DESIGN CRITERIA FOR A CONCEPTUAL END EFFECTOR FOR PHYSICAL HUMAN ROBOT PRODUCTION CELL

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Abstract: Speed, precision and repeatability are virtues of industrial robots which are relied on by manufacturing firms but also necessitates segregating them within controlled fenced areas. Therefore, industrial robots cannot cooperate with line workers in assembling task. With recent developments in robotics, new possibilities have emerged that can enable manufacturing firms to be flexible and cost effective. This paper presents preliminary results from investigations into the possibility of a man-machine production cell where plastic panels are assembled under the car. A conceptual man-machine collaborative production cell will be presented detailing characteristics required to ensure safety.

Keywords: Human-Robot Collaboration, Mixed-model assembly Line, Flexible Manufacturing.

1. INTRODUCTION

Technological advancements such as the introduction of lightweight materials (plastics, carbon fibre, aluminum etc.) have improved the efficiency and performance of cars. An example of light weight components are the plastic panels that are installed under the car to improve overall aerodynamic performance and fuel efficiency. Automotive companies predict an increase in the use of light weight components, which represents a considerable challenge in terms of manufacturing flexibility on a Mixed Model Assembly (MMA) as they must take into account an inrease in the number of variants (Diffner., 2011; Jonsson., 2013).

Automotive manufacturing facilities are loosely separated into two plants depending on the level of automation – a fully automated robot driven (Welding and Painting plants) and a hybrid final assembly plant (Figure 1) where line-workers are assisted by power-assist devices (Krüger, et al., 2006; Krüger, et al., 2009). Speed, precision, flexibility and repeatability are virtues of industrial robots which are highly valued by manufacturing firms, but their high inertia have the potential to be a major safety risk. Therefore robot workspaces are fenced (Svensk Standards, 2011), ensuring relative safety for the operator but limits possibilities for collaborative work between line-workers and robots.

Recently, there has been many technological advancement within the areas of hybrid robot control which aims to solve perceived issues associated with robot safety (Brogårdh, T,. 2007). A safe collaborative assembly cell, where line-operators and industrial robots collaborate to complete assembling tasks, is seen as an important technological solution for several reasons including

- Ability to adapt to market fluctuations and trends (Krüger, et al., 2009).
- Have the possibility to decrease takt time while maintaining ergonomic load (Öre F. et al, 2014).

The purpose of this paper is to investigate the possibility of an assembly cell, where an operator work alongside a robot (without safety fences) to collaboratively assemble underbody- plastic panels. As shown in Figure 1, the correct panels have to be secured on a moving assembly line where the car moves above the work cell.

Fig. 1. An ABB industrial robot welds Body in White parts (Volvo Cars 2014) which is a completely automated process in most car assembly plants (left). A line worker performing final assembly using a power assist device (right).

The research work which was done through a case study will be presented in this paper and is structured as follows: Section 2 will briefly discuss state of the art of collaborative robot and robotic systems; Section 3 will give an overview of the current assembly cell detailing requirements for a new collaborative assembly cell; Section 4 will describe the conceptual assembly cell as well as an end effector to be mounted on a test robot. The paper will conclude with a brief review of the results and a discussion of future work.

2. PRACTICAL HUMAN ROBOT COLLABORATION

Industrial robots are designed for speed, accuracy and repeatability and therefore are mechanically stiff with fast settling time (Siciliano, B., & Khatib, O., 2008). These robots are geared towards performance and efficiency, whereas collaborative robots need to be designed for safety as they function in close proximity to human beings. The following sections describes state of the art of robots and associated systems whose main purpose is to ensure safe collaborative environment.

2.1. Robot Safety Systems

Robotic systems refer to the equipment either on the end-effector or around the robot such as sensors, warning lights and safety switches. Sensors are intended to feed information to the controller, so that a correct course of action can be planned and executed by the robot. Researchers have different approaches for robot safety guided by the principle of avoiding impact, and more recently predicting impact by observing the environment (Morato C et al, 2014).

Intelligent robot motion is an actively studied area, where planning algorithms use sensor information (such as vision, proximity, radar etc.) to make the robot intrinsically safe. Research has been focussed on developing methods for obstacle avoidance, human and object pose detection and estimation, gesture recognition and pattern recognition (Chen et al (2006); Ellekilde et al (2009); Krüger, et al., 2009). This has resulted in industrial grade systems such as SafetyEye (Pilz, 2014), PickIt (Intermodalics, 2014) etc. that are ready for deployment on the manufacturing floor. Redundant sensor network is also considered an important criteria for a fault tolerant robotic system. There is ongoing research to develop robots that are physically safe regardless of the safety systems attached to it and will be described in the following section.

2.2. Safe Industrial Robots

The mechanical design of the robot can also contribute to a safe work environment. Research efforts include the following:

1. Develop robots with low inertia so as to minimize impact related injury. Barrett Technologies (WAM, 2014) have pioneered the idea of cable drives which makes the robot naturally back-drivable and is considered an important characteristic for safety. Another example is the light weight robot from DLR – the DLR LWR-III – which have a payload/weight ratio of one (Albu-Schäffer. et al, 2007). Other notable light weight robot manufacturers include Universal robots, Rethink Robotics, Kuka Robotics etc.

2. Multi-axis force and torque sensors installed on the joint allows for higher fidelity control of robot motion and its ability to respond to impact.
3. Clutches such as magneto-rheological (MR) clutches, installed between the motor and the joint allows fast decouple of their inertias upon impact (Yadmellat, P, et al 2013).

3. CASE STUDY

In order to investigate the possibilities of a man-machine collaborative assembly-cell, a research project titled ToMM (Collaborative Team of Man and Machine) was initiated with academic and industrial partners representing the Swedish automotive industry. A case based approach (Leedy, P. D., & Ormrod, J. E, 2005) was chosen to develop concepts for Human Robot Collaboration (HRC) and also to develop physical prototypes. During the case study semi-structured interviews were performed with engineers and operators at Volvo Cars (VCC). Furthermore, own observations were collected by working together with assembly line workers. The research project group representing engineers from three automotive companies has contributed with a wide range of needs identified during three different factory visits during the autumn/winter 2013/2014.

This section describes a work-cell at Volvo Cars assembly plant that was identified as a possible candidate for HRC. This section will also describe basic requirements that were identified via interviews and company visits.

3.1. Assembly-Cell Overview

To improve the overall aerodynamic performance and fuel efficiency of the car, plastic panels are installed under the car to allow smooth airflow. There are many variants and the correct panel has to be installed depending on the car. Currently, the Mixed Model Assembly process is done manually by the line worker and the plan-view of the assembly cell is shown in Figure 2. The assembling sequence can be fundamentally divided into two steps. 1. The process of manually securing the panels under the cars using clips. 2. Securing the panels with bolts using a power assist device (see Figure 1, (right)). The work procedure can be elaborated as follows:

1. The operator identifies the car on the assembly line by reading the information label.
2. Then the line worker proceeds to select the the correct plastic panel and installs clips onto the car-panel.
3. The operator picks up the plastic panel and place it under the car using previously installed clips.
4. The operator walks to the pneumatic screw driver (marked as blue circle), picks it up and walks and position herself under the car.
5. Finally, the operator manually secures approximately 8-10 bolts under the car.

3.2. Requirement specification

Spending time on the assembly line allows for direct contact with the various actors (line workers, managers, engineers) that contribute to the car assembling process. These visits contributed to understanding and formalizing basic requirements and can be formulated as follows:

1. VCC’s assembly plant expects to increase production rate from an average of 52 cars per hour to 65 (approx. 25%) without significant investments.
2. Flexible solutions that can accommodate a few variant should be prioritized.
3. VCC would like to reduce their dependency on pneumatic and hydraulic power as they have proven to be maintenance intensive. Therefore, electrically driven devices are preferred.
4. Proposals for new concepts should allow for minimal changes to the upstream & downstream assembly cells.
5. A light weight fixed robot could be specified that has a range comparable to that of a typical line worker (160-200 cm vertically calculated with the end effector).
6. The proposed solution should be safe for the line workers and should not distract or interfere with their tasks. Possible safety issues should be quantified and documented. It should also be possible to stop the robot in case of an emergency.
7. The current assembly cell was not considered to be stressful or injury prone. However, the interviewees agree that the bolt tightening operation were fairly monotonous and could be completed by a machine.

These requirements were used to develop the conceptual assembly cell – a space sharing system of man and machine (Krüger et al., (2009)) – which is presented in the following section.

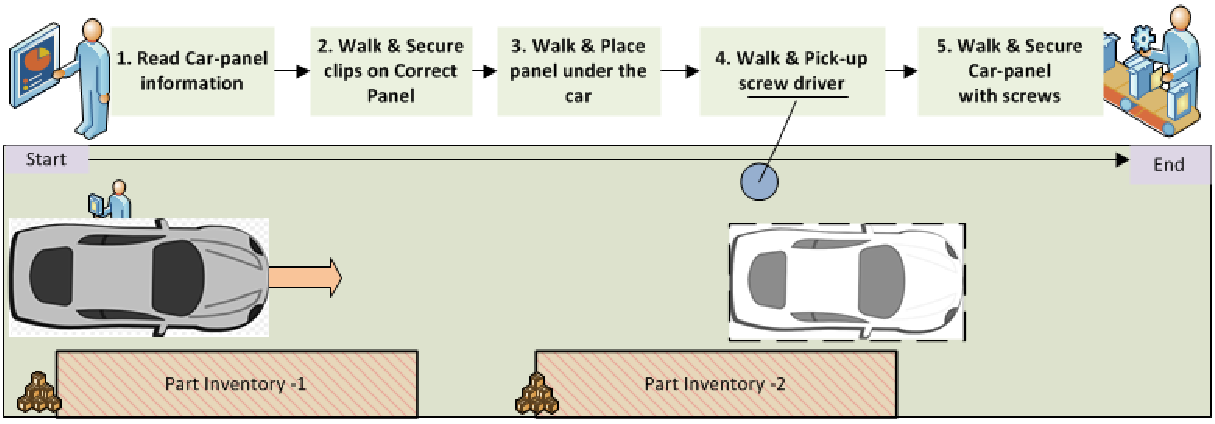

Fig. 2. Illustration of the current work process for the operator from reading information from the label to finishing assembly operation for one car.

4. PRELIMINARY RESULTS

The assembly process described in Figure 2 was used as a starting point to develop the conceptual assembly cell. The proposed assembly cell along with an end-effector – designed to be used in a collaborative environment – will be described in this section.

4.1. Conceptual Assembly Cell

Figure 3, illustrates the proposed collaborative assembly cell. Discussion with the line workers and managers have resulted in this work process where the operator will continue in securing car parts under the car while the robot will fasten the required number of bolts to secure it firmly.
The concept shows two cameras which view the workspace horizontally. Though it is more efficient to have a camera viewing vertically (from top to bottom), it is not feasible as the car moves on an overhanging line.

4.2. Conceptual End Effector

Traditionally, an end effector is a custom equipment, installed on a robots final link, and is designed to do a specific job. For an end effector to be installed on a robot working around humans, the following design criteria were specified: 1. The primary job of fastening screws. 2. The secondary function of interacting with the operators through physical or non physical devices. Figure 4 shows a digital rendering of the end effector's design and can be described as follows:

1. The magazine which can hold approximately 40 M5x25 bolts, was designed to automatically load the bolt through a spring loaded mechanism.
2. The indicator lights (red, orange and green) was installed to allow the nearby operators to understand the state of the robot. For example, red would indicate that the robot is working or going to move, orange could indicate that the magazine needs to be changed and green could indicate that it is okay to approach the robot.
3. The handle and the safety button (also known as the dead man's switch) was installed to take control of the robot in case of an emergency.
4. A commercial off-the-shelf electric powered fastener with a torque rating of 2-5Nm.

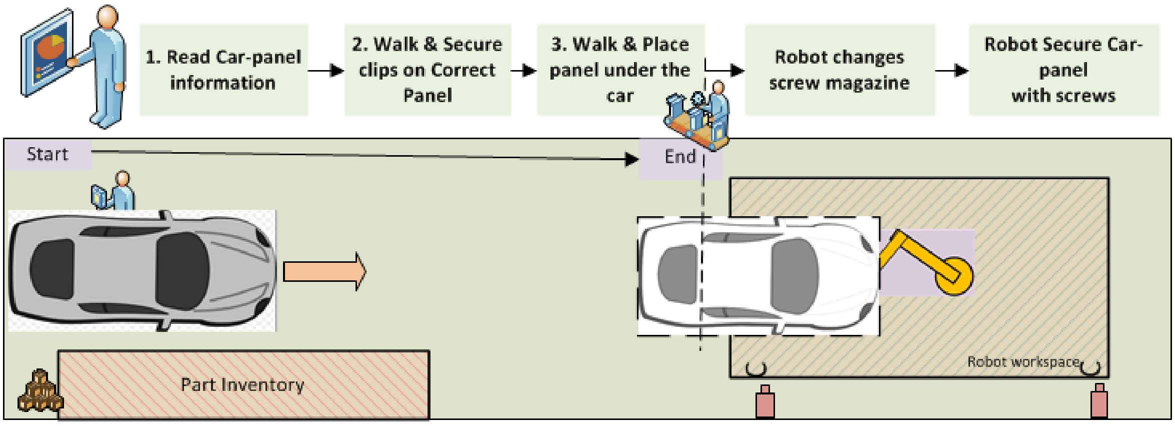

Fig. 3**.** Illustration of the concept work process for the operator from reading information to placing the car panel. The robot will secure the car panel with bolts.

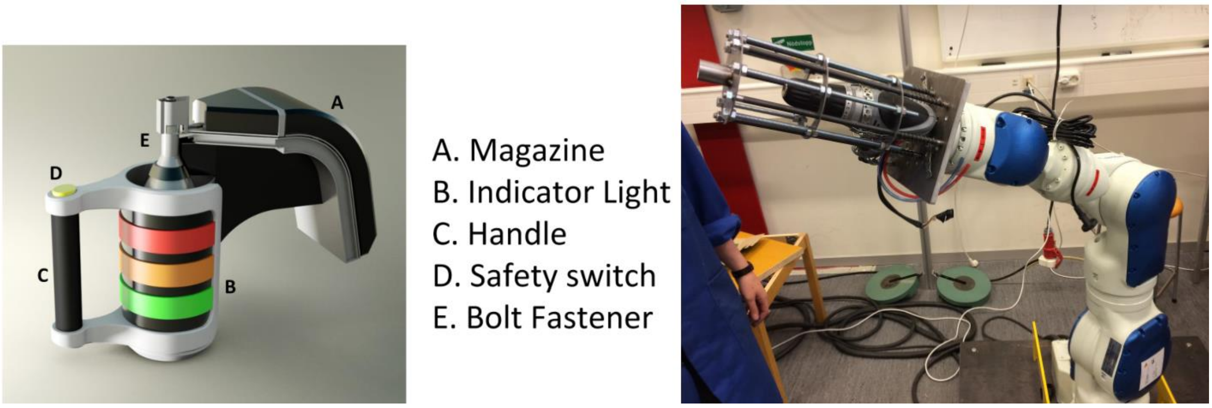

Fig. 4. Rendering of an automated bolt fastener (Left). The end effector mounted on a test robot – Yaskawa Motoman SIA20D (Right).

Figure 4 (right), shows the initial prototype of the nut runner mounted on the test robot which have a payload of 20 kg. The prototype weighs 14kg which includes the weight of the material mentioned in Figure 4, as well as the vertical forces generated during operation.

5. DISCUSSION

The main difference between the proposed assembly cell (Figure 3) and the current cell is the installation of a robot along with a camera system. The robotic system should have a vertical reach of approximately 160-200cm. The nature of collaboration in the proposed assembly cell can be described as a space sharing system (Krüger et al., (2009),) where the line worker and the robot share a common workspace i.e, the assembly cell. The assembly cell can further seperated into two workspaces 1. The operator workspace and 2. robot workspace. Figure 3, shows the robot workspace being monitored by cameras. Robot safety standards suggests that the movement be stopped if an operator enters its workspace.

There exist many industrial solutions for monitoring a work cell such as SafetyEye mentioned in Section 2. Workplace safety monitoring systems must be able to detect and classify moving objects as either the operator(s) or other devices that can exist in an unstructured environment. For these reasons, multiple vision based systems is proposed to monitor the assembly cell as it allows the robot programmer to plan robot motions which are safe for operators.

Safety is an important design criteria for collaborative robot cells. However, it is important to ensure the robot will be able to complete assembly tasks. Therefore, warning lights have been installed on the end effector to notify the operator about the state of the robot (Section 4). The design thinking was to limit operators walking into the robot workspace and thereby stopping or slowing down the robot. Hardware are prone to failure and researchers have highlighted the importance of redundant sensor networks in the development of fault-tolerant systems. The vision system with multiple cameras along with warning lights (and handle with kill switch) act as redundant source of sensory information for the controller.

Many researchers are working towards defining and understanding the nature of human interface devices such as warning lights or display screens, for industrial use. The effectiveness of these interterfaces could have direct correlation to safety. The human robot interfaces described in section 4 have been kept to a minimum. Optimal interfaces will depend on the final design of the end effector and should not compete for attention of the line-worker i.e there should not be many sources of information for the operator to react upon during emergency.

On a assembly line, assist-devices are custom machines used to support assembly operations. However, industrial robots can be programmed to do different tasks such as assembly operations or material handling depending on the end effector installed on the robot. Therfore, they are generally viewed as a more flexible solution. The task of screwing M5 bolts does not require high precision robots that are common in the industry today. Light weight robots from Universal Robots or Kuka Robotics could serve these purposes better.

6. CONCLUSION

Advances in robot technology continues to find new application areas for both industrial as well as service robots. This paper describes an assembly cell in an automotive plant and proposes a concept where a line worker and an industrial robot perform parallel tasks i.e A Collaborative Workspace. Furthermore, an end effector was designed to be used in a collaborative environment and prototyped with the aim of securing bolts under the car, have been described in detail. The design of the end effector were guided by two objectives: Safety of the assembly line workers and Performance of the assembly cell with respect to production rate. These contradicting objectives will be further researched within the ToMM project. Also, preliminary work is underway to understand the nature of assembly stations that would benefit from human-robot collaboration.

ACKNOWLEDGEMENT

This work has been primarily funded by Vinnova and the authors would like to thank them for the financial support. The authors would also like to thank ToMM project members for their valuable input and suggestions. The author would also like thank students of the following two courses given at Linköping university during Spring 2014.

1. TMKT68– Jan-Erik Runge, Frida Christensen, Elin Gawell, Erik Åström, Julia Jakobsson, Ellinor Hjelm and Gustaf Sjöstrand.
2. TMKT69– David Stomilovic, Fredrick Högborg, Jonas Arkman, Per Axelsson and Viktor Sundh.

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