Analyses and Study of Human Operator Monotonous Tasks in Small Enterprises in the Era of Industry 4.0

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Abstract. Attraction towards Industry 4.0 is evolving in the academic and industrial communities providing new solutions to reduce the workload of human operators by integrating new technologies into the manufacturing processes. To reduce human operators' time and/or reduce performance of boring tasks, collaborative robots (cobots) can be integrated into workplaces. The term cobots (collaborative robots) designed for cage-free work or that which contains robots that can directly work with human workers without safety barriers on the manufacturing floor. Recent cobots consist of human like arms which can be a supporting tool for the human worker or it can assist him as a co-worker in the same workplace.

This paper provides results of study of human operator's workplaces in small and medium enterprises(SME) to integrate enabling technologies of industry 4.0 and to find new solutions to reduce work load and to increase the productivity of production. In SMEs there are many cases where human operators perform monotonous tasks, implementation of cobots and mobile robots to the workplaces can provide good support for monotonous tasks of human workers, handling the tasks that require high precision or repeatability. The paper describes the integration of cobots into the workplace of a manufacturing company where monotonous, cumbersome and stressing activities affect the wellness of the workers. The paper analyzes the current workflow and the ergonomic load of the worker, further developing the appropriate task distribution between human and robotic operators and demonstrates open source technologies to accomplish human robot collaborative applications.

Keywords: Cobots, ergonomics, SWOT analyses

1 Introduction

Industry 4.0 (I4.0) is evolving in academics and companies trying to find new solutions to reduce work load and increase productivity of productions by integrating new technologies into the sector. For example, to reduce human operators' process time and/or reduce the burden of tedious tasks, collaborative robots (cobots) could be integrated into workplaces. The term cobots (collaborative robots) designates cage-free robot that can directly work with human workers without safety barriers on the manufacturing floor. Recent cobots are human like arms which can act as a tool for human worker or as co-worker in the same workplace as shown in figure 1. In the following research papers integration of collaborative and mobile robots into human workspaces for repetitive tasks execution have been studied. Automatic progressive framework proposed in [1] where the operator programs a collaborative robot by demonstrating a task in which the robot performs pick and place repetitive movements autonomously after an unknown number of demonstrations. The results of the paper [1] have been demonstrated in laboratory level and have not been implemented in a real industrial case scenario. Task-based programming and task sequence planning method for human robot collaborative assembly was proposed in [2] where the contemporary collaborative work of robots and humans share tasks in the same workspace and executes assembly jobs. Unlike in [3] proposed a multi criteria method for planning of shared human robot collaborative assembly tasks. The product assembly sequence is generated from CAD models. The proposed method has been evaluated in automotive industry based on ergonomics, quality, technical feasibility and productivity criteria. In [4] authors demonstrated collaborative industrial like task execution where the agents are human operator, mobile robot and the manipulator. In case study of [4] robot manipulator finds a workpiece using a camera that is randomly positioned on the mobile robot and executes pick and place tasks. Applicability of commercially available open source components and integration of different technologies belonging to industrial robotics and commercial components into one eco-system is presented in [5] and studied the integration of different I4.0 enabling technologies namely: Robotics, IoT and fog/edge computing.

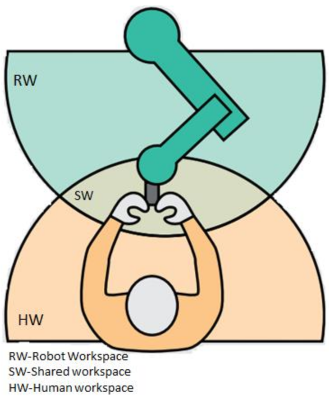


Fig. 1. Human operator and robot workspace's source from [6].

In contrast to the above-mentioned researches, this paper studies current manufacturing processes in an SME by identifying operator tasks workload and operator ergonomics. Further, based on the ergonomic assessment worksheet (EAWS) results, different solutions to reduce human operator workload in repetitive tasks are proposed. Depending on the workpiece component, different ideas to design the integration of modern robots into the work cell is discussed.

The paper is organized according to the following topics: problem definition and description by analyzing the condition of the SME; human operator's repetitive task analyses using ergonomic evaluation tool and requirements for integrating new technologies; proposed scenarios SWOT analyses and conclusions.

2 Description of the Problem

In spite of I4.0 era, in SMEs there are still situations where human operators perform monotonous tasks. In the company under study, one such tedious task consists of detaching the metal components from the metal sheet after a laser-cut. An example is shown in figure 2(A) represents general view of metal sheet and figure2(B) where the metal components that are supposed to be detached after laser-cut have micro joints to avoid their unwanted detachment.

A: General view of metal sheet B:Magnified figure, metal components

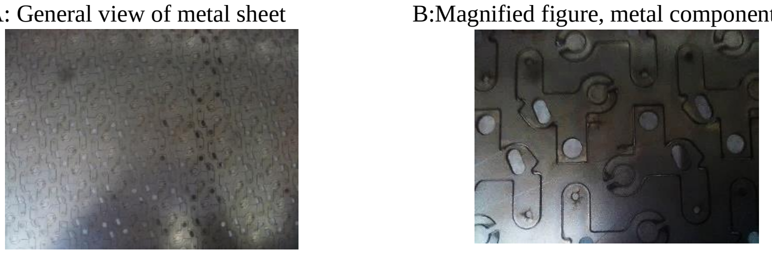


Fig. 2. Detachable metal components in the metal sheet with micro joints

Figure 3 shows laser cut components in the metal sheet. Moreover, the figure depicts the micro joint position and space between the component and metal sheet that is less than 2 mm.

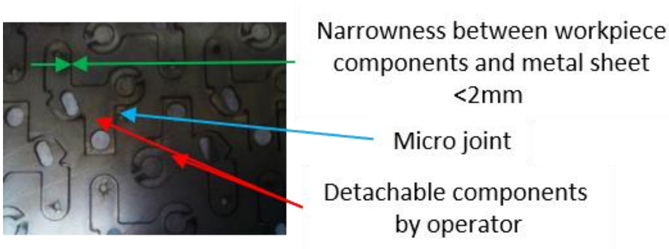


Fig. 3. Detached metal components from the metal sheet by operator.

The detachment tasks are time-consuming and provide stress to the human operator. Moreover, if micro joints are present, the human operator cannot detach workpieces just by hand, he/she usually uses extra forces (using rubber mullet or vibration hammer with air) to detach the workpieces from the metal sheet.

After a few hours of such repetitive work, the human worker gets exhausted and sometimes the workpieces are deformed. Integration of robots into the workplace, could reduce stress and time of the human workers and improve the ergonomics of the work-station.

2.1 Human Operator Workflow to Detach Metallic Components after Laser Cut.

In this chapter, a detailed description of the work process is provided. Figure 4 represents a workplace and the work process of the human operator that removes components from the metal sheet after laser-cut. To understand operator monotonous tasks and workplace ergonomics, daily works of the operator have been divided into small parts and analyzed: starting from placing metal sheet after laser-cut to the workplace of the human operator, removing components, sorting and placing removed components to the boxes, transporting packed boxes and removing remained metal sheets from the workplace. Workflow steps of the tasks during the working process are shown in figure 5.

Fig. 4. On the left: manual detaching; on the right: detaching with instrument

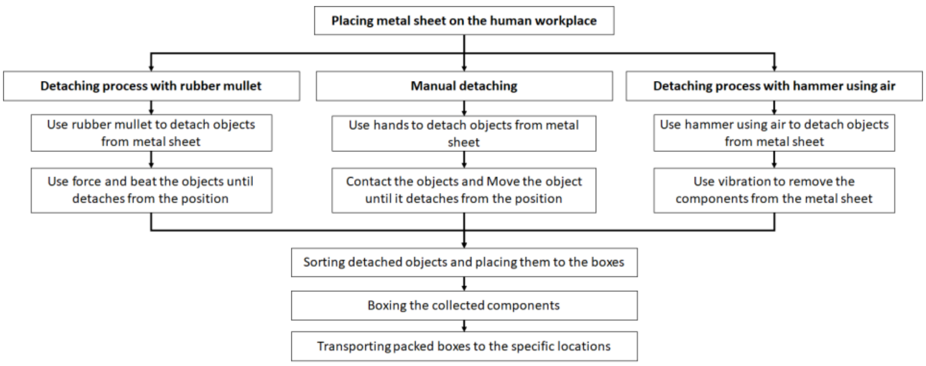


Fig. 5. Process flow of the human operator.

The workflow of the human worker described in figure 5 compose of three main detaching methodologies: manual detaching; detaching using rubber mullet and detaching using a vibrating hammer.

Each approach process is described in detail and after removing components a human worker places the components into boxes and transports boxed components to the specific locations.

A repetitive work performance by the operator usually lasts from one to five minutes and duration depends on the size (thickness, width and height) of the metal sheet and a number of components.

To understand the physical tasks of the human operator, five minutes of working time has been recorded, observed and described in the following:

1. Go to laser-cut machine and pick up the metal sheet (5kg, from 400 mm above floor height, at a horizontal distance of 1000 mm), bring the metal sheet to the workstation (distance <2m) and place it on the workplace (workplace table size – 1600x3300x1030 cm).
2. Detach the components by pushing and pulling up and down vertically with a force <0,3 N.
3. Collect all detached components into the boxes.
4. Place boxed components (weight 1-7 kg) to container (distance <2 m)

The process flow and the observed five minutes of working time give a clear view about operator repetitive works and possible integration of new technologies for each phase of the tasks and to develop applications to reduce operator time and remove monotonous works.

2.2 Conditions and Requirements of the Workplace to Integrate Industry 4.0 Components and Tools

Before reorganizing workplace and integrating new types of robots (mainly cobots) with grasping techniques, the condition of the workstation and detaching tasks of the human worker have been studied. The workplace situation and some important features of the detaching components from metal sheet have been identified as follows:

Condition and situation of the workplace of the operator during detaching tasks:

- The gap between workpiece components and the metal sheet is <2mm: sometimes, the human operator faces complex tasks to enter with finger and detach the component. In this case, he uses external tools such as magnets or vibration hammer using compressed air that is noisy.
- Between workpiece components and metal sheet (blank) might have more than one micro joints.
- The laser-cut metal sheet is on the 2D surface.
- Industrial condition - metal sheet might have dust, burr after laser cut
- Metal workpiece components might have different holes
- Different 2D shaped workpiece components in the same metal sheet.

Requirements for the robot in workstation:

- Grasping gripper of the robot must be able to hold metallic components after laser-cutting
- The robot should work in the same workspace with a human operator.

Knowing the situation and workplace condition of the operator, integration of cobots could be a right approach for several reasons:

- Capability to work in the same workplace as a human operator;
- Reduce the workload of the operator by taking dexterity tasks;
- The working duration can be set up longer than the human operator;
- Flexibility and adaptability for different tasks in different workspaces;
- Ability to work in industrial condition including in dust and polluted air;

These working conditions and requirements of the human operator give a better understanding of the workplace constraints before implementing new tools and technologies.

3 Ergonomic Work Assessment of Human Operator

Before implementing new technologies at the workplace of the human operator, the physical workloads of the worker at the workstation have been evaluated.

To perform ergonomic work assessment of the operator there are different screening tools and methodologies. In [7], rapid entire body assessment(REBA) tool is presented. REBA is used to assess selected body posture, forceful exertions, type of movement or action, repetition and coupling of the operator. To evaluate the posture, force and movement associated with sedentary tasks Rapid Upper Limb Assessment (RULA) method is developed in [8]. Ovako Working Posture Analysing System (OWAS) is a method to identify and evaluate poor working postures [9]. OWAS considers factors such as health and safety but mainly focuses on the discomfort caused by the working postures[10]. Unlike abovementioned tools, EAWS [11] is a tool to assess holistic physical workloads. The EAWS tool is developed based on ISO standards [12-14] and it evaluates physical workload only on a three zone (traffic light scheme). In this paper, EAWS tool is selected to assess the physical workload of the operator because it gives a very quick mapping of the different risk areas of all working tasks and to concentrate all the efforts for rapid redesigning.

EAWS tool evaluation is based on printed assessment worksheet paper and pen. Evaluation using EAWS comprehends four sections: evaluation of working postures and movements with low additional physical efforts between 3-4 kg; action forces of the whole body or hand-finger system; manual materials handling and repetitive loads of the upper limbs.

To evaluate the workload of the operator during the removal of metal components from the metal sheet, the process flow described in figure 5 and observed five minutes working process in subsection 2.2 have been used.

The first assessment using the EAWS tool is estimating the load of the manual material handling per shift (8 hours).
First manual detaching of metal components from metal sheet has been evaluated. It is assumed that human operator handles detaching the metal components (<3 kg) by pushing and pulling - 1 point; for the posture is up right and/or not twisted load at the body while detaching – 1 point; holding load manipulation time per shift around 73 min – 5 points. For carrying the load it is assumed that the metal sheet is less than 10 kg – 1.5

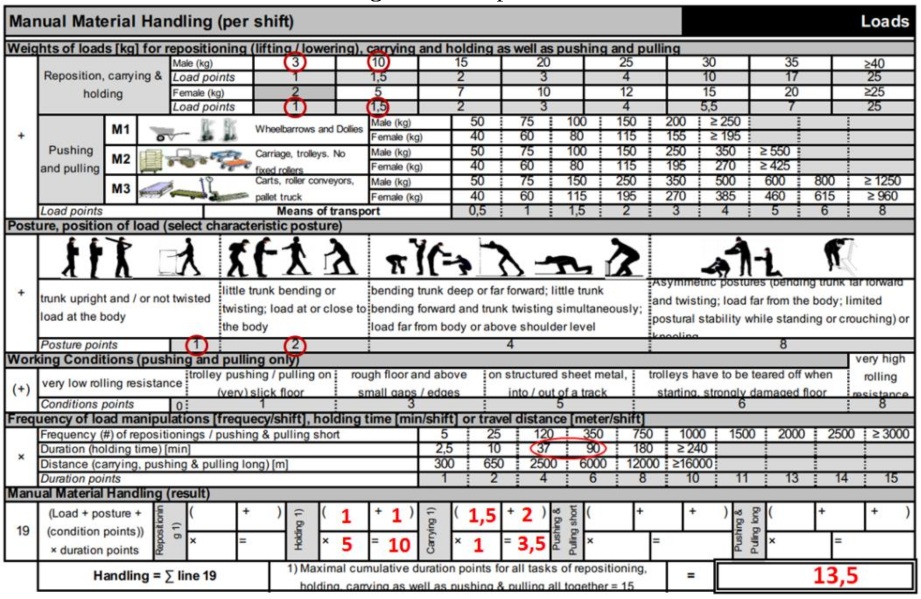
points; during loading the metal sheet human operator posture is little trunk bending, sometimes twisted and the component is close to the body – 2 points; duration holding time is less than 2,5 minutes - 1 point. Manual material handling result for detaching and carrying the load can be estimated as follows:

$$Result = (Load + posture + condition\ points) * duration\ points \quad \textbf{(1)}$$

Afterwards, the sum of all results in 13,5 as shown in line 19 of figure 6. Such value is slightly less than 15, which is the maximum cumulative duration point for all manual tasks.

$$Manual\ Handling = \sum line\ 19 \quad \textbf{(2)}$$

Manual material handling assessment shows that the load of the operator can be reduced and could be a reason to redesign the workplace.



Manual Material Handling (per shift) — **Loads**

Weights of loads [kg] for repositioning (lifting / lowering), carrying and holding as well as pushing and pulling

Reposition, carrying & holding	Male (kg)	3	10	15	20	25	30	35	≥40
	Load points	1	1,5	2	3	4	10	17	25
	Female (kg)	2	5	7	10	12	15	20	≥25
	Load points	1	1,5	2	3	4	5,5	7	25

Pushing and pulling											
M1	Wheelbarrows and Dollies	Male (kg)	50	75	100	150	200	≥ 250			
		Female (kg)	40	60	80	115	155	≥ 195			
M2	Carriage, trolleys. No fixed rollers	Male (kg)	50	75	100	150	250	350	≥ 550		
		Female (kg)	40	60	80	115	195	270	≥ 425		
M3	Carts, roller conveyors, pallet truck	Male (kg)	50	75	150	250	350	500	600	800	≥ 1250
		Female (kg)	40	60	115	195	270	385	460	615	≥ 960
Load points	Means of transport		0,5	1	1,5	2	3	4	5	6	8

Posture, position of load (select characteristic posture)

trunk upright and / or not twisted load at the body	little trunk bending or twisting; load at or close to the body	bending trunk deep or far forward; little trunk bending forward and trunk twisting simultaneously; load far from body or above shoulder level	Asymmetric postures (bending trunk far forward and twisting; load far from the body; limited postural stability while standing or crouching) or kneeling
Posture points: 1	2	4	8

Working Conditions (pushing and pulling only)

very low rolling resistance	trolley pushing / pulling on (very) slick floor	rough floor and above small gaps / edges	on structured sheet metal, into / out of a track	trolleys have to be teared off when starting, strongly damaged floor	very high rolling resistance
Conditions points: 0	1	3	5	6	8

Frequency of load manipulations [frequecy/shift], holding time [min/shift] or travel distance [meter/shift]

Frequency (#) of repositionings / pushing & pulling short	5	25	120	350	750	1000	1500	2000	2500	≥ 3000
Duration (holding time) [min]	2,5	10	37	90	180	≥ 240				
Distance (carrying, pushing & pulling long) [m]	300	650	2500	6000	12000	≥16000				
Duration points	1	2	4	6	8	10	11	13	14	15

Manual Material Handling (result)

19	(Load + posture + (condition points)) × duration points	Repositioning 1)	Holding 1)	Carrying 1)	Pushing & Pulling short	Pushing & Pulling long
		(+) × =	(1 + 1) × 5 = 10	(1,5 + 2) × 1 = 3,5	(+ +) × =	(+ +) × =

Handling = ∑ line 19	1) Maximal cumulative duration points for all tasks of repositioning, holding, carrying as well as pushing & pulling all together = 15	=	13,5

Fig. 6. Manual material handling assessment.

Next step is to assess forces applied onto arms and whole body using the EAWS tool. One time detachment of metal component requires 3 sec. force applied onto the arm can be calculated as intensity per duration that is 3 points. Since the operator doesn't apply other forces to the body sum of all actions remain 3 as shown in figure 7.

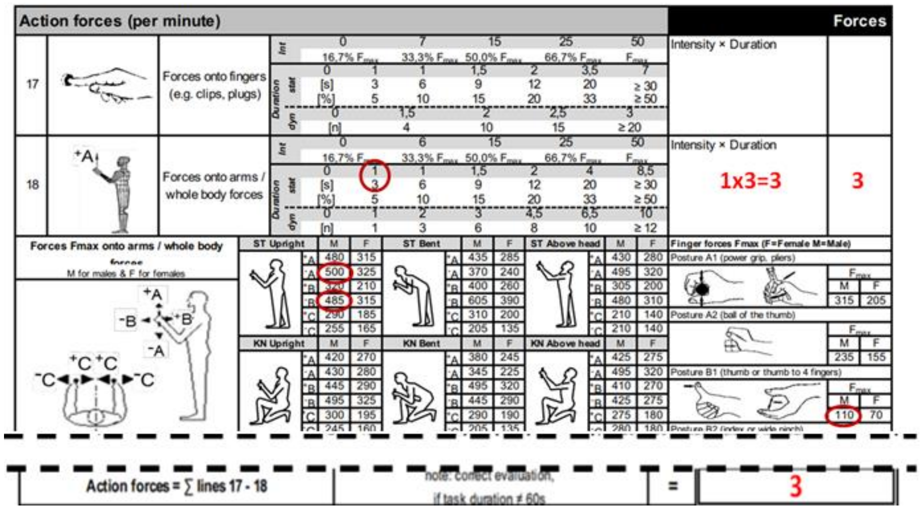


Fig. 7. Action force evaluation.

For the last tasks, 3 and 4 in subsection 2.2 that are boxing components and placing boxed components to the container operator uses additional force between 40 - 70 N and weights below 7 kg. These tasks have been evaluated using postures part of the EAWS worksheet described in figure 8. In our tasks operator stands in front of a working table that is confined space and executes detaching operations sometimes from far reach distances for this asymmetric posture assigns 2 points. Sum of all lines of postures is scored 15 points which represents "green" situation.

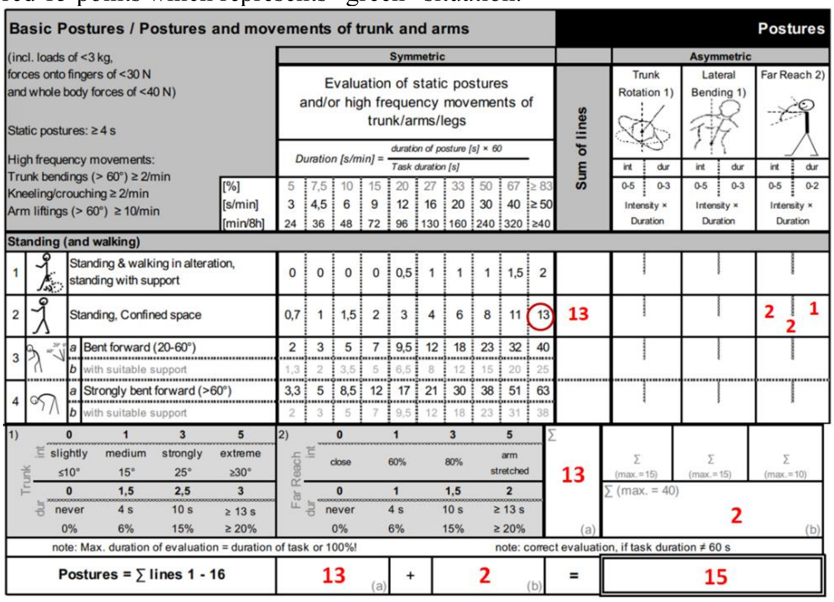


Fig. 8. Postures evaluation.

In figure 9, extra points are given for using extra tools depending on tools' weight and frequency of use. Since the operator sometimes uses rubber mullet or vibrating hammer, multiplying intensity and frequency of use those tools assigns 5 points in this section.

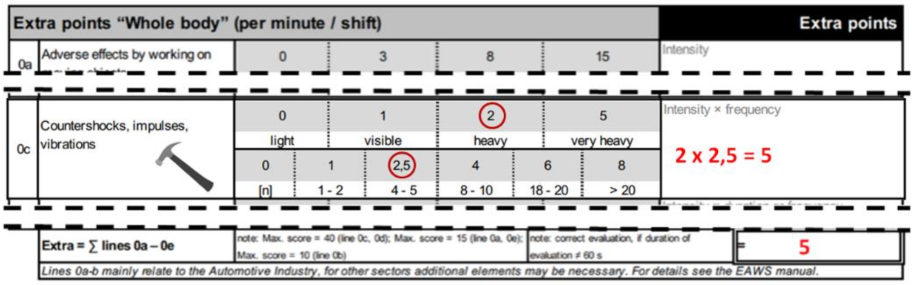


Fig. 9. Extra points for using extra tools.

The final evaluation of the "whole body load" of the operator is estimated by summing all part that is 15 points (working postures) plus 3 points (action forces) plus 13,5 points (manual materials handling loads) plus 5 points (Extra tools) equals 36,5 points that are shown in figure 10. This means the overall result is still in the "yellow" road.

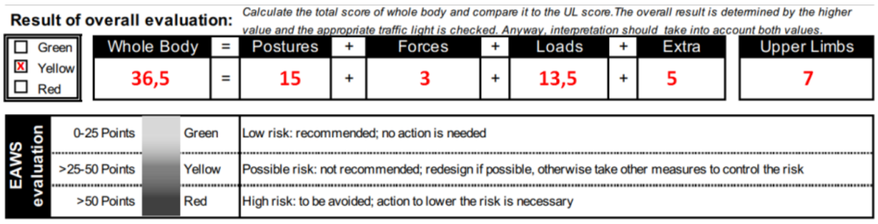


Fig. 10. Assessment of whole body.

To perform a full evaluation, upper limbs load in repetitive tasks have been evaluated in figure 11 and scored 7 points that is in "green" road but not added to the whole body.

After evaluations, the results of the EAWS tool showed risky sections such as manual handling and postures that could be reduced by integrating new technologies and that can lead to redesign the workstation.

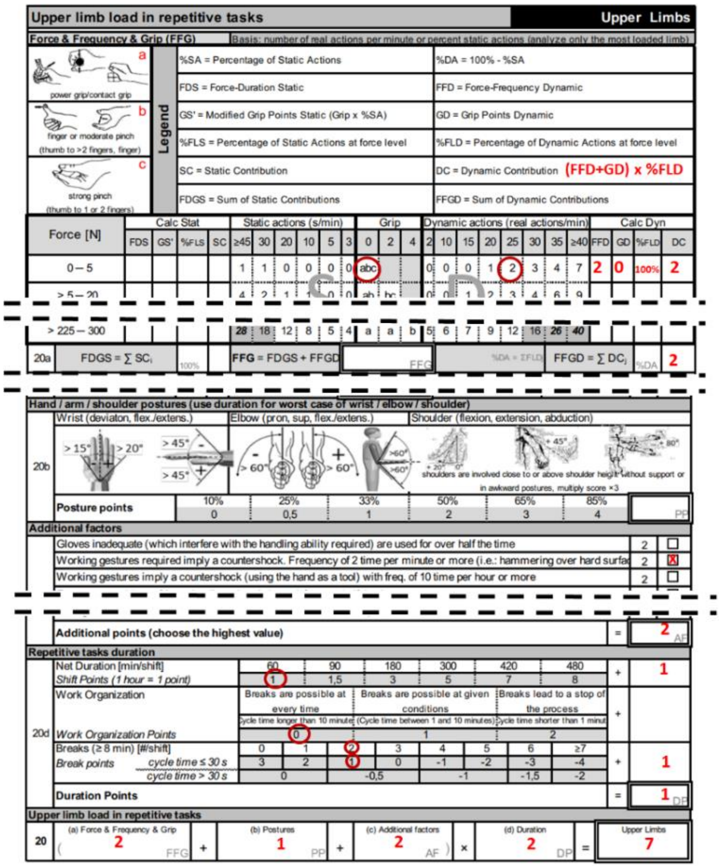


Fig. 11. Upper limbs evaluation section

4 Proposal of Collaborative Robot Integration in Human Operator Workplace

To develop a human-robot interaction system for the detaching of metal components, different levels of interaction in the shared workspace can be defined. In figure 12, there are different interaction levels [6] and different integration of cobots into the human workplace:

- the robot is operated in a traditional cage - *cell*;
- human and fence free robot work alongside each other but do not share a workspace - *coexistence*;
- the human worker and the robot share a workspace but only one of the interaction partners is actually present in the workspace at any one time – *synchronized*;

- both interaction partners may have tasks to perform at the same time in the (shared) workspace, but they do not work simultaneously on the same product or component – *cooperation*;
- human worker and robot work simultaneously on the same product or component - *collaboration*.

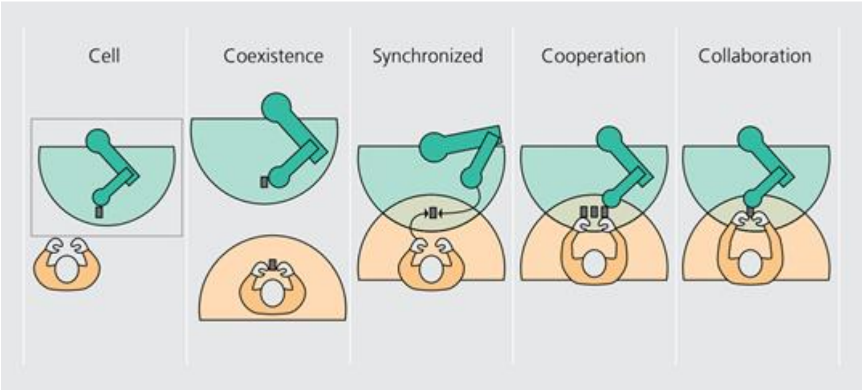


Fig. 12. Different levels of cooperation between a human operator and a robot source from [6].

After the identification of the interaction levels, tasks distribution between human-robot interaction system (HRIS), human operator and robot manipulator has been identified and described in table 1.

Table 1. Task distribution between human operator, robot manipulator and HRIS.

Pro-cesses	Process descriptions	Approach description	Work distribution in processes
1	Placing metal sheet on the work-place	Manual placement into the refer-ence position	Human
2	Get positions and orientations of all target components	Estimate component locations: Us-ing CAD file or vision system	HRIS
3	Approaching to the component	The gripper is positioned near by the target component	Robot
3.1	Coming into contact	Gripper is almost in contact with the target component	Robot &&Gripper
3.2	Grasp the component	Contact is achieved	Robot && Gripper
3.3	Detaching action	Moving the gripper in different di-rections in such a way that detaches the metal component	Robot/Human-Ro-bot/Gripper
3.4	Moving process	The gripper and component are joined and component can be moved to specific position	Robot && Gripper
3.5	Realising process	Releasing process is occurred by gravity when grasping force is deac-tivated	Robot &&Gripper
3.6	Move back	Robot manipulator is moving from position where released the com-ponent within the limited speed	Robot

3.7	Start position back	Move to the start position	Robot
4	Boxing collected components	Manual handling	Human
5	Transporting packed boxes to the specific locations	Manual handling	Human

Knowing the interaction levels of human and robot, three ideas have been realized. Short description of the case studies are described as following:

1) Metal component detaching that has micro joints using *human-robot collaboration approach*: If the metal sheet components have micro joints, human-robot collaboration approach can be used where the tasks are performed in the same time by human and robot. The workflow is the following:
   A human operator enters the coordinates of the metal sheet component using the teaching pendant or reading the CAD file; robot holds the workpiece while the human operator detaches the workpiece applying some force to different directions; robot moves the detached workpiece to the target position.
   After each detaching task, the human operator enters new coordinates to detach a new workpiece or manipulator reads new coordinates from the CAD file of the metal sheet.
2) Metal component detaching that has micro joints using *human-robot cooperation approach*: If the metal components have micro joints, human-robot cooperative approach can be used. In this case, a human operator enters the coordinates of the workpieces using the teaching pendant reading the CAD file; a cobot manipulator moves to the workpiece and applies appropriate movements to detach the workpiece; robot moves the detached workpieces to the target position; the human operator waits until robot manipulator finishes its task, then he or she enters new coordinates or reads again coordinates from the CAD file to perform new tasks. For every new component dedicated activity is in a sequence not at the same time.
3) *Automatic detaching* of metallic components approach can be applied when there are no micro joints in the metal components:
   robot reads from the CAD file of the metal sheet the coordinates of the metal component; robot reaches the workpiece position, actives the robot gripper to grab the workpiece; robot moves to the stocked position and releases the workpiece;

In the next section, there is a SWOT analysis of the proposed approaches. It provides a valuable description of the processes and contributes to evaluating future strategies.

4.1 SWOT Analysis of Proposed Approaches

Smart selection and integration of robust and inexpensive workstation in a company can support the longevity of production lines and improve financial situation. For proposed approaches, SWOT analyses [15] have been performed as a tool for strategic alternatives. Table 2 shows the SWOT analyses results. The strength of the automatic approach is more than other approaches but it should work for 24 hours that means the company has to pay anyways for the electric power and there is no human monitoring during unattended work shifts. On the contrary, the automatic approach can completely reduce operator tasks but the threat in this case operators lose their jobs. Integrating Human-robot collaborative/cooperative approaches lead the integration of new robots to the workstations and operators remain in their positions with robots but they are required to be reskilled.

Table 2. SWOT analyses results

	Strength	Weaknesses	Opportunities	Threats
Human-robot collaboration/cooperation approach	• Robot takes dexterity works of the human • More precise than human • Passing repetitive tasks to robot • Safe approach for operator	• Work duration is equal to human working hour 8 h. • Human and robot work simultaneously and in sequence that means more time required to execute tasks compare to automatic approach. • Redesign a workstation to integrate cobots	• Integration new enabling technologies • Possible to perform multiple tasks in the same time • Flexibility of robots that can be integrated to other applications • Less risk to lose human operator job. They still work together in these two approaches.	• Buying robot and paying salary to operator. • Lack of operator skills to work with robots
Automatic approach	• Robot works in 24 hours autonomously • The same time can perform multiple tasks • More reliable approach compare to other approaches • More safe than other two approaches, no interaction of operator • Robot can work in industrial condition including in dust and polluted air	• Power consumption 24 h • Redesign a workstation to substitute operator with a robot • Lack of monitoring	• Remove risks from operator by integrating automatic detaching system using robots	• High risks to lose jobs for human operators

5 Conclusions and Future Works

Analyses of workflow and ergonomics of physical workloads at the workstation of the human operator during repetitive work to remove components from metal sheet after laser-cut in SME has been evaluated using the EAWS tool. A final evaluation of EAWS worksheet resulted with 36,5 points for “whole body load” of the operator that is the sum of all sections: 15 points (working postures) plus 3 points (action forces) plus 13,5 points (manual materials handling loads) plus 5 points (Extra tools). According to the EAWS tool, the overall result is in “yellow” road that means there is a possible risk and if possible redesign workstation or “manual material handling loads” and “posture” sections points that are high points can be reduced by integrating new I4.0 technologies. For this reason, three ideas have been proposed (human-robot collaborative, human-robot cooperative and automatic detaching approaches). By integrating collaborative robots to the human operator workstation, a company can reduce physical loads of the operator in repetitive works. Afterwards, SWOT analyses of three methods have been performed to choose for the company the best approach to redesign workstation of the operator. The results of SWOT analyses suggest to redesign(if necessary) workplace of the operator by integrating automatic approach that has more strength to detach metallic components. This approach must be considered if there are no micro joints on the components. For the components with micro joints human-robot collaborative or cooperative approach can be implemented. In the future, the redesigned workplace of the operator with cobot and above mentioned approaches will be studied and evaluated.

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