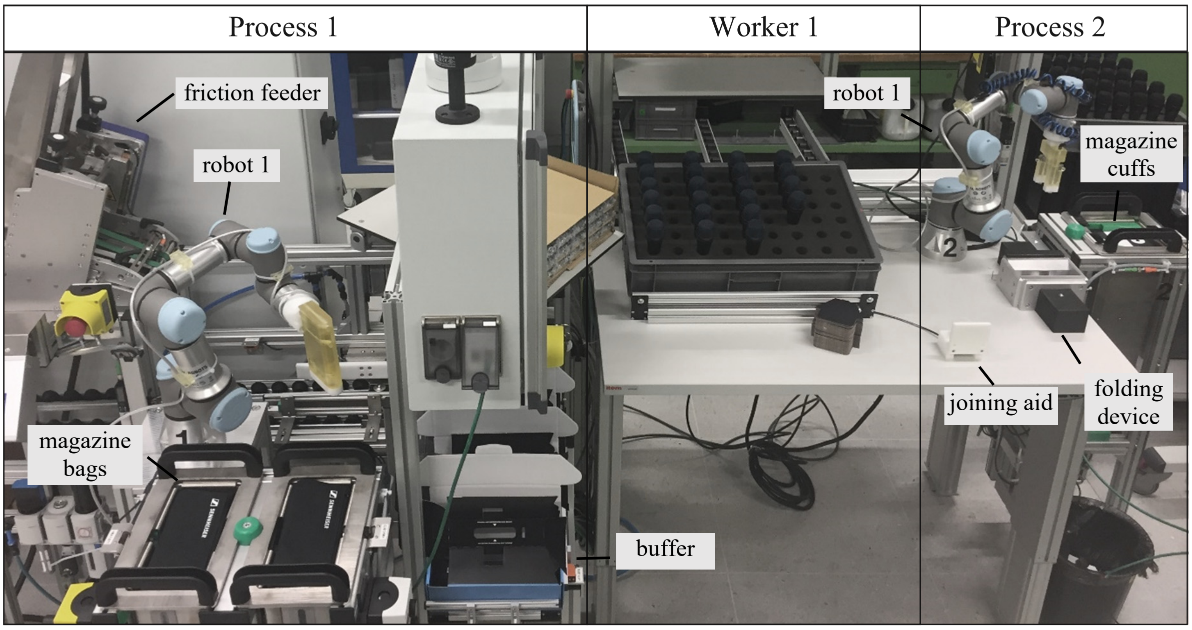


Figure 3: Implemented assembly system for the packaging process for microphones with two robots

In the manual process, the worker removes the carton from the buffer and inserts a microphone clamp and an insert. The operator then picks up a microphone, performs a quality check and inserts it into the cuff provided by the second robot (Figure 4, left). Finally, he inserts the microphone with the cuff into the carton, seals it and places it on a labeling machine.

Table 2: Collaborative Packaging Process

Step	Process 1 [s]	Worker [s]	Process 2 [s]
insert bag + manual, fold carton bottom	17		
convey in buffer	3		
insert clamp and insert		7	
fold, wide and provide cuff			16
visual inspection of microphone, joining with cuff, close carton, place on labeller		16	
∑	20	23	16
due to parallelization ∑	17	18	16

In the second automated process, the cuff is expanded, folded and made available to the operator. A self-developed fixture is used to widen the cuff. Two pneumatic cylinders are used to expand the cuff after the robot put it in the device (Figure 4, right). Since the robot works in the same working area and on the same product (cuff) with the worker, this is a collaborative process. The cuff is both folded and the openings widened by pneumatic cylinders. As for the first process, a suction pad was specially designed for this purpose. The magazine works on the same principle as the one in robot process 1. After folding and widening, the cuff is placed on a joining device so that the worker can reach it. An inductive sensor is installed in the joining device, which detects the microphone inserted by the worker. The robot waits until a

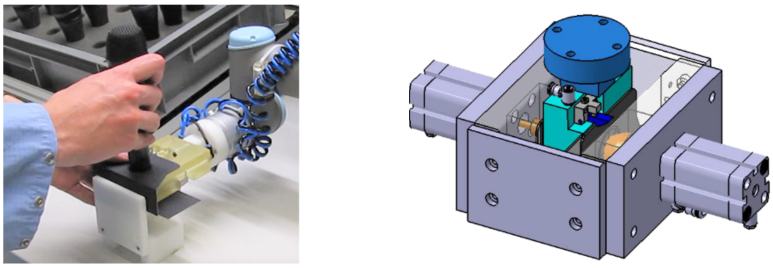


Figure 4: (left) Handing over the cuff; (right) developed widening equipment

microphone is detected and then starts with the next cuff. In this way, the employee is controlling the cycle time, since a new cuff is prepared simultaneously by the robot.

4.2 Safety

In principle, DIN EN ISO 10218-1 [15] and ISO/TS 15066 [16] must be complied with for applications with collaborative robots in Germany. The safety of the person is guaranteed by safe hardware in the robot or by a safety-rated control system. Additional safety housing and distance monitoring can be used in this case. To ensure safe operation within the framework of ISO/TS 15066, the biomechanical force and pressure limits defined in the standard for the various body regions must be met. Therefore, force and pressure measurements are carried out at all potential pinching and contact points. If the limit values were exceeded, the acceleration, speed or force limitations of the robot would have had to be adjusted. These measurements were already carried out in the initial test setups in order to be able to draw conclusions about the expected cycle time at an early stage of development.

Particularly critical squeezing points in the force and pressure measurements have been evaluated between the robot gripper and the folding device in the second process. For this reason, additional padding was attached to the folding device. All in all, rounded edges were added at the grippers and the devices, so that the safety limits can be fulfilled at all potential contact points during the whole application. For the risk assessment, however, it is not only the robots that have to be considered but also the entire system. The system is controlled by a safety PLC, which ensures, for example, that the pneumatic cylinders can only extend at certain times to prevent injuries to the operator. Finally, a CE declaration of conformity is drawn up taken all the safety standards into account.

4.3 Economic Efficiency

In addition to the goal of ergonomic relief for the worker, the packaging process should be able to be carried out by just one person. Productivity should be increased and economic profitability is not least the prerequisite for automation. In production, the packaging station is operated in two shifts and in rare cases three shifts, so that four employees are planned for the workplace. The collaborative process allows this to be reduced to two employees. This saving is offset by the costs for the system, which are made up of the material costs and the working hours. The working hours account for a large part of the costs. This can be explained above all by the new technology of collaborative robots, which is very time-consuming due to the lack of experience in process development and, in particular, in risk assessment. In order to counteract precisely this problem, the SafeMate research project subsidizes working hours and, in some cases, material costs. This enables an ROI of fewer than two years, which is required internally at Sennheiser. The experience gained through the SafeMate project thus contributes to the fact that future applications can be implemented faster and thus more cost-effectively.

5. Conclusion

In this paper, an opportunity for assigning tasks between humans and robots in HRC is described using the example of a workplace for packaging microphones. Based on the process description, the work contents could be divided economically and capability-based. It turned out that for an efficient solution an employee should work together with two robots. In addition, a friction feeder was installed in order to meet the required cycle time.

Difficulties in the implementation were particularly evident in the handling of the parts. Some packaging materials made of paper behave differently depending on the prevailing environmental conditions (e.g. temperature and humidity). This influences the process stability if the robot cannot react to the corresponding uncertainties. In addition, the authors recommend a precise feeding of semi-finished products in order to provide appropriate conditions for automation. At the same time, the achievement of specified cycle times is sometimes only possible with increased effort due to compliance with the relevant safety standards. This is primarily because the speed of the robot is reduced in order to maintain the contact forces with the worker.

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Biography

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