Acceptation criteria of a movable cobot for polishing activities in naval industries

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***Abstract*— Naval industries is currently in mutation. Operations such as polishing are still today manually performed due to traditional context and "hand-made" is seen as a quality made. Unfortunately, it leads to musculoskeletal disorders and many ways are currently investigated to improve the working conditions. Even if exoskeleton or cobot (collaborative robot) were proposed few years ago, their integration in France stays limited. Moreover, companies faced to a fear of operators to let their job to a robotic system even if they try to reinsure it by showing that these systems needs their expertise. In order to help the operator in its job, a movable cobot was designed to perform simple and tiring polishing activities where the operator has a low added value. This paper deals with a methodology to identify, analyze and measure the acceptability factors to integrate a system to help the operator in its activity. After the description of the problematic that naval industry currently meets and the activities to be performed, the dimension of acceptance of a cobot are analyzed. Then, the movable cobot is presented. Finally, the development of the cobot and the feedback of the acceptance of such an assistive system tested by the company is highlighted.**

I. Introduction

Naval industry is currently in mutation due to a growth in their activities. Traditional operation such as polishing are manually performed due to several reasons. First of all, these companies produce products with high added values and hand-made is a guarantee of quality. Secondly, the dimension of their product (several ten of meters) is so large that investment cost can be important. Finally, companies wonder how it will impact their process knowing that a new process is time consuming. Though, the cost related to Musculoskeletal Disorders (MSD) pushes industrial companies to improve the working conditions. Even if a first generation of exoskeletons were born in late 1960s, numerous exoskeleton stays bulky, heavy, not adapted to human morphology and their integration in France stays limited due to several ergonomic factors. Recent developments on exoskeleton are numerous based on new material use, new control law and sensors systems with a deep study on the behavior of arms and legs for a better intuitiveness [1]. Ergonomics is a key to integrate these new systems and in recent years, Ergoskeleton terms appeared to describe new systems that could be able to give feedbacks about the ergonomics of person's movement [2]. Various architectures allow for example the transfer of the loading to carry it to the legs (Strongarm® [3]) or to give upward force to the forearm to compensate for the weight of the tool and help maintain posture (Exoskeleton Skelex). This passive exoskeleton is promising solutions for their autonomy [4]. These systems are dedicated for one task and one posture. Once the person switches to another task, the assistance can by easily desactivated by lowing arms down, allowing natural gestures. These systems are not perfect but provide a physical help and are well suited for exiguous workspaces.

Figure 1. Operator with and without an Exoskeleton to support the tools for polishing activities

Even if these systems seems to be well adapted, operators feeling must be taken into account and human factors are important criteria that needs to be studied. Recent works present interdisciplinary projects which mix researches in cognitive sciences, ergonomics, mechatronics, and mechanical engineering to propose dedicated system to help operators in their jobs [5]. Technological Readiness Level (TRL) presented its limit to insert systems in companies and new scales with human factors were presented [6]. The novelty of the paper is to experiment a user centered method based on acceptability criteria evaluation [7, 8] on a movable cobot. Robot are more and more used in company for repetitive tasks but, for flexible products, cobot are more and more used in order the operators to interact easily with it. Cobot is a derivative of robot where cobot means collaboration between human and the robotic system. Various manufacturers of robotic solution based on different technologies. Solutions allow sharing workspaces or directly working with the robot. Depending on the task to be performed, the energy of the cobot represents the limit in order the operator to be able to interact. Its integration must follow the Directive « Machines » 2006/42/CE.

In this paper, we present the development done around a new robotic system which is a movable cobot. A Universal Robot UR 10 is fixed to a Neoditech® platform allowing to perform tasks around boat hull. This paper is organized as follows: the polishing activity is first characterized. Due to the importance to consider the operator as a pilot for the movable cobot, a copy of the human gesture is analyzed with videos and the record of forces. We then focus on the

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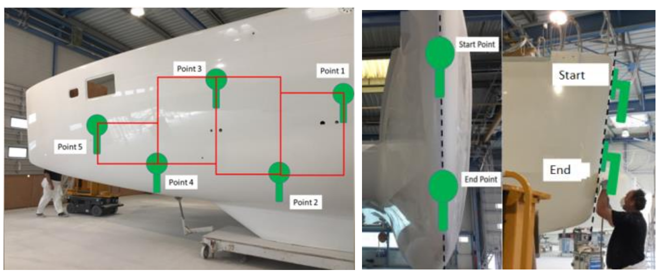
development performed on the movable cobot and the methodology to characterize the acceptability of the system with trials performed with an operator. We finally present the integration inside the companies and the strategy that will be used to insert this new technology inside this company.

II. Polishing Activities Characterization

A. Activities in the company

Hull striping of high dimension hull is a complex operation leading to various defects. Operators, after having a look on the hull must perform reparations and on every hull, they must perform tasks on the parting line of the mould. Polishing activities shew that the operator dislikes operating on high scale surfaces or with tiring postures: he squats, raises the hands above shoulders and the applied forces were considered as “critical”. These postures have a high risk of provoking musculoskeletal disorders (MSD) and justify the need for assistance. High quality standards force the operator to control meticulously the completion of the polishing system. To facilitate the introduction of the movable cobot, the objective is to simplify the learning of the trajectory of the cobot by the operator specifying two points (start point and end point) representing a polishing window (Figure 2). To well understand how the operator behaves, a task analysis was done.

Figure 2. Activities to be performed on boat : polishing window selection



B. Task analysis

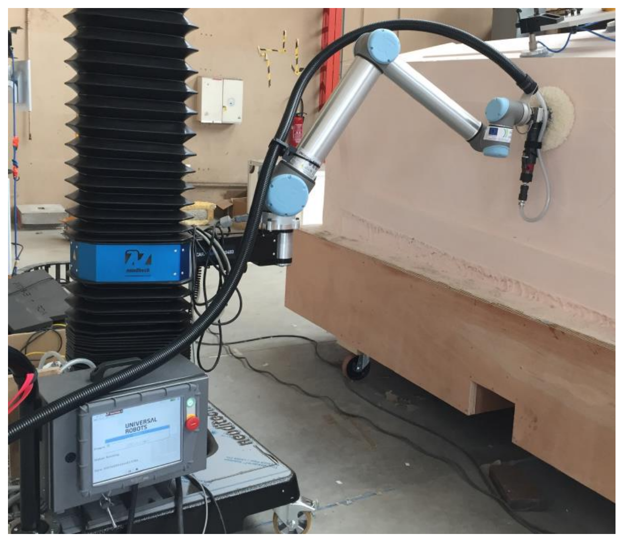
To acquire the know-how of the operator, a serial robot maintains a Kistler sensor on which a representative part of polishing activities is fixed (Figure 3). Various positions corresponding to the one lived by the operator allow us to understand the strategy used by the operator to reach the expected quality. It can be observed that operators perform some vertical and horizontal trajectories (grid pattern) and depending on the rotation direction of the polishing system, he applied forces or not. The forces are quite important reaching some picks of 60N. After the activity, an evaluation questionnaire allowed to characterize global satisfaction, utility, physical, cognitive and occupational impacts.

III. Movable Cobot Development

The movable cobot is a Universal Robot UR10 with a maximum payload of 100N. A force sensor Optoforce® is fixed on the end effector to improve the behavior of the robot extracting the process forces and torques applied on the boat. The polishing system is the one used by the operator, a pneumatic one. All the system is fixed on a Neoditech® system which is a heavy platform allowing the displacement of high loading on a large surface around it. In our case, the Neoditech® platform is able to maintain a loading of 500N at 2 m around the platform. The platform is equipped with one steered wheel. The controller of the robot is fixed on the platform. 2 wires stay on the floor: the pneumatic alimentation and an electric wire which allows the displacement by hand of the cobot on the floor. The Neoditech® version is a standard one where the robot raises at 2m high. Some improvements will be done in the final version to be able to reach all the surfaces of the hull.

Figure 3. Polishing activity on a kistler sensor following various postures, recording of the forces.

Figure 4. Movable cobot including Neoditech® system, UR10 equiped with Optoforce



IV. Organization of the Development between Company and University of Nantes

The acceptation of a new system needs the support of the whole company: operators, manager and the management board. Project team includes the responsible of the numerical transition, an ergonomist and a production manager. Developments are performed by the University of Nantes. It is a 9 months project including 6 months to develop it and 3 months to test it inside their workshop in order to reach to the final specifications of the movable cobot. During 6 months, 3 meetings have been operated. The first one was to understand company expectations regarding operator’s assistance. The second one was conducted with an operator to evaluate the prototype and gather his perception. The last one will be take place at the end of September 2018 with direction and the project team before cobot implementation on site. Once the development performed, verification and validation step are performed inside our center of research and unsuitable use is tested. Inside the company, a Failure Mode and Effects Analysis has been done to prevent risks. Confidence is built from the very first moment of use.

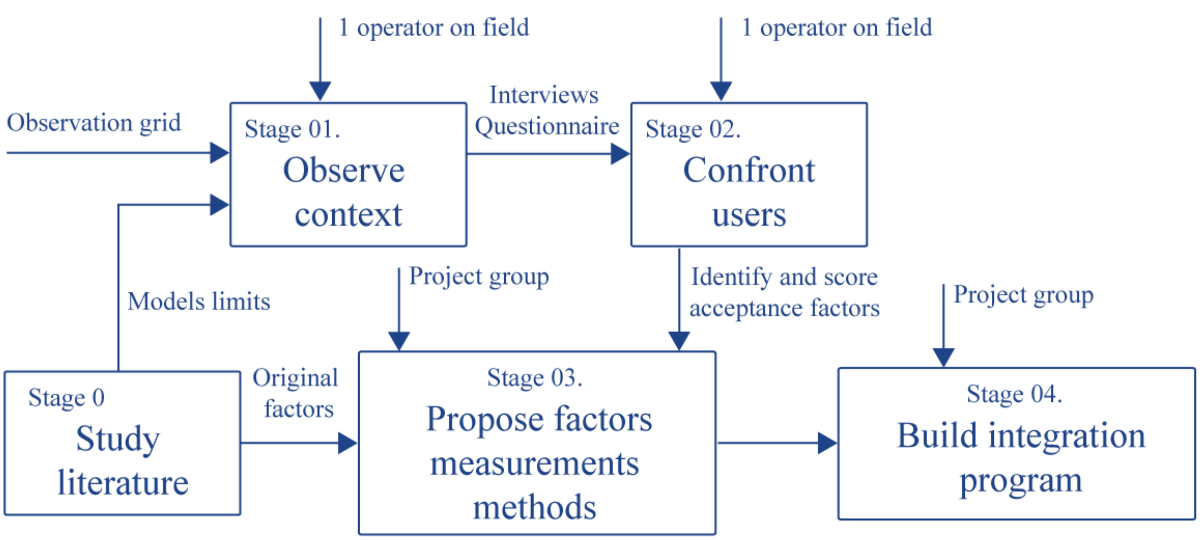
Figure 5. Operator is manipulating the polishing system to learn the window to polish

V. ACCEPTANCE OF THE SYSTEM

During the study of the acceptance, the operator is aisle from the project team and training is performed by the responsible of the project. It includes a presentation of the cobot system, some trials with the force control to manipulate the cobot by hand and a presentation of the interface developed for this application. The Interface Human Machine integrates a common interface "Universal Robot" including a "play" button allowing the launch of a dedicated program. Once the program is launched, pop-up windows asks for the parameters in terms of disc diameter, % of coating surface, orientation of the window to polish (horizontal of vertical) and the learning of the first point and the second point (Fig. 5). The duration of the learning phases takes 1min 30. Once everything is recorded, the robot starts the polishing of the surface. The operator observes the robot and gives it feedback about the results. The project team does the same in order us to listen everybody on the topic. The methodology used for the acceptance follows 5 steps (Fig. 6):

1. Study of the literature on technology acceptance and gather factor hypothesis.
2. Observe and analyze of the occupational context: we carried out an ergonomic occupational analysis and gathered insights of what could change with a cobot in this context. Based on observations, we built an interview grid to self confront operators on observations.
3. Identify subjective satisfaction criteria from operators: operators were asked to describe their tasks and describe the time, type of strain they encountered. Acceptability criteria are identified from open interview and scored by the distribution of 100 points among the criteria mentioned.
4. Propose factors measurements: from usability measurement literature, we assessed measurements methods. When no methods existed we used the previous observation and self-confrontation stages to assess relevant hypothesis.
5. Integrate factors in program: an industrial integration program was discussed and written with project group, detailed later.

Figure 6. Methodology applied to analyze the acceptance of the cobot and better integrate the system.



VI. RESULTS

5.1 Characterization of acceptance factors from the field

From open interview, the operator verbalized several notions related to acceptance. To the question 'what would be the necessary conditions for you to accept this new system on your daily life? The answers were related to the notion of Control (physical and perceptive): 'need to control the machine, move it freely' and 'feel you keep control on the work', 'I could teach him, it executes'. To Utility: 'has to release pain' and 'do the job'. To Usability: 'easy to use, to learn'. To Impact on work: 'it has to perform the same quality standards', 'cannot check on his work and redo the work'. The operator was cautious on how this new system could influence his maneuverability 'it is maybe not useful for all tasks so I need to be able to move it quickly and move around easily. Cables would be a problem.' Verbatims were rephrased into factors: Utility, Usability, Control/Appropriation and Occupational Impact. We merged them with selected factors from literature that are related to our context.

5.2 Factors of acceptance and measurements methods

From field study and literature analysis, we proposed to measure factors with both objective and subjective methods. The measurements of factors will be done in a further study. Table 1 shows factors and their related measurement methods.

5.3 A framework for a better industrial design

This user centered methodology emphasized needs that will be translated into design recommendations. For example: the need of 'feeling control' from perception will stress a specific attention to hands prehension and system maneuverability. New human gestures will have to stay as natural as possible to avoid new physiopathoganic postures. The physical interaction with this cobot (without optoforce) starts when 10N is detected. Moving it while carrying the digital tablet was difficult during a long period. It seemed obvious to install a handle with a button to be able to manipulate the cobot with 2 hands. Moreover, a support will be designed to carry the tablet. In this way, easy to use/learn will be answered by a smooth human interaction, balanced with preprogrammed actions but that will allow flexibility. These design criteria will be integrated in the new version of the system in order to better perform the task.

VII. CONCLUSION

This paper presents a user centered method to integrate a movable cobot for activities in naval industries. It allows the characterization of the process performed by the operator. Then, a methodology based on various step allows defining the human factors to take into account and the maturity to integrate the system inside the company. From this model we can build an integration protocol from familiarization to adoption that will suit the case study environment.

VIII. PERSPECTIVE

The perspectives are numerous as the integration inside the companies is soon. Some questionnaires are currently being prepared to evaluate via a quantitative study the desire for control [9], the attitude towards the robot [10] and other qualitative factors regarding the quality of the robot work. Once the robot will be operational, a new usability will be conducted to study the physical and cognitive interaction with the movable cobot to conclude if the cobot is well adapted to the tasks. This architecture seems to be promising for this application and the board management has high expectations in this solution.

IX. ACKNOLEDGEMENT

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Table 1. Factors and associated method to evaluation the perception of the movable cobot

Factor	Objective easure	Method	Subjective measure	Method
Affective aspects				
1. Subjective user Satisfaction			Verbatims, scoring factor categories with 100 points	Individual survey after test of minimum 15 min of work with cobot
Cognitive aspects				
2. Efficiency for quality standards	Control quality from workshop managers	Number of returns in workshop	Evaluation (scoring on Likert scale)	Individual survey after test
3. Ease of learning /memorizing	installation/ timings	Time the installation (adjustments included)	Evaluation (scoring on Likert scale)	Individual survey after familiarization class
4.Easy to use	Number complaints during tasks	number of complaints	Evaluation (scoring on Likert scale)	Individual survey after test of minimum 15 min of work with cobot
5. Control perception	Prehension behaviour with device	Cobot log records of prehension	Self confrontation (verbatims)	Individual survey after test of minimum 15 min of work with cobot
6. Cognitive Impacts (perceived exertion)	Perceived exertion	Perceived effort scale BORG CR10 with / without system	Borg Scale Self confrontation (verbatims)	Individual survey after test of minimum 15 min of work with cobot
Occupational aspects				
7. Utility/utility for all tasks	number of arm releasing	Observation and counting	Evaluation (scoring on Likert scale)	Individual survey after test of minimum 15 min of work with cobot
8. Safety/few errors	errors due to cobot	Counting errors due to cobot	Evaluation (scoring on Likert scale)	Individual survey, workshop chief follow up.
9. Occupational Impacts	Task duration	Time task duration with / without system After same familiarization class	Self confrontation (verbatims)	Individual questionnaire after use between 15 minutes to 2h.
Physical aspects				
10. Physical control	Number of adjustments during task	Counting number of touching needed.	Evaluation good prehension and manoeuvrability(scoring on Likert scale)	Individual survey after test of minimum 15 min of work with cobot
11. Physical impacts	Cardiac cost, posture analysis.	Cardiac cost protocole, posture observation method (Rula).	Evaluation (scoring on Likert scale), Self confrontation (verbatims)	Individual survey after test of minimum 15 min of work with cobot