Safe Human-Robot Cooperation with high payload robots in industrial applications
SAPARO

Deliverable 4.1 – Collaborative workspace hardware

Authors:

Christian Vogel

Jochen Vetter

Name of the Coordinating Person:

Dr. Norbert Elkmann

Institution of the Coordinating Person:

Fraunhofer Institute for Factory Operation and Automation, Sandtorstrasse 22, 39106 Magdeburg, German

1 Introduction

This document aims in presenting the current state of the working prototype. As this deliverable is defined as prototype the efforts and works are mainly presented as screenshots and pictures commented by short textual descriptions.

2 Task 2: Tactile floor development and adaption

This section will give a briefly overview of the work done in Task 2. The objective of this task was to design and develop the sensor system of the tactile floor. As specified in deliverable D1.1 the tactile floor covers an area of 4.0 by 6.0 meters. As seen in the following pictures the sensor system consists of single quadratic white tiles that include 4 by 4 sensor cells. The tiles can be easily interconnected by conductor band and allow a fast buildup of the entire floor. Altogether we needed 8 by 12 tiles to cover the entire area. In the following pictures the buildup of the tactile floor is illustrated.

Figure 1: Buildup of sensor system that consists of single quadratic tiles.

Figure 2: Buildup of sensor system that consists of single quadratic tiles.

Figure 3: Finished buildup and wiring of sensor system that consists of single quadratic tiles and conductor band.

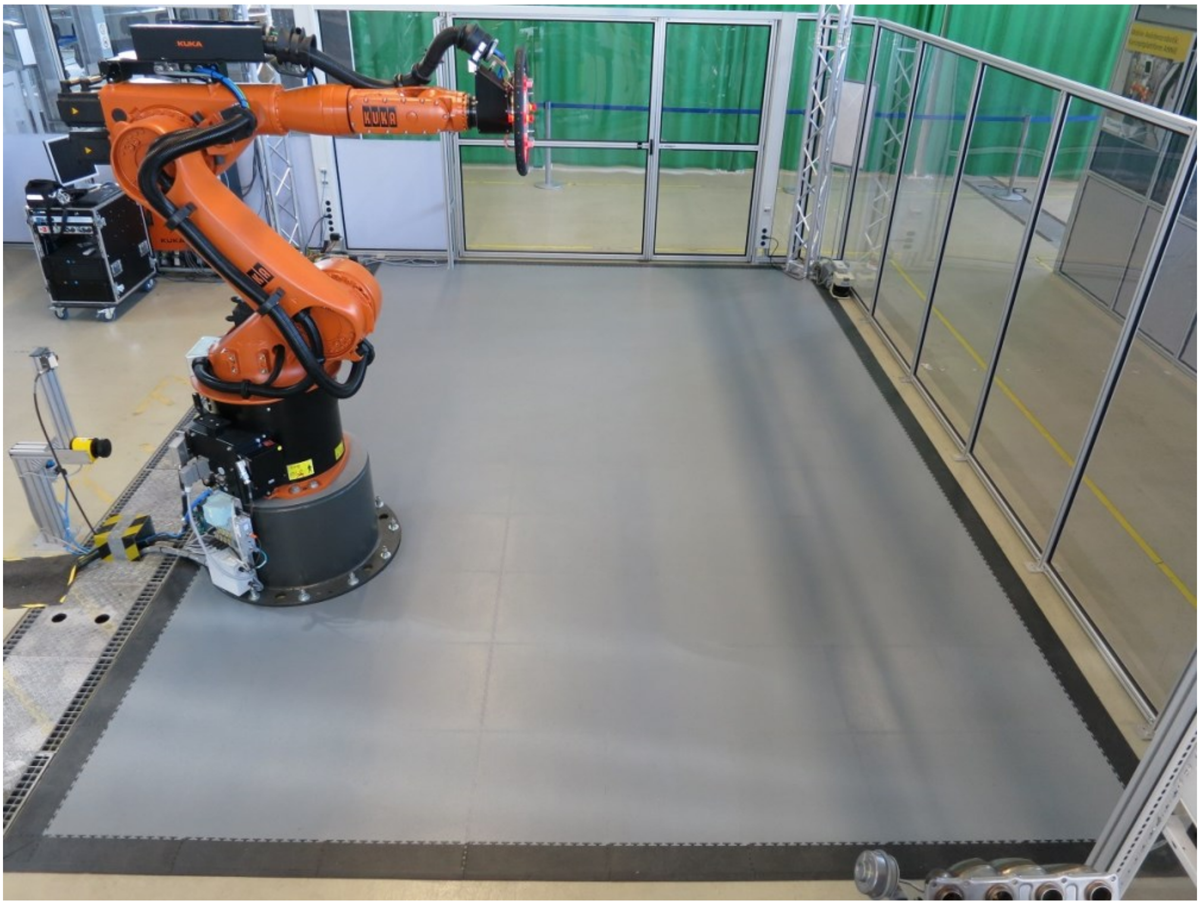

Figure 4: Finished buildup of tactile floor consisting of sensor system and covering by industrial mats.

In figure 1 to figure 3 the laying out and the wiring of the sensor system is shown. Figure 4 depicts the resulting tactile floor after the laying out of the covering that consists of single industrial mats as shown in figure 5, left. Furthermore, all sensor cells are connected to the controller board (see figure 5, right) that is responsible for measuring the sensor data and to provide them via USB for subsequent processing.

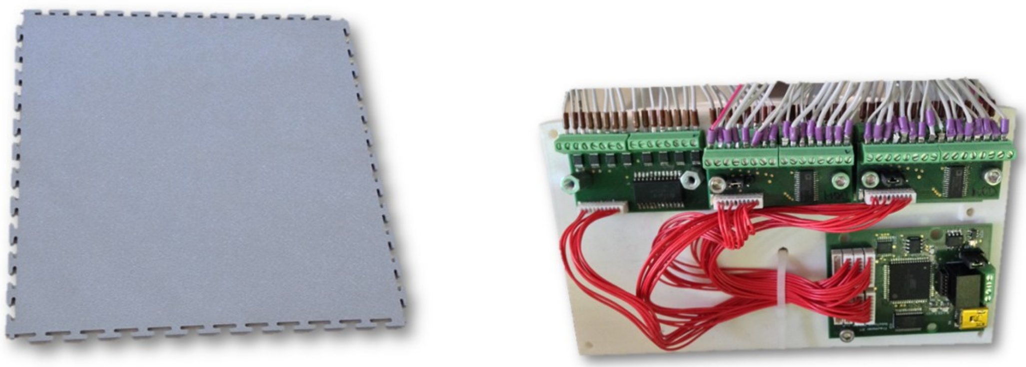

Figure 5: Industrial mat (left) used as covering for the tactile floor and controller board (right) to measure sensor data of the single sensor cells.

3 Task 3: Projection system development and adaption

This task deals with the design and development of the projection system. In deliverable D1.1 we described the requirements and further specified the projectors (Acer P5327W, see figure 6) used in the experiment. After adjusting the projector's optics to the projection distance, they were calibrated intrinsically. Here, the projectors are emitting a calibration pattern that consists of an aligned circle arrangement. This circle pattern has to be projected from various perspectives while a camera detects them from a defined position. For this, a camera was mounted on top of the system carrier to detect the projected circle patterns. For every projector perspective the extracted circle positions are recorded. To allow an easy reposition of the projector perspective the projector was mounted on the tool center point of the robot. Here, we implemented a robot program for moving the projector to 20 different positions. This allows a convenient calibration of all 4 projectors.

Figure 7 depicts the original camera image used to detect the circle pattern projected by a projector mounted on the tool-center-point of the robot. The extraction of the single circles of the projected calibration pattern is shown in figure 8. On basis of the image coordinates and the appropriate world coordinates of every single circle, the intrinsic parameters of the projector can be estimated.

Figure 6: Projection system consists of four Acer P5327W.

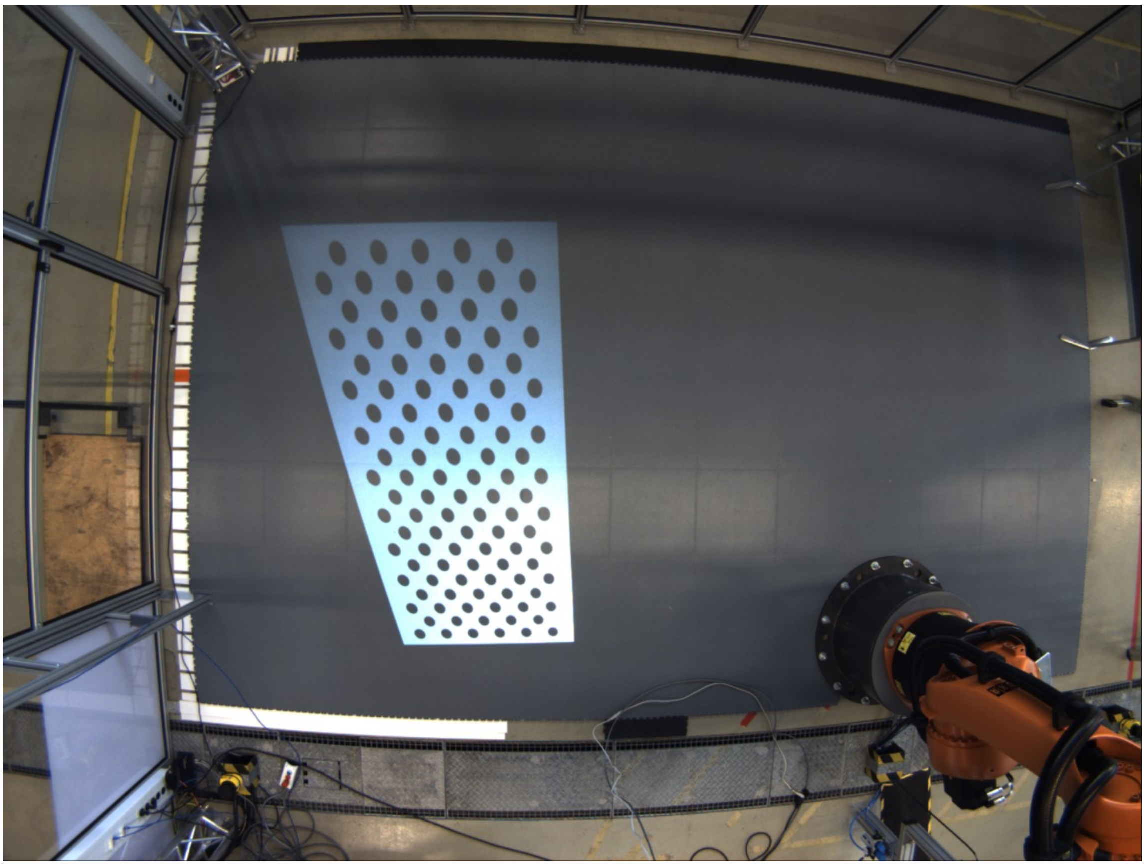

Figure 7: Image of the camera that was mounted on top of the system carrier. Projected circle pattern used to calibrate the projector intrinsically.

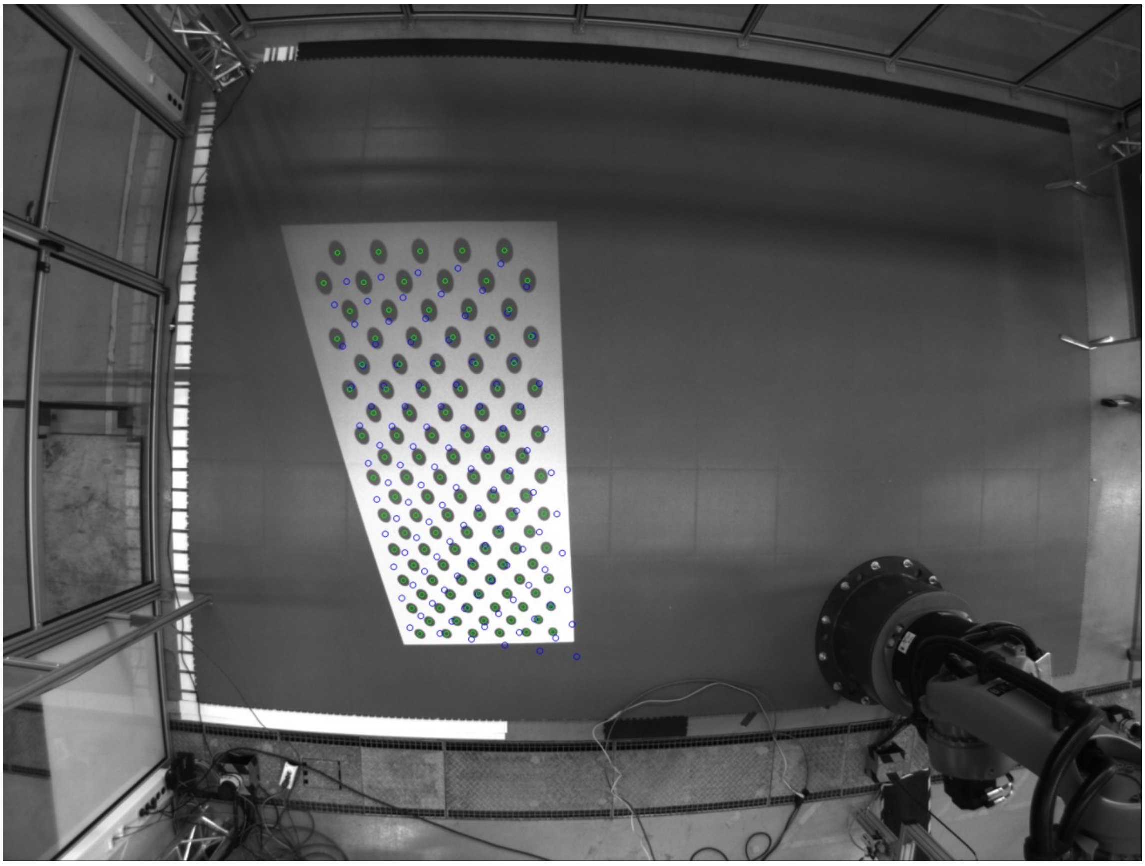

Figure 8: Camera image and marked circle pattern that was projected by one projector.

To illuminate the entire area of the tactile floor we equipped the system carrier with 4 projectors, as pictured in figure 9, figure 10 and figure 11. Here, we use additional round pipes with an adapter plate to mount and adjust them conveniently.

The projectors are connected to the computing hardware by HDMI cables. The graphics hardware (NVIDIA® NVS™ 510) used is capable of providing 4 time-synchronized images to the 4 projectors.

Figure 9: Projectors are mounted by an adapter plate and round pipes to the system carrier. The two projectors illuminate an area of 4.0 by 3.0 meters.

Figure 10: Positioning and adjustment of the four projectors.

Figure 11: System carrier with mounted projection system.

4 Task 4: System integration

The integration of all hardware and software components to a working complete system is the objective of Task 4. This mainly comprises the setup of the system carrier, robot system as well as the tactile floor and projection system. Besides the mechanical and electrical buildup the integration of software components and interfacing have to be accomplished in this task. Here, especially the calibration of all parts to a common coordinate frame is necessary. As the calibration of tactile floor and robot system was done by means of measurements, the calibration process for the projectors was more challenging. Here, we needed an additional camera that was temporarily mounted on top of the system carrier. The camera was calibrated by a common calibration sheet with respect to the specified world coordinate frame. After mounting and adjusting the projectors at the system carrier they were calibrated extrinsically by projecting a calibration pattern onto the tactile floor, as depicted in figure 12. The camera views and extracts the calibration pattern that was further processed to determine the projector's position. In figure 13, the estimated position of one projector is visualized by a light red frustum. As this procedure was executed for every projector, finally all projectors were calibrated with respect to the world coordinate frame.

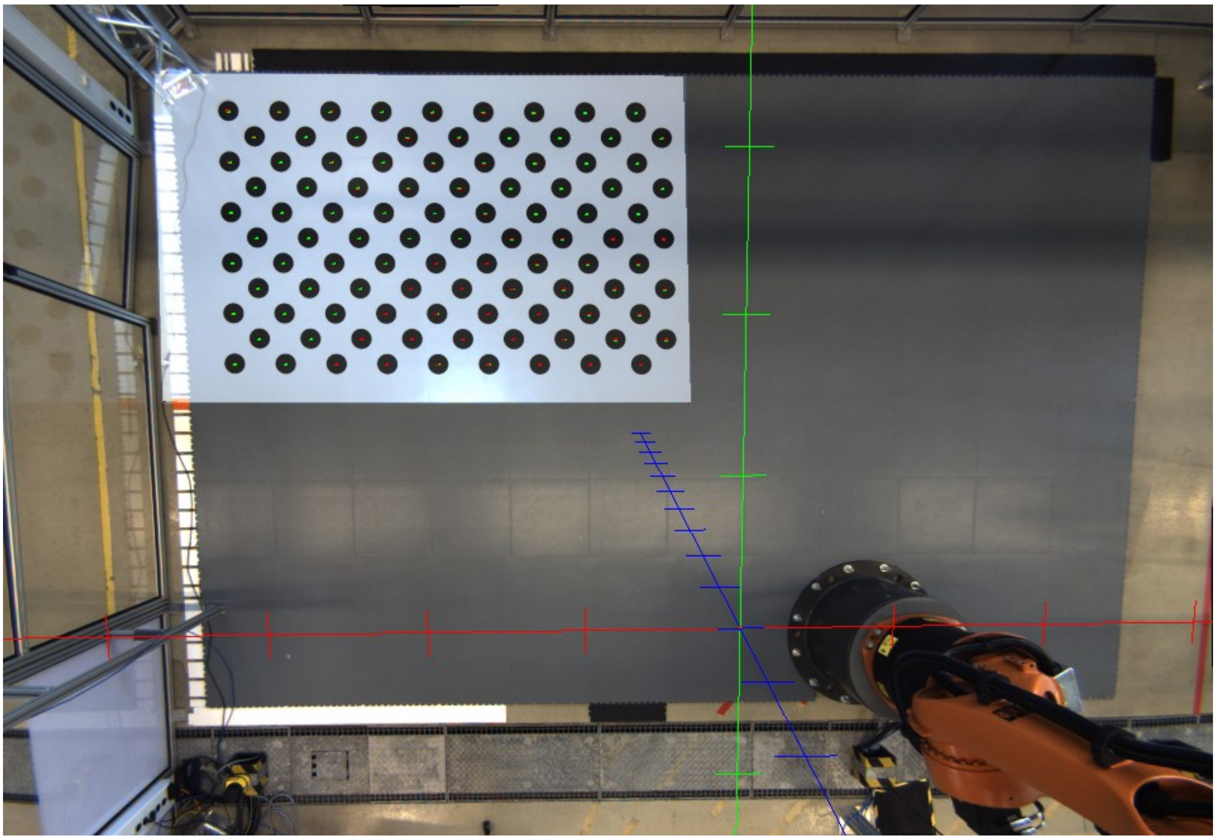

Figure 12: Camera-View: Projected circle pattern used to calibrate the projector extrinsically.

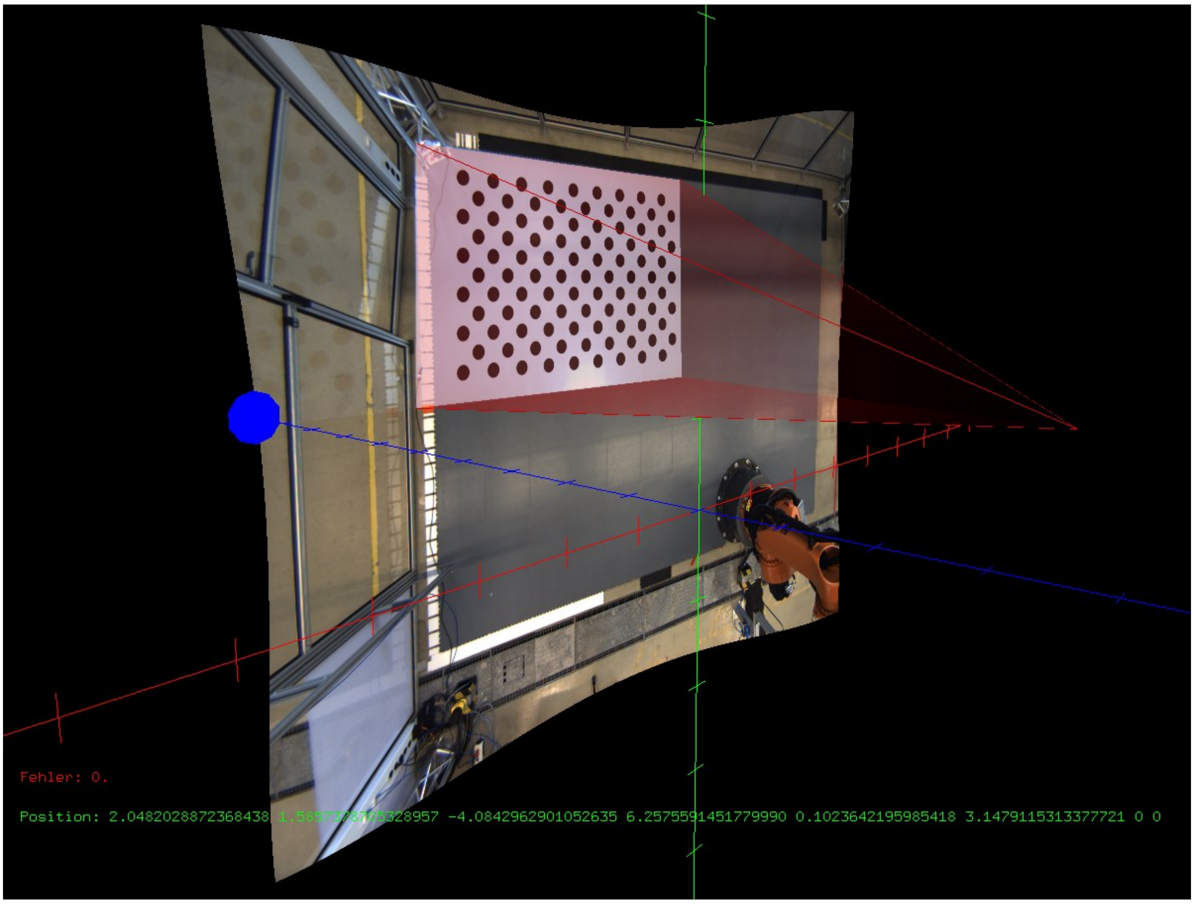

Figure 13: AR-View: Extracted circle pattern and determined projector's position visualized by a red view frustum.

After finishing the calibration process all components were firstly tested on its own and further in concurrence. For this, a simple scenario was implemented that includes a preprogrammed motion trajectory of the robot. Further on, a free area, warn area and a critical area were manually defined and monitored by the tactile floor. These static safety zones were visualized by the projection system as shown in figure 14. As the robot is entirely moving inside the critical area, a detection of a human in the warn area will lead to a reduced motion speed while a human in the critical area stops the robot's motion immediately, as depicted in figure 15.

We further implemented a method that visualizes online the sensor data of the single sensor cells of the tactile floor. In detail, if a sensor cell is triggered by a human, this cell is particularly illuminated by the projection system, as shown in figure 16.

Actually, the entire system comprising the hardware and software components is completed. The safety relevant monitoring of the human moving on the tactile floor is finished. The projection system is capable of visualizing the safety zones as well as the sensor data of the single sensor cells. Next steps include the implementation of the various safety approaches defined in deliverable D1.1.

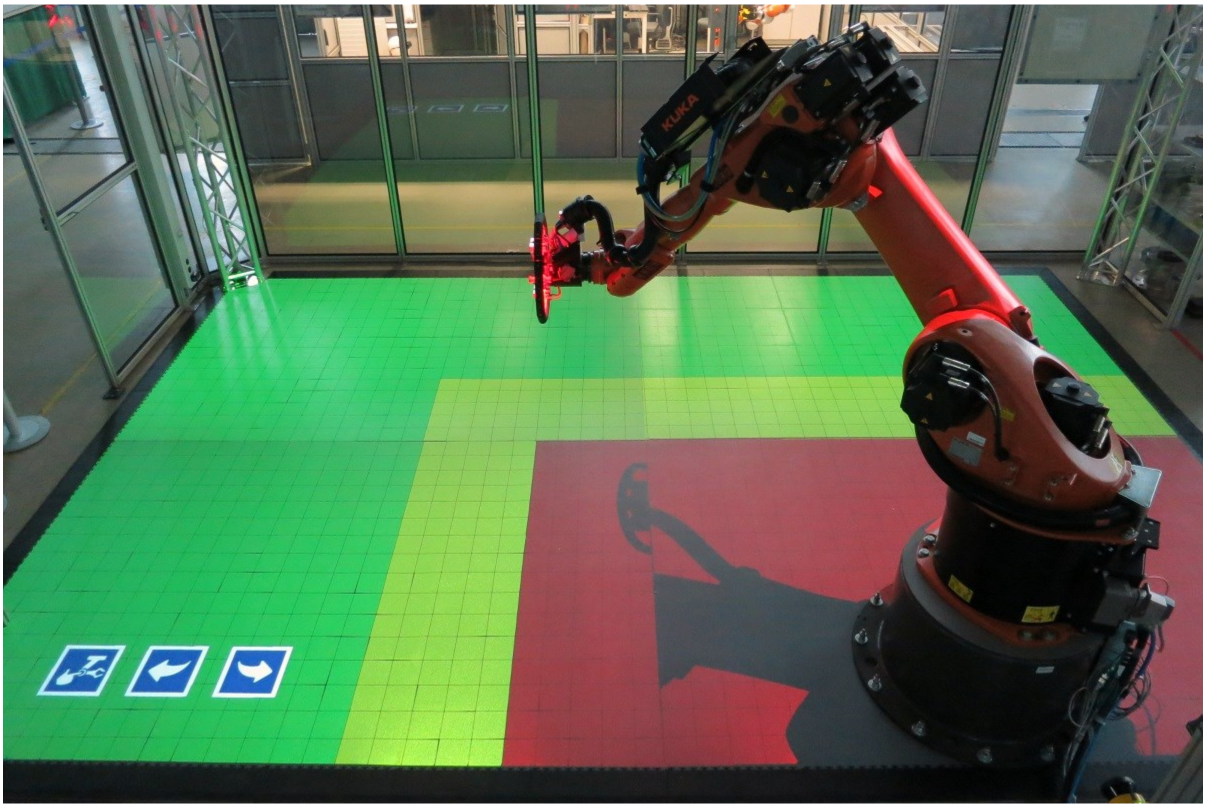

Figure 14: Static safety zones monitored by the tactile floor while the robot moves. The projection system visualizes these safety zones appropriate (free area-green, warn area-yellow, critical area-red)

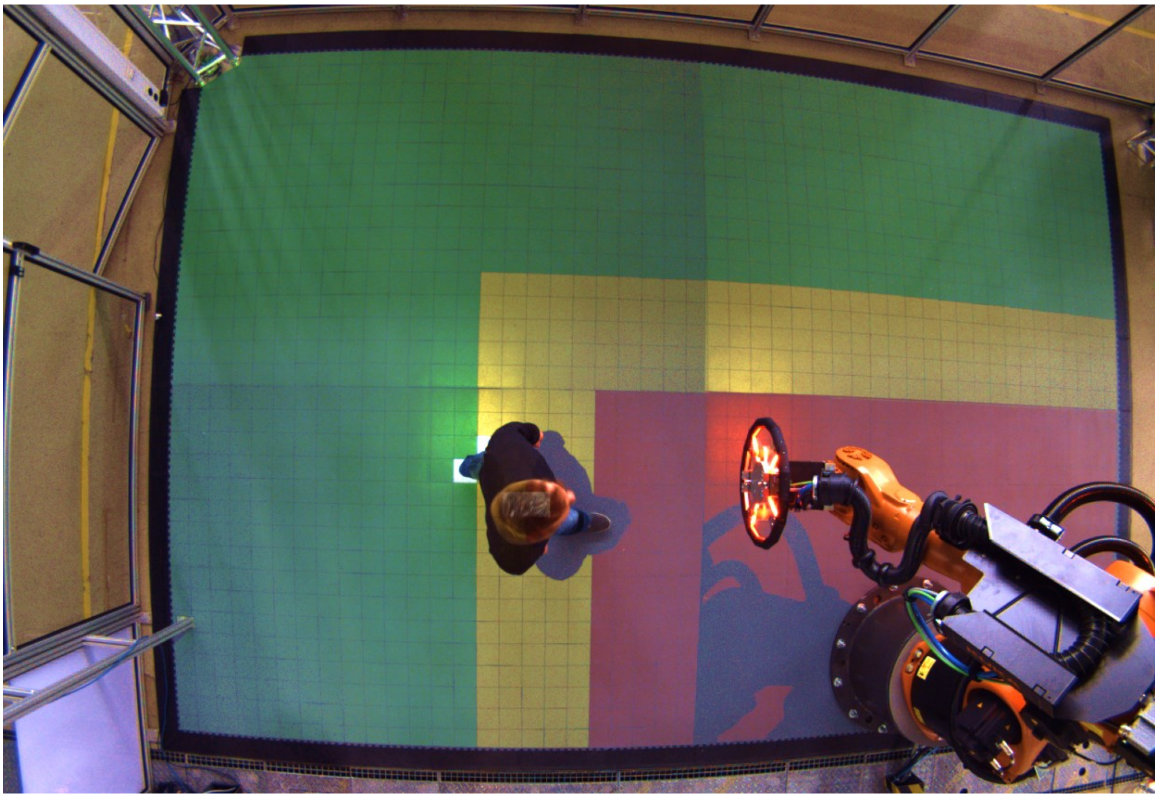

Figure 15: As the human enters the warn area and critical area, the robot stops its motion immediately.

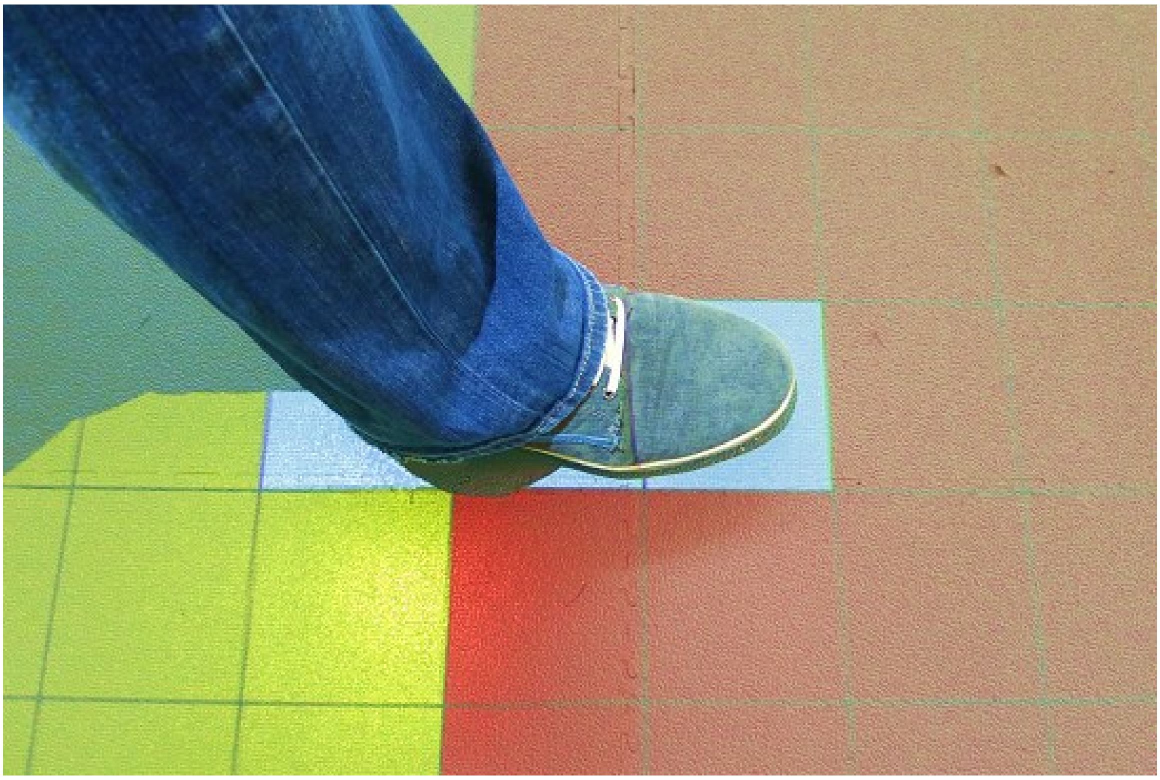

Figure 16: Triggered sensor cells are illuminated by the projection system. Warn area and critical are visualized.