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HUMAN SAFETY IN ROBOT APPLICATIONS – REVIEW OF SAFETY TRENDS

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ABSTRACT: Interaction between humans and robots was always having great attention, as robots should never hurt human beings. With technological development the totally separated operation of robots is being changed to closer cooperation. Industrial robots now can detect humans in their work-envelope and reduce their speed according to the motion of the human. This is a radical change to the previously in-fenced and no human in work-envelope concept. This paper is investigating today's policy and standards in human - robot interaction along with solutions for security of production cells. An example demo setup will also be shown, where the utilization of the newest technologies is emphasized. The paper also deals with introduction of high level control of security through simulation software.
KEYWORDS: Robot Safety, VALIP, Flexible Robotic Cell, Safeguards

INTRODUCTION

It has been said that the only constant in life is change. The ever changing field of robotic engineering and robot application is gaining new followers each day. In accordance to this, the safety standards and trends must be continuously updated and revised.

From the first robot idea to modern robot systems, two fundamental robot attributes are: the power to handle super-human payloads and the flexibility enabled by full range of motion. And exactly these main attributes pose a danger to people working with them. At first, robots were caged up, distancing the robot from the operator to prevent injuries. If the operator needed to interface with the robot – to load or unload parts within the machine's work area– the safety control system would need to help to confirm that the robot was in a safe state. This often meant full stop for the robot and cutting its power source, resulting in reduced productivity.

New software-based safety systems slow down a robot to a safe speed or direct robot's motion to a safe position, allowing people to share the same workspace with far less risk of injury. New technologies require, so called "collaborative robots", allowing the robot and the people to share the same workspace and work side-by-side. In accordance to this, safety solutions and standards must follow these upturns.

The organization of the paper is as follows: section 2provides a brief overview of the main characteristics of the most commonly used protective devices in robotic cells. Section 3presents most important standards relevant to designing the safety solution for robotic cell. Section 4 shows the practical use of previous two sections while designing flexible robotic cell at Narvik University College. Section 5 explains the integration of safety with VALIP system while section 6 concludes the paper.

SAFETY SOLUTIONS

Depending on the purpose of the robot system, there is a broad range of safety solutions. Within this paper we will retain focus on safety requirements for small robotic cells, as well as using robots in educational purposes.

The choice of selecting the best safety solution depends on the specific job that the robot is performing, the working area and the possibility of injuries for the people. The best choice for protective measure is a device or a system that provides maximum protection with the minimum impact on normal machine operation.

Safety-rated programmable logic controllers (PLCs) play a crucial role in a robotic work cells. They collect input data from sensors about a status of a person within the robot work space, as well as inputs from safety devices such as e-stops, pendants, sensors and interlock switches. PLC outputs help control the robot power circuit, robot servos, as well as any other devices within the cell.

Physical protection - guards

If the robot is performing a task that does not need human interference, the best solution is to use this form of protection. The good aspect of using physical protection is distancing the operator from the hazard and protection from flying objects.

The guards often have a door with interlock switch fitted to the guard door. While the door is open, the robot is not moving. The operating process starts once the doors are closed and locked. If the doors are opened during the operating process of the robot, robot stops, and to have it started again, it is needed *to press the reset button. This button is located outside the protected area to prevent trapping the personnel inside the robot working area.*

Figure 1 shows robotic cell safeguarded by guards, safety mats and light curtains.

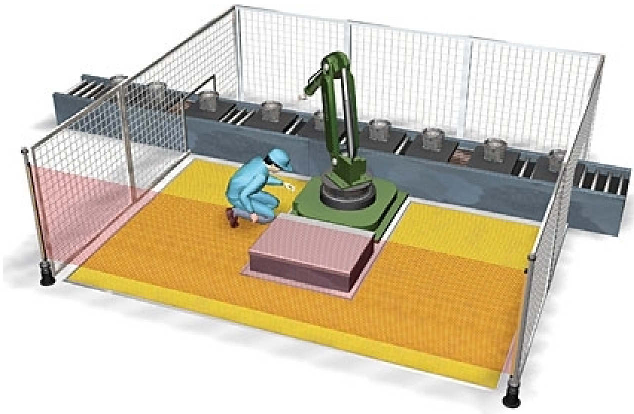

Fig. 1. Example of the robotic cell [9]

Optical protection

This form of protection is suitable when objects are to be passed in and out of the risk area, without stopping the industrial process. The main advantage of optical protection is the overall visibility of the robot and the working process.

- ***Laser scanners***

Safety laser scanners use pulses of light complemented with rotation mirror that deflects light pulses over an arc, thus creating a plane of detection. These scanners are based on the principle of "time-of-flight" measurement. The scanner emits very short pulses of light and at the same time an electronic stopwatch is started. If the light strikes an object, it is reflected and received by the safety laser scanner. The safety laser scanner calculates the distance to the object based on the time between sending and reception of the pulse.

Laser scanners create two zones: 1) a warning zone and 2) a safety zone (fig. 2). The warning zone provides a signal that does not shut down the hazard but informs personnel that they are approaching the safety zone, by optical or soundalarm. Objects entering or detected inside the safety zone cause the laser scanner to initiate a machine stop signal.

The main advantage of the laser scanners over horizontal light curtains or mats is the ability to reconfigure the scanning area. The shape and the size of the protected area is configured by corresponding software and downloaded to the scanner. They can also be programmed to accept specific intrusions that meet a certain shape profile, using additional sensors. Laser scanners support multi-zone safeguarding, where the overall scanning range of one device is divided in max 4 zones, with each zone supporting a warning and safety zone. They can be mounted either horizontally or vertically.

Disadvantage of the laser scanners is slower response time and lower level of resolution compared to light curtains.

- ***Camera systems***

Safety camera systems are electro-sensitive protective devices that use image processing technology to detect intrusion into hazardous area. These cameras can be used to monitor rectangular horizontal or vertical planes of nearly any size. When the camera detects intrusion, it sends a signal to the safety controller. They can be used for hand or body detection.

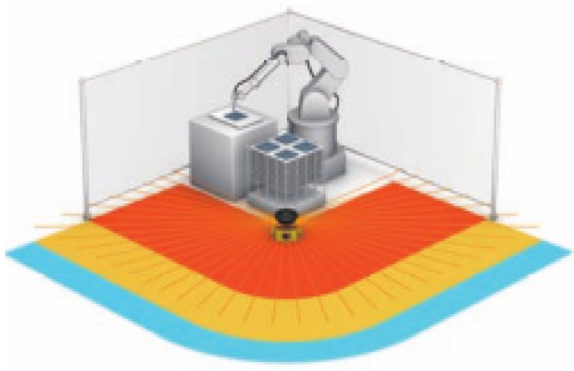

Fig. 2. Laser scanner [9]

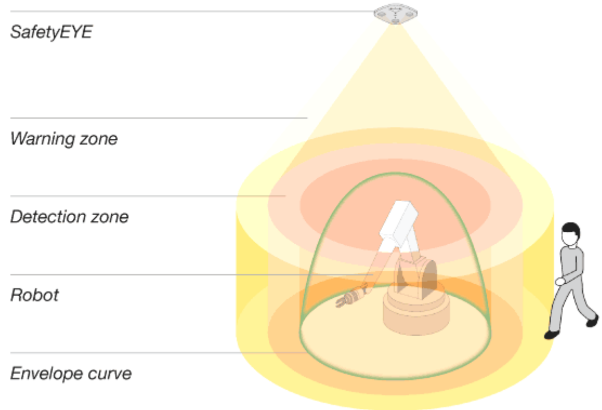

Fig. 3. Safety camera [13]

- ***Light curtains***

Light curtains are most simply described as photoelectric presence sensors. They must be placed at such distance to prevent the user from reaching the hazardous area before the danger is eliminated.

Safety light curtains consist of emitter and receiver pair that creates a multi-beam barrier of infrared light in front of, or around, a robotic cell (fig. 4). To eliminate susceptibility to interference from other opto-electronic devices, the LEDs in the emitter are pulsed at a specific rate, with each LED pulsed sequentially so that an emitter can only affect the specific receiver associated with it.

The working process is compound of scans, where every beam is checked. When any of the beams get blocked, the light curtain control circuit turns its output signal off. The output signal is used to control the hazard, whether to reduce robot speed or to stop it completely. In case of the failure of one of the components of the light curtain, the output signal is sent to stop the robot movement and to the control unit.

Light curtains are often integrated into the safety system by connecting them to the safety PLC. In that case the PLC handles switching the loads, the start/restart interlock and external device monitoring.

One of the important criteria when selecting a light curtain is the resolution. Resolution is the theoretical maximum size that an object must have to always trigger the light curtain. Most frequently used resolutions are:

- *14mm - commonly used for finger detection*
- *30mm - used for hand detection*
- *50mm to 70mm – commonly used for limb detection*
- *>70mm – larger values are used for full body detection.*

Important advantage of the light curtains is function for blanking and muting of the beams. Blanking function allows few of the beams to be disabled to accommodate objects typically associated with the process. These objects must be ignored by the light curtain, while the light curtain still provides detection of the operator. There are two types of blanking:

- *Fixed blanking-used for blanking the portion of the light curtain because of the machine fixture, work piece or the conveyor. This function requires for the object to be in the specific area at all times. If any of the beams programmed as "blanked" are not blocked, a stop signal is sent to the machine;*
- *Floated blanking – this option allows an object to penetrate the sensing field at any point without stopping the machine. This is accomplished by disabling up to two beams anywhere within the sensing field of the curtain. The number of blanked beams depends on the resolution of the light curtain.*

Muting function allows for the beams to be blocked for a programmed period of time. This is often used for loading/unloading the cells. To use this function the curtains must be equipped with horizontally positioned sensors to detect the object entering the robotic cell. After receiving signal from the sensors, the beams are blocked for a programmed period of time. After this time has passed the protection is turned on again.

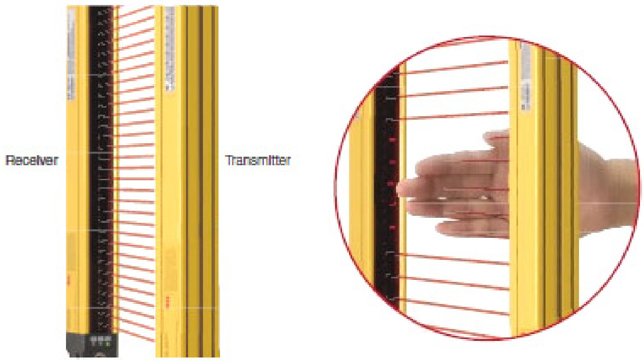

Fig. 4. Light curtain [9]

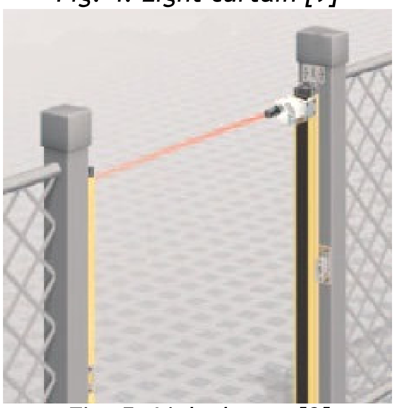

Fig. 5. Light beam [9]

Light curtains can be mounted horizontally or vertically, depending on the type of the protection needed. Also, the important advantage of the light curtains is the use of mirrors. Mirrors are used to deflect the beams, guarding two sides of a robotic cell with one pair of the light curtains. It has to be emphasized that the use of two or more mirrors is not recommendable because of signal loss and difficulties in the alignment of the beams.

- ***Light beams***

Light beams are photoelectric presence sensors, used for long scanning range. Theycan be designed with a single beam or with multiple beams barrier. Light beams are mainly used to detect personnel or objects entering the robotic cell. If the beam is blocked, the stop signal is sent to the robot.

The main difference between multiple light beams and light curtains is the resolution. Multiple light beams have a minimum resolution of 150mm and are used for long scanning range, up to 70m.

Mirrors can also be used to deflect the beams, thus simplifying the overall layout of the cell.

Safety mats

Presence sensing mats and controls are used where perimeter access guarding of a smaller area is required. Less downtime occurs because it is not necessary to set up or remove mechanical safety barriers during operation and maintenance. Multiple safety mats can be wired in series to form a complete floor-level guarding system. A signal is transmitted through the upper and lower plates separately via two wires connected to each plate. The signals through the safety mats are monitored by a controller. When the sufficient pressure is applied to the active mat area, the conductive plates touch causing the output relays in the controllers to de-energize and a stop signal is issued to the machine. If the wire should brake, or be at any way disconnected from the controller, or should the safety mat be punctured, the stop signal will be sent. The controller will not restart until the malfunction is removed.

Safety mats are completely sealed thus liquids presents no danger to the safeguarding of the cell.

SECURITY STANDARDS

In order for a machine to be made safe it is necessary to assess the risk that can result from its use. Risk assessment and risk reduction are described in EN ISO 12100:2010 and ISO/TR 14121. Note that the significance of a hazard depends upon both damage and probability of occurence.

When a risk assessment shows that a machine or process carries a risk of injury, the hazard must be eliminated or contained. In basic terms this means preventing any access to the relevant parts while they are in a dangerous condition. To achieve this, we can choose either: preventing access during dangerous motion or preventing dangerous motion during access.

Two main standards that deal with this question are EN ISO 13855:2010 and EN ISO 13857:2008.

EN ISO 13855:2010 deals with positioning of safeguards with respect to the approach speeds of parts of the human body. The position of the *safeguard depends on calculated minimum distance. Minimum distance is defined as calculated distance between the safeguard and the hazard zone necessary to prevent a person or part of a person reaching the hazard zone before the termination of the hazardous machine function [2]. One of the main aspects for calculating the minimum distance between robot and safeguard is the overall system stopping time. This time consists of two components:*

- *Maximum time between the occurrence of the actuation of the safeguard and the output signal achieving the OFF-state*
- *Maximum time required to terminate the hazardous machine function after the signal from the safeguard achieves the OFF-state. The response time of the control system of the machine shall be included in this component.*

General equation for calculating minimum distance to the hazard:

$$S = (K \cdot T) + C$$

where:
S is the minimum distance, in millimetres (mm);
K is a parameter, in millimetres per second (mm/s), derived from data on approach speeds of the body or parts of the body whose value depends on the resolution of the safeguard;
T is the overall system stopping performance, in seconds (s);
C is the intrusion distance, in millimetres (mm), and depends on the resolution of the safeguard.

There are also specific requirements for the orthogonal approach to the detection zone, parallel approach, and also arrangements for angled approach or for the approach where the path from the detection zone to the hazard zone is restricted by the obstacles.

The minimum distance value obtained this way should be measured from the robots most extended position, maximum arm reach.

This standard also addresses the calculation of the minimum distance requirement for preventing circumventing of the protective equipment by reaching over the safeguard.

$$S = (K \cdot T) + C_{RO}$$

where:
CRO is additional distance which a part of the body can be moving towards the hazard zone prior to the actuation of the safeguard (values are listed in the standard).

EN ISO 13857:2008 standard defines the safety distances to prevent hazard zones being reaches by upper and lower limb. The calculation of the distance depends on the risk assessment by ISO 12100 and ISO 14121, whether the risk is low or high, on the height of the hazard zone and height of the protective structure. After collecting this information, standard offers values of different safety distances in the table.

The important question that has to be answered is if the person can be between the safeguard and the hazard. If this is possible the reset switches should be positioned outside the hazard zone. In this case the operator has to be outside of the hazard zone to reset the protection.

ROBOTIC CELL AT NARVIK UNIVERSITY COLLEGE

Utilization of these standards and above mentioned safety technologies will be reflected in the design of flexible robotic cell in the laboratory at Narvik University College.

Laboratory at NUC consists of three robots:

- *KUKA K30-3*
- *ABB FlexPicker IRB340*
- *ABB IRB 1500*

For designing the robotic cell, primary task was to define work assignment for the robots which will include synchronized operation for all three robots. The assignment consists of the following (fig. 6):

- *KUKA robot will be placing plates on one of the conveyors*
- *ABB IRB 1500 robot will be placing small part on the other conveyor*
- *ABB FlexPicker will place the parts on the plate in a specified pattern.*

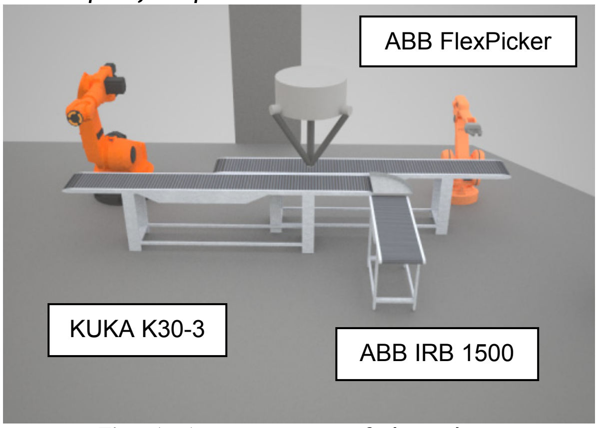

Fig. 6. Arrangement of the robots

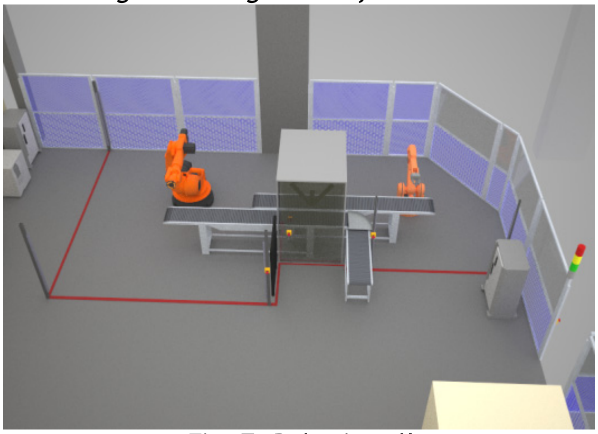
Fig. 7. Robotic cell

After a few versions of the robotic cell, the final decision about safeguards involves using partly physical and partly optical fence. The reason why the fully physical fence was not used primary lies in the function of these robots. Robots will be used for educational purposes, so the programming of the robot and the robot movement and task execution should be easily seen. The reason why the full optical fence is not used is simply the cost of these devices. With this solution, robot movement can be monitored with the operator standing at the safety distance. Figure 7 shows the final layout of the cell.

The robotic cell is surrounded by physical fence, with a door containing a lock to prevent unauthorized access. ABB FlexPicker has its own housing due to its construction. The ABB IRB 1500 robot is protected by *one pair of the light curtains with hand detection resolution. KUKA robot is protected by one pair of light curtains with a deflecting mirror on the corner. Emergency stops are placed at the entrance of the cell and at the main points near the robots.*

In the process of designing this robotic cell, the distances between the robot and the guards are calculated according to the standard ISO 13855:2010.

The robotic cell will be monitored and controlled by safety PLC. It will be possible to give command to the PLC through specially designed user interface. This interface will be installed on one of the computers in the laboratory. Next section explains the operating principles of this interface.

INTEGRATION WITH VALIP

VALIP is an acronym which stands for Virtual Joint Laboratory for Advanced ICT (Information and Communication Technology) in Production. It represents a virtual copy of the real environment, e.g. laboratory or production environment with machines, robots and industrial equipment, allowing the collaborators to remotely access the resources that would otherwise be unavailable to them [1].

The important part of this virtual reality is the safety of the robots, equipment and personnel. If the operator from e.g. Banja Luka is using VALIP to remotely access robots in Narvik, he will see the robotic cell in virtual reality, but cannot be aware of every angle and every danger that can happen as he is using virtual reality and cameras have blind spots. For that reason, integration of safety is important part of VALIP. This is a new born idea, and will first be integrated with robotic cell in Narvik.

The primary idea is to have a program that will communicate with safety PLC on one side, and virtual reality generator on other side. This program will represent one of the main components in VALIP system.

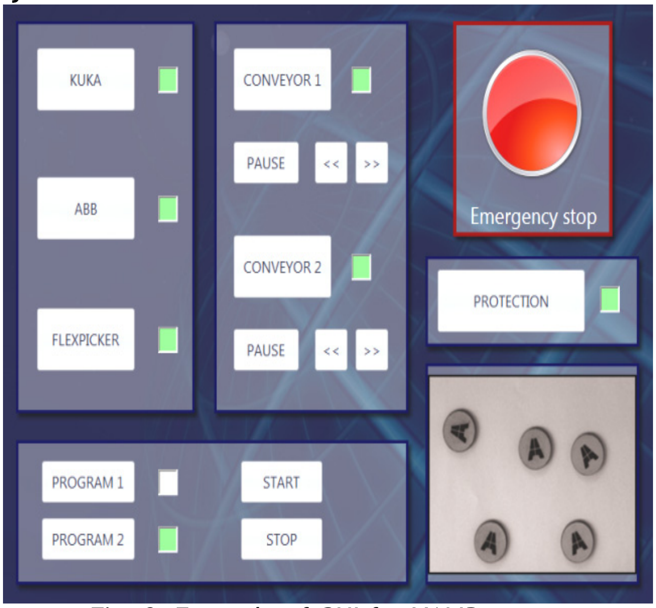

Fig. 8. Example of GUI for VALIP system

When the safety light beams are blocked, PLC will stop the robot and send a signal to designated component in VALIP system which will further inform the whole system about the new state of the cell. Virtual reality generator will reflect this information to visual presentation of the cell.

The reverse communication will also be possible. Person who is remotely operating the cell will be able to send commands to the PLC to power the robots or the conveyors, through user interface rendered in virtual reality.

This way the operator has a complete understanding of the robotic cell, movement of the robot and its safety. The visualization of this program is represented in the next figure.

CONCLUSIONS

Human safety in robotic cells is one of the most important aspects when it comes to designing the robotic cell. The market today offers a broad range of security equipment and solutions. The final choice depends on the specific robot task, the robot surroundings and the level of human interference. Above mentioned standards should be consulted when designing the robotic cell and choosing the safeguard for the maximum protection.

Integration of security in VALIP system represents new concept of visualization of the robotic cell. As security is important part of robotic cell it also represent important part of virtual reality, to safeguard the robot, equipment and persons who might find themselves in the surroundings. It is also important for the remote operator to be aware of these facts and this is where this VALIP component has a primary role.

ACKNOWLEDGMENT

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