Automaatiopäivät[22] 2017 Seminar:
Safe collaboration of operators and industrial robots

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ABSTRACT

When a person enters the workspace of an automatically running robot, the traditional solution to ensure safety is to stop the robot by using protective stop or emergency stop. Protective stop and emergency stop cut the servo power, which is a foolproof way to stop the robot. However, restarting can be laborious, since it must be done outside of the robot workspace. In addition, stopping a full speed running robot takes time, since the breaking distance of the robot is quite long. Long stopping distance cause a long safety distance between a person and the robot. If the robot maximum speed can be reduced, the breaking distance and also required safety distance is decreased drastically. To have practical safety distances in robot cells, the robot speed must be reduced before there is a need to stop the robot. Monitored safety-rated stop allows quick and even automatic restart, but to ensure safety, stopping performance needs to be monitored adequately. Typical solution for monitoring the stopping performance is robot's safety controller. VTT has developed a dynamic safety system, which monitors the speed and separation between persons and the robot in order to keep the stopping distance of the robot small enough to avoid collisions. The dynamic safety system enables safe continuous working beside the robot, automated restarting after a stop and switching tasks of the robot according to human position. The collaborative operations described in standards allow also power and force limiting in small robots or controlling the motion manually i.e. hand guiding, enabling device or hold-to-run buttons.

1 INTRODUCTION

International safety requirements for industrial robots were published already 1992 (EN 775), which means that there is already a long tradition for safety requirements of the robots. The basic rule is that, the operator stays outside of the safeguarded area during automatic run, but during teaching, the operator may be beside a slow moving robot. The old standard does not mention collaboration of humans and robots, but the idea is to keep them separate. The current robot safety standards (ISO 10218-1:2011 and ISO 10218-2:2011) define collaboration modes of humans and robots/1/, /2/. The collaboration is defined more specifically in the first edition of “ISO/TS 15066 Robots and robotic devices — Collaborative robots” /4/. It was published at February 2016. The technical specification defines requirements, especially, to light-weight collaborative robots.

This paper is related to traditional industrial robots, which by applying additional safety means can have a collaborative mode. The idea of the presented dynamic industrial robot safety system is that the robot stops before it can hit a person. The new technologies enable flexible fenceless safety systems and dynamic safety regions alongside a host of other attractive features for human-robot co-operation. One challenge related modern industrial robots is that it takes long time and distance to stop a robot. Thirty years ago a typical maximum speed for a robot was 3 m/s and stopping distance was 40 cm for emergency stop and 90 cm for servo stop, which keeps the servo power on. Currently typical maximum speed for a robot is 5 m/s and also capacity and outreach are higher and then stopping distance (servo stop) can be 2 m. 2 meters is quite a long distance to stop a robot. This means almost half of the practical working area of the robot. Reasonable solution to reduce stopping distance is to reduce speed. For example, ABB IRB 4600, with 21.8 kg load and speed (TCP) 2500mm/s has stopping distance (servo stop) 65 cm, which is more convenient than 2 m. As the speed slows down the stopping distance drops dramatically. Emergency stop (and protective stop) is quicker than servo stop, since it initiates quick braking and cuts servo power. However, it does not provide quick start-up, which is required in human-robot collaboration. Servo stop or actually safety-rated monitored stop can provide also controlled braking without high deceleration, which could drop objects from the robot tool. Therefore, emergency stop is reserved only to emergency and failure situations. The main funder of the project is TEKES (the Finnish Funding Agency for Innovation).

2 COLLABORATIVE ROBOT WORKSPACE

The ISO 10218-1 and ISO 10218-2 standards are harmonized standards, which means that by following them the relevant requirements of the Machinery Directive are also fulfilled. The focus of the standards is on safety of industrial robots and robot systems. Collaborative robots are described more detailed in ISO/TS 15066.

Collaborative robot is defined in standard ISO 10218-2 as follows: Robot designed for direct interaction with a human within a defined collaborative workspace i.e. workspace within the safeguarded space where the robot and a human can perform tasks simultaneously during production operation /2/. Basically, the idea is that robot does not hurt a person and the means to protect a person are controlled force and speed, separation monitoring, hand-guiding and safety-rated monitored stop. **Figure 1** shows the means that can be applied in manual or collaborative operation. In emergency stop servo power is cut off, whereas in collaborative modes the servo power is on. This means that restarting is easier and can be automated if the risk assessment allows it. Collaborative modes cannot be realised with any robot with simple safety system, but it requires a specific robot and/or a safety system for separation and robot control. Typically, in automated mode protective stop is applied when a person enters the robot workspace. This means that servo power is off and restart is made outside of the robot workspace.

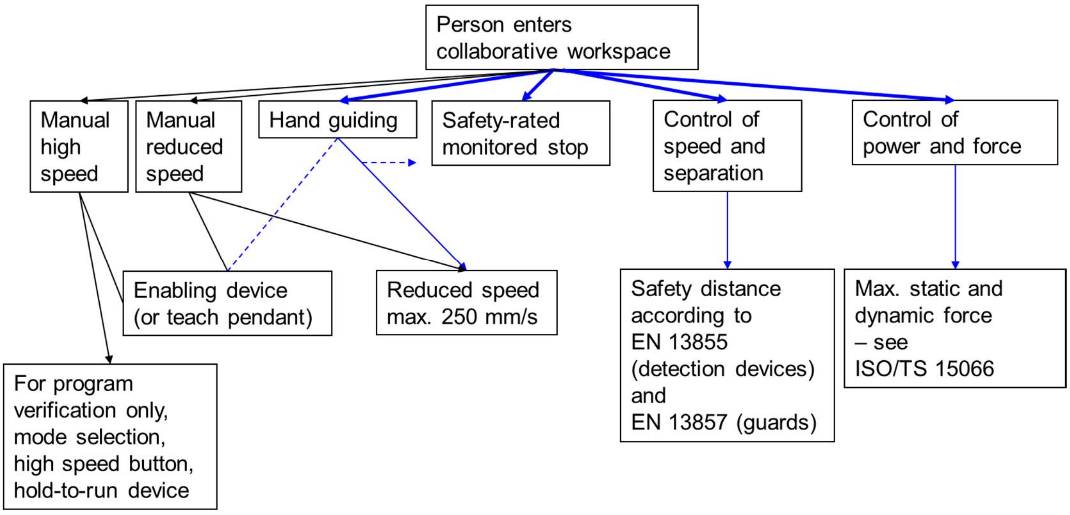

Figure 1. *Collaborative and manual modes applied in collaborative workspace.*

The standard specification ISO/TS 15066 allows an impact of a robot against a human being, if the force and pressure are limited. The standard defines the maxim forces and pressures (biomechanical limits) that may occur in collaborative mode. For example, maximum force against face in 65 N (pressure 110 N/cm2) and kneecap 220 N /4/. The maximum forces against other body parts are between those two values. This means that the risk assessor must estimate, which parts of the human body can be exposed to the force. The specification gives both maximum force and pressure limits and neither limits may be exceeded. Pressure value exceeds easily when the part touching a person is sharp or small. It is difficult say exactly, which force would be harmful to a person and therefore it is possible that values presented at the standard specification may change in the future.

3 DYNAMIC SAFETY SYSTEM

The aim has been to generate solutions that are built according to the current safety regulations. The target are bigger and traditional industrial robots. The aim has also been to enable well-functioning work processes. One of the key principles is to avoid unnecessary emergency and protective stops after human detection and to make the system restart easier. Several features of the suggested conceptual solutions have been demonstrated. A core demonstration has been an advanced safety arrangement to enable collaboration between human and large industrial robot in shared work space, where a human and a robot are working in the same system.

The system is detecting human motions by two separate systems. The primary system is based on Microsoft Kinect or any other human detection sensor and secondary system is based on an actual safety sensor. We used Microsoft Kinects, which are placed so that they cover needed approach area in front of the robot and they are used to detect worker's distance to danger zone of the robot. X- and Y-coordinates of the worker location are transferred to the master computer and predicted position of the worker is calculated based on the speed and direction of the worker.

Speed of the robot is reduced according to the predicted position of the worker. The speed can be altered according to workers distance to the TCP (Tool Center Position) or the distance to the closest danger zone border, where robot is allowed to move. When speed is reduced it is monitored with the safety controller and the robot safety area is reduced accordingly. Respectively, robot speed is increased according to the safety area. The correct safety area and speed are synchronized by the safety controller and safety PLC (if there is one). The secondary system, which applies only certified components, acts only, if the primary system fails. We can use either safety laser scanner or machine vision based safety system for human detection, safety PLC for synchronizing safety areas and speeds and safety controller for robot monitoring. **Figure 2** shows a typical configuration of the dynamic safety system. However, the devices may vary depending on the complexity of the needed safety system. The safety controller is a part of the safety system. It monitors that the set speed limit is not exceeded and that the robot stays at the defined work area. The robot safety controller does not control the position and speed of the robot according to the robot program, but according to predefined limits. Therefore, the safety does not depend on the program of the robot, but the defined limits of the safety controller. Also, the robot controller monitors the program performance and also it can stop the robot in case of a failure. The safety controller is separate from the robot controller and it cannot predict (there is currently one exception and in the future more) the next movements of the robot. The robot can exceed the limits, but this causes immediately protective stop. The exceeding of the limit should be counted to the safety distance /5/.

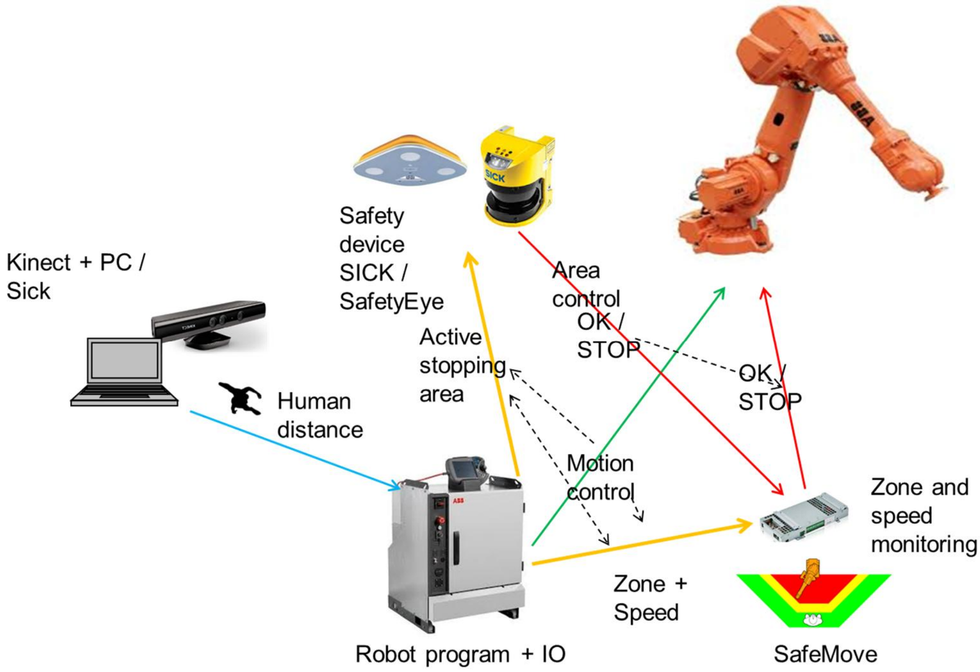

Figure 2*. Devices used at the dynamic safety system.*

The safety controller allows also the switch between different allowed work areas of the robot. This enables change to robot work flow, if a person is working at the area of next task. The robot work program must be made to support this feature. One feature is that the detection of the worker is shown via informative graphical display.

The safety philosophy of the dynamic safety system is that two (or more) safety cases are determined so that the safety level is similar to each other. The two opposite cases are large safety area and high speed or small safety area and slow speed. The non-safe device (Kinect) is applied only to choose the relevant safety case. If the safety case is wrong then either 1) Kinect fails to detect a person then the robot is stopped by the primary safety device (large safety area), or 2) Kinect detects a person continuously, because of a failure and only slow speed is applied. In both cases, the robot is functioning safely, but production is not practical and the failure can be revealed. The benefit is that when a person enters the robot working area, the robot is moving at the slow safety speed and the person can go safely near the robot according to pre-calculated safety distance. The safety distance depends (among others) on the speed of the robot. The robot is stopped (safety-rated monitored stop), if a person is approaching the distance required for stopping the robot. If a person rushes to the area and speed is not reduced adequately, a protective stop is triggered. Protective stop is initiated also, if there is an area behind the detection zone (e.g. on a table), where a person could hide without detection. Protective stop requires acknowledgement outside of the robot workspace. Safety controller is needed to verify the robot speed, TCP position (allowed area) and stopping performance. The primary safety device is needed to stop the robot according to the pre-defined safety distances. This safety philosophy makes it possible to work beside a robot safely without stopping the robot. **Figure 3** describes the function when a person is approaching the robot. **Figure 4** shows the relation between speed and stop area.

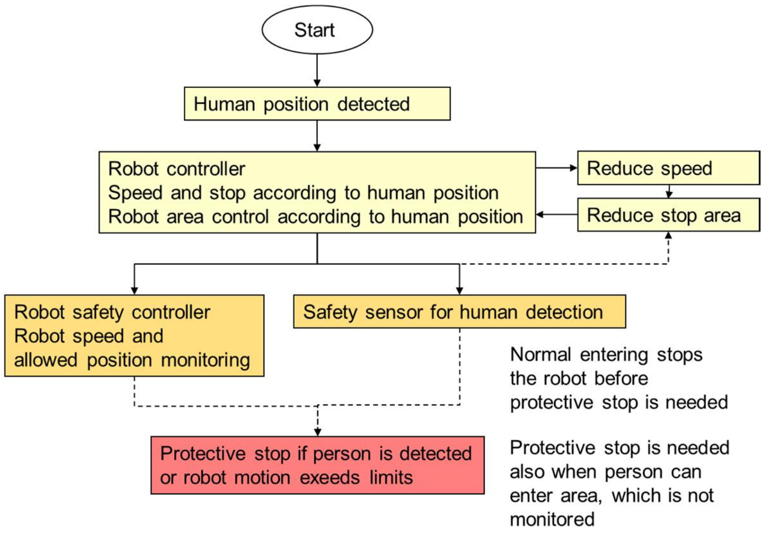

Figure 3*. The process how speed is reduced and safety-rated monitored stop applied before protective stop is triggered, if necessary.*

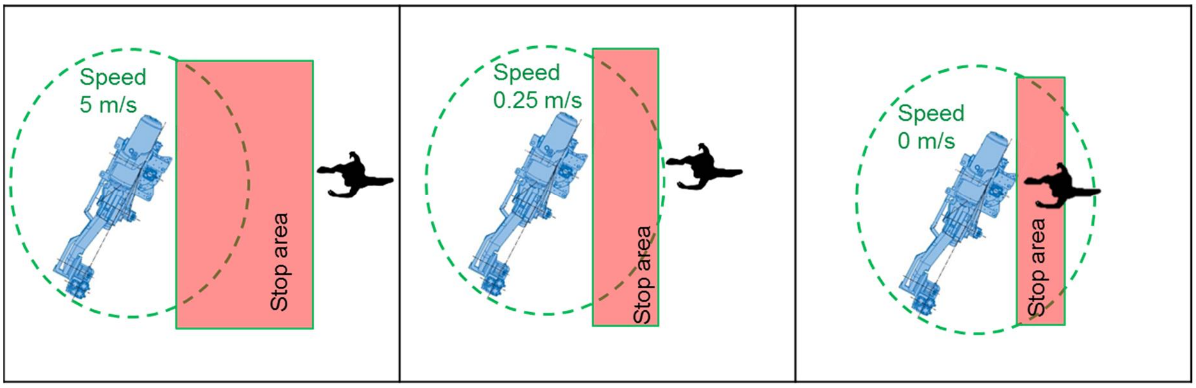

Figure 4*. Relation between speed and stop area. As a person gets closer to the robot, the speed and stop area are reduced.*

4 SAFETY CONFIGURATOR

The configuration of the dynamic safety system is complex procedure. For each case the robot's maximum speed, maximum workload and allowed work area has to be set. To facilitate this, a database of robot stopping distances in different speeds and workloads has been gathered. A tool based on this database has been created to aid in configuration of the dynamic safety system. In the software tool, the user can place different sensors and robots from the library to a layout representing the dynamic environment. The scanning areas of the sensors are shown with automatically generated safety areas. The safety areas are generated automatically against given robot speed and workload can be configured as needed. Several different safety configurations according to different parameters can be automatically generated and configured where (the parameter can be e.g. speed of the robot or worker locations beside the robot). Allowed robot work areas can also be defined. The configuring tool shows the needed separation distance thus all created configurations are according to the safety regulations. The tool can import and export safety configurations to some devices. The devices that cannot be accessed by the tool are configured manually by the instructions provided by the software tool. The tool also supports configuration of MS Kinect cameras of system described in previous chapter.

5 CONCLUSIONS

The dynamic safety system for robots is a versatile and complex system. Since it is versatile, several sensors can be added to the system and it can be seen, how well they cover the area to be monitored. For simple systems safety PLC is not always required, but safety controller and safety sensors are. Since the dynamic safety system is complex, it is difficult to configure it reliably manually. Therefore, the safety configurator is required. The dynamic safety system shows that, in the near future, safety systems for collaborative heavy industrial robots are rather complex. The strategies to ensure safety may depend on dynamic speed and separation control or control of speed, force and power or simple separation of persons and robots.

6 REFERENCES

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