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# Designing an Interactive Serious Game to Investigate Acceptability of Human-Robot Collaboration in Manufacturing

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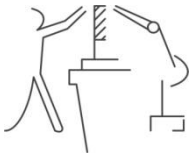

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OPERATIONAL PROGRAMME EDUCATION AND LIFELONG LEARNING
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS MANAGING AUTHORITY
NSRF 2007-2013
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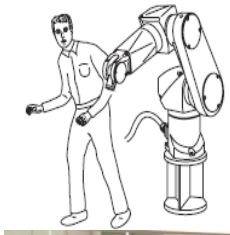
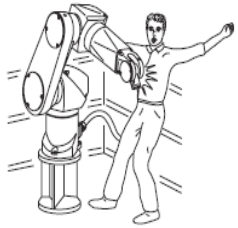
# Context

- **Human-Robot Collaboration (HRC)**
  - necessity in modern MS
  - coexistence, Collaboration and Synergy
    - complex tasks, productivity
  - various H-R interaction forms
  - segregation vs. sharing the physical environment (safety fences vs. fluent HRC)

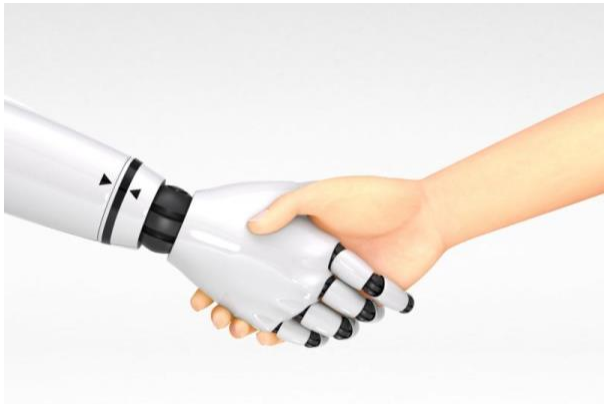


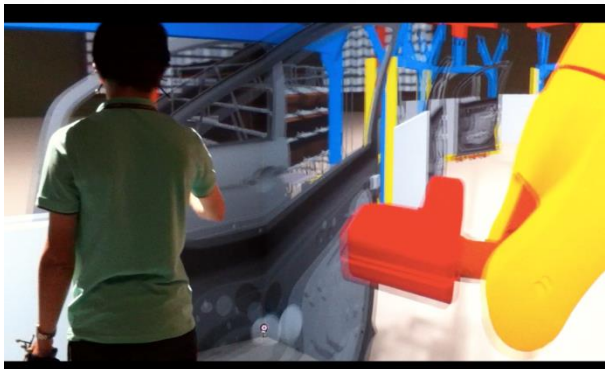



- Safety Issues (physical & mental)
  - no injuries
  - awareness and anticipation of robot motion
- Acceptability of HRC

# Context

- **Interactive Serious Games - VRTSs**
  - efficient tool to study HRC acceptability
  - provide perceptual cues and feedback
    - simulate beyond stop-and-go interaction
  - transfer knowledge to real-world operation skills
  - provide enhanced perception of robot motion



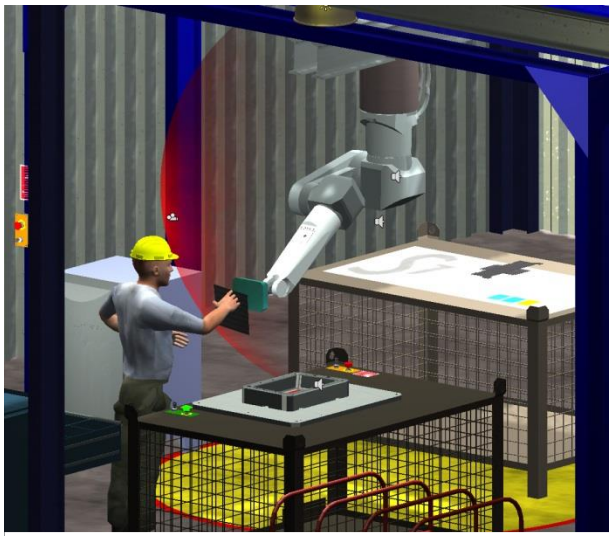


- **Project Goals**
  1. platform for experimentation
     - HRI techniques / HRC fluency
  2. investigate users' experience and behaviour
  3. investigate HRC acceptability in regard to safety issues
  4. consider safety-based robot motion programming

# Use Case

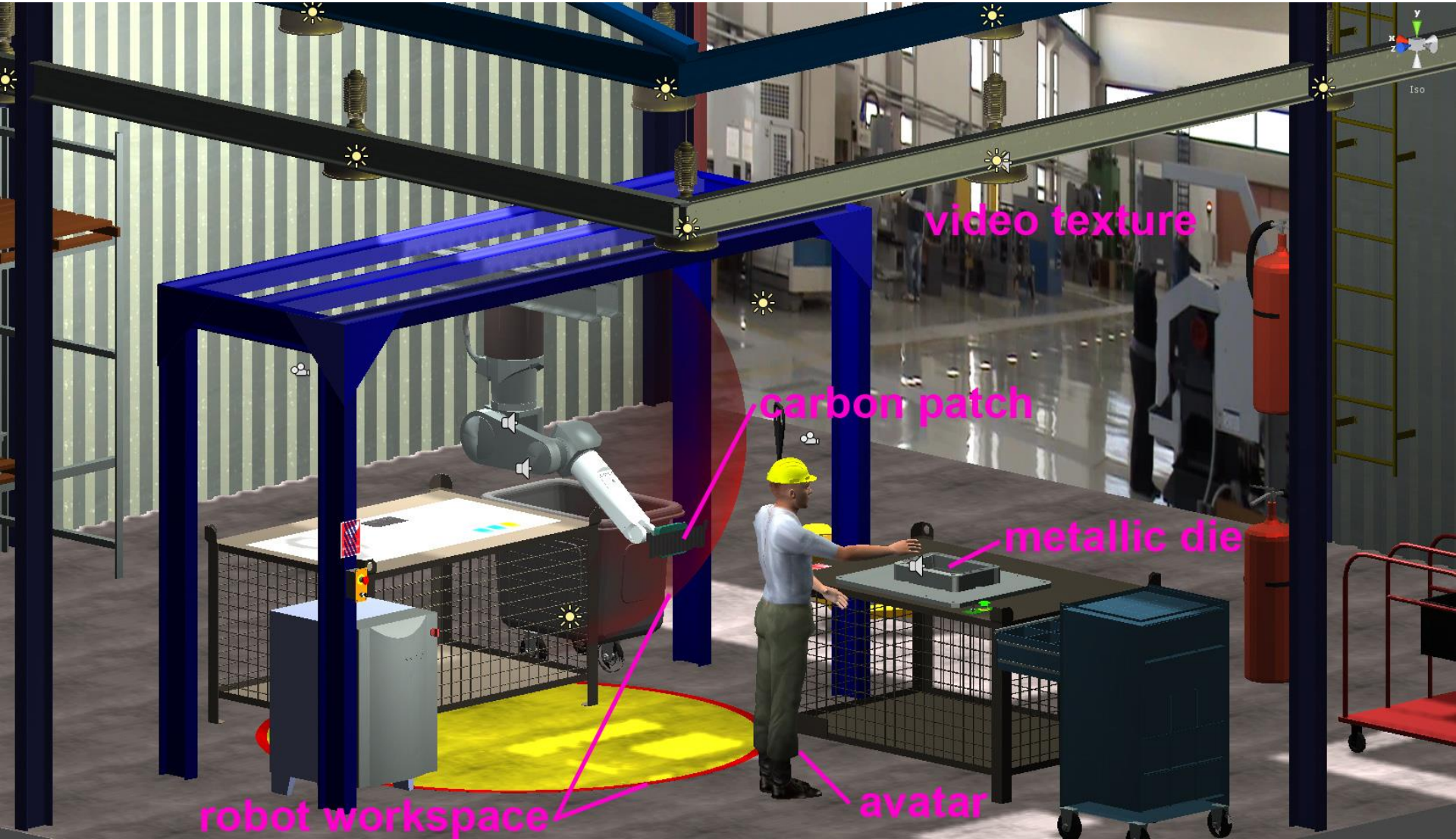
- **Global presentation**
  - H-R collaborative tape laying for composites
  - a human-controlled avatar and a robotic manipulator execute tasks while sharing their workspace
  - typical hand-to-hand direct collaborative scenario

- **Emergencies**
  - human's position relative to the robot
  - visual and audio stimuli (alarms)
  - robot speed reduced
  - robot's orientation might change



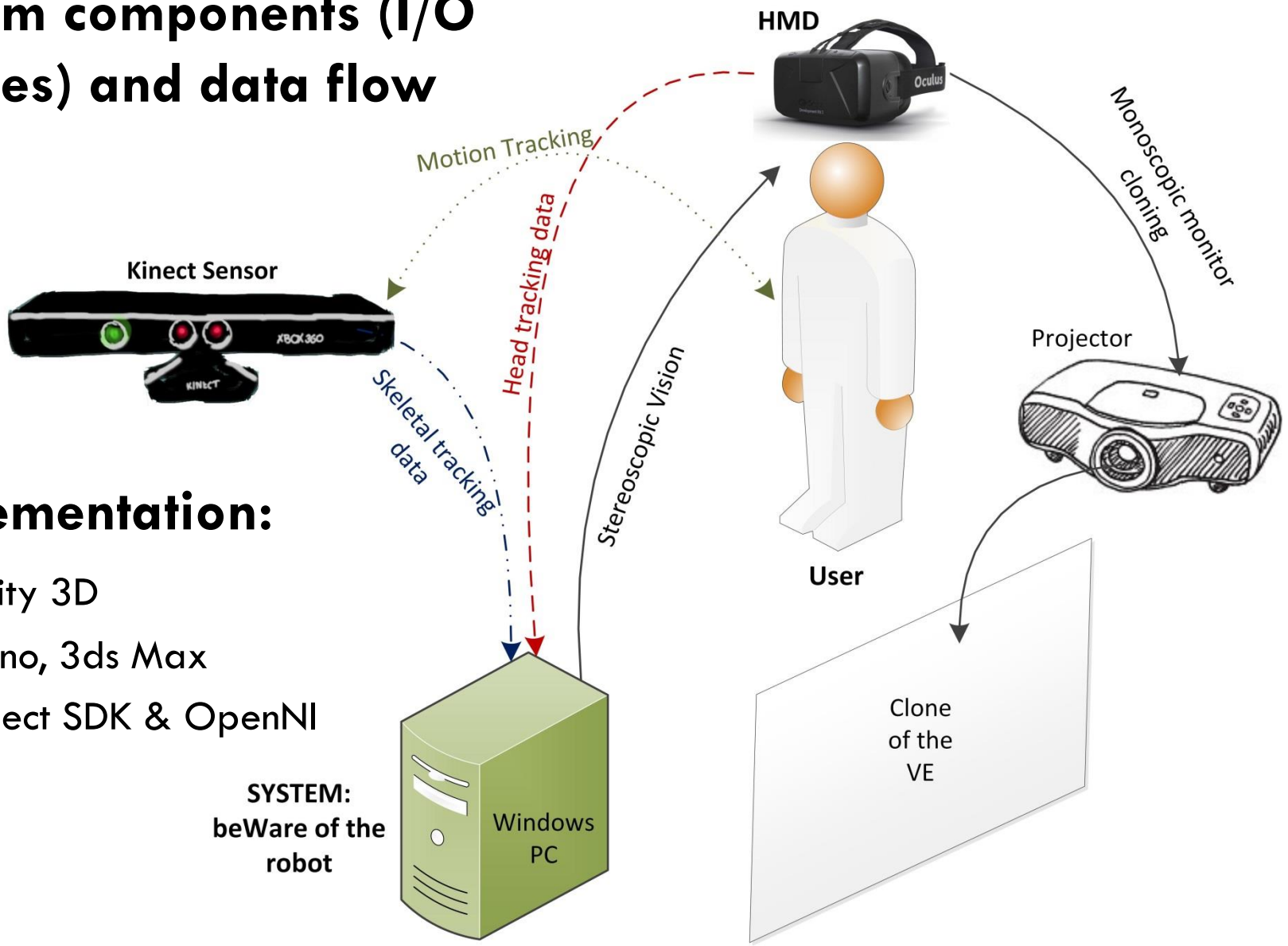
# Overview - "beWare of the Robot"

- **Interactive Serious Game - VRTS**
  - The Virtual Environment (VE)



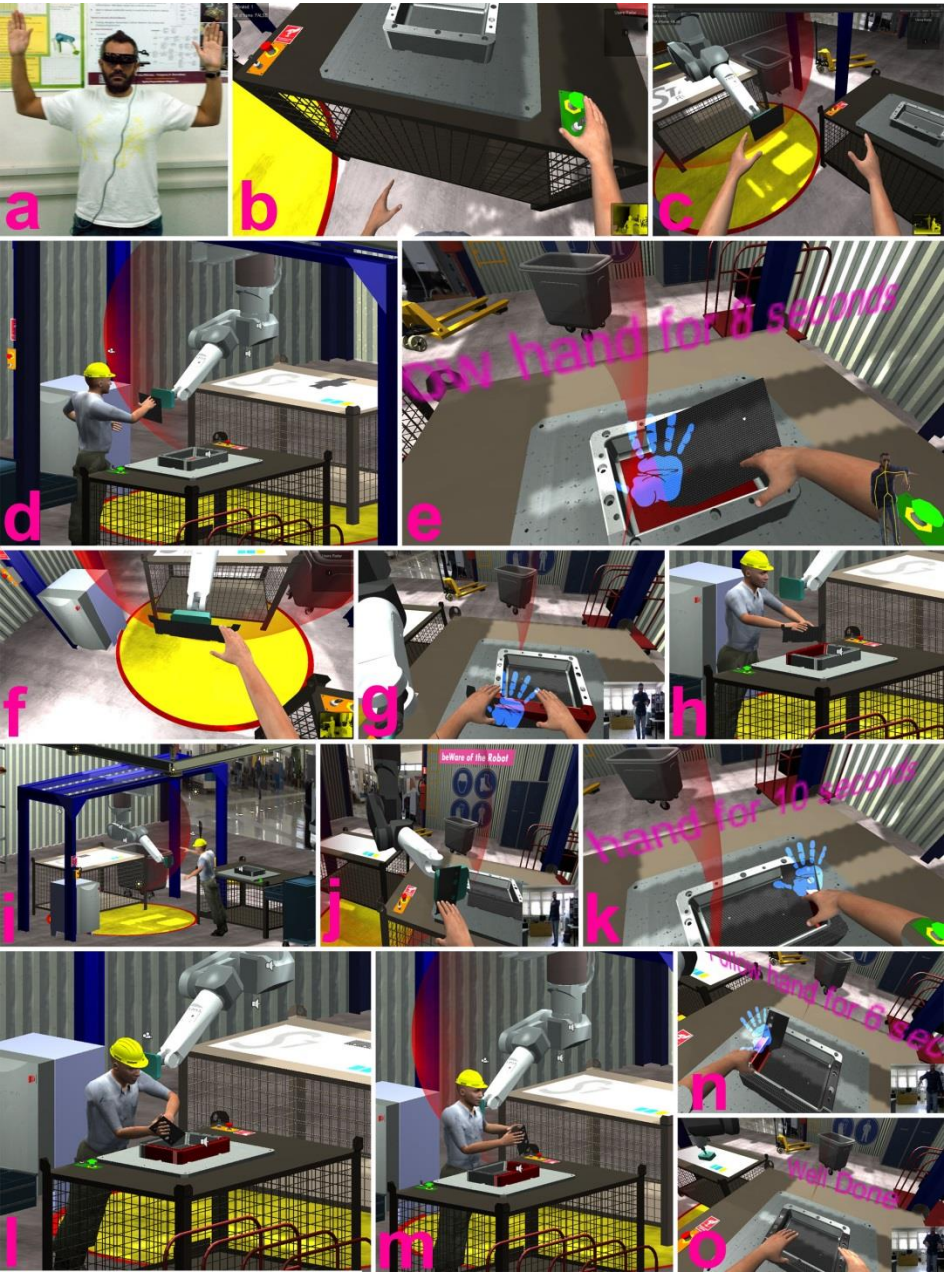
# System Setup - "beWare of the Robot"

- **System components (I/O devices) and data flow**



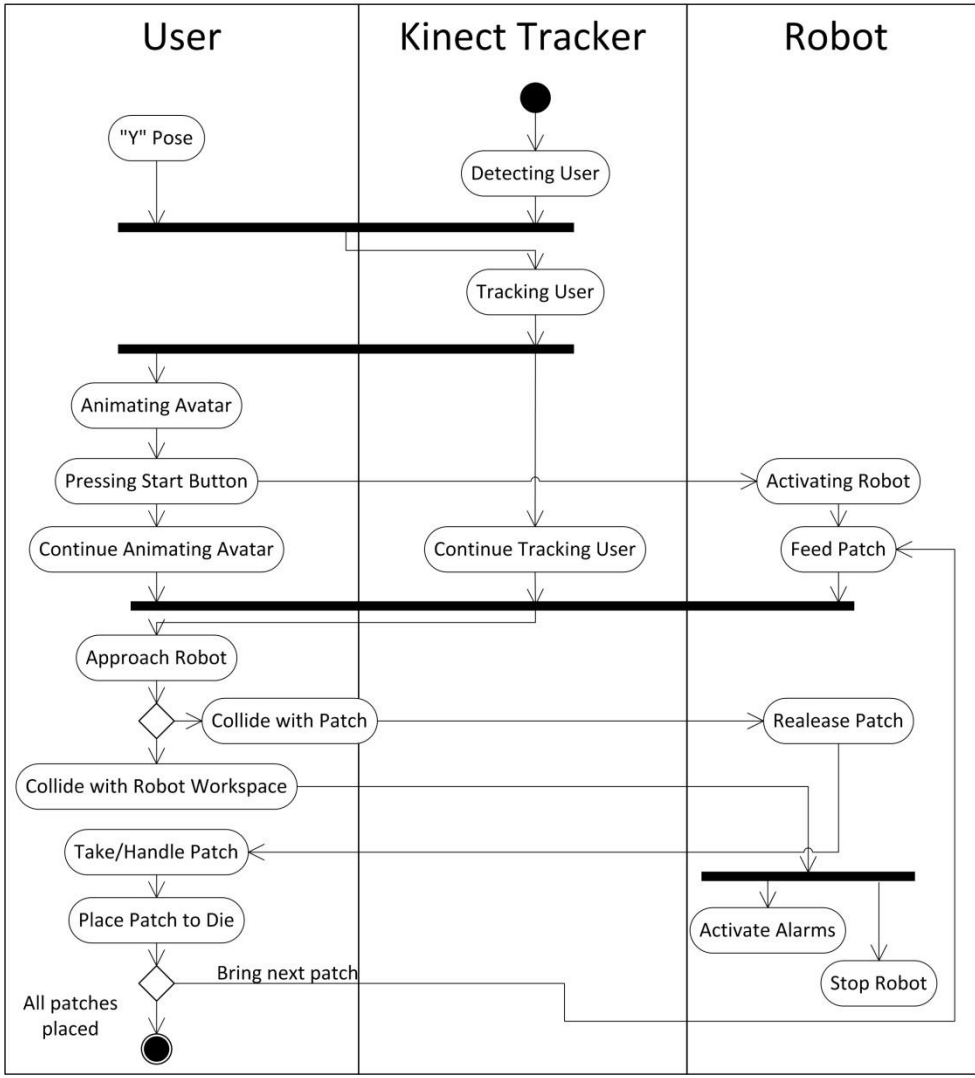

- **Implementation:**
  - Unity 3D
  - Rhino, 3ds Max
  - Kinect SDK & OpenNI

# Scenario - Storyboard




**Activity Diagram: Swimlanes**

beWare of the Robot workflow of the main tasks



# Video

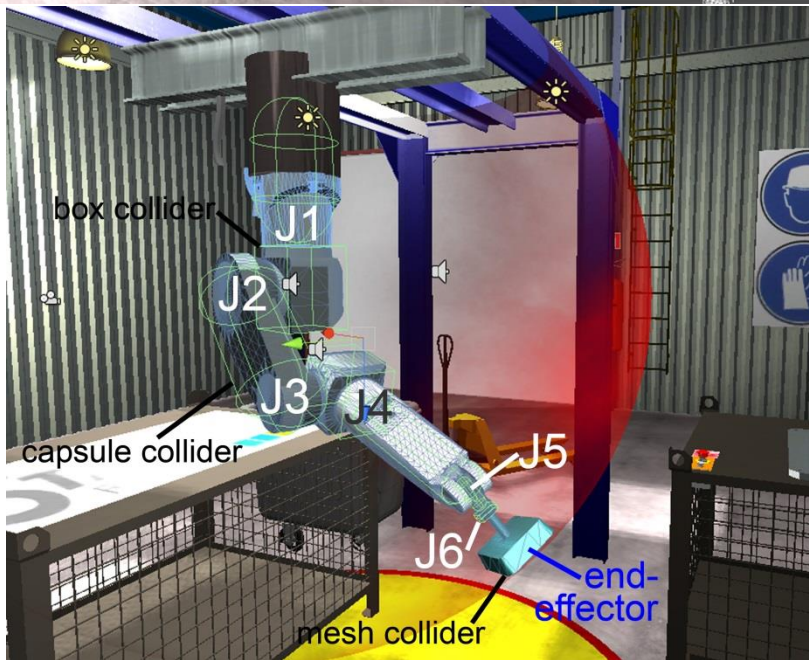
# Main actors

## Avatar

- avatar to enhance presence
- camera(s) attached to the head
- 1st person perspective
- 11 tracking points with Kinect™
- biped – humanoid animator
- physics (colliders, rigid body)


## Robotic arm

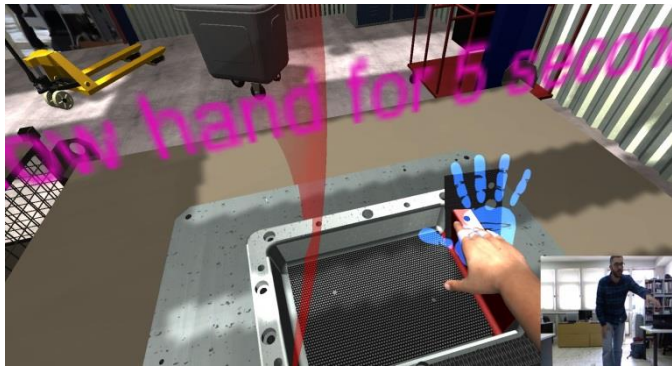
- 6R Stäubli RX 90L robot manipulator
- forward kinematics control implemented with quaternions
- pneumatic end-effector (gripper)
- physics (colliders)
- work envelope visualization (red surface - ≠ physical fidelity)



# Interaction techniques

- **Wide variety and cross-task**
  - natural interaction techniques (schemes) for:
    - selection
    - manipulation
    - navigation (travel)
    - system control
  - collision detection and triggering
    - primitive-shape colliders (>25 fps)
  - rigid body physics
  - ray-casting technique
  - tracking-driven virtual hand (physical motion)
  - real walking technique

  - metaphors during the hand-laying task



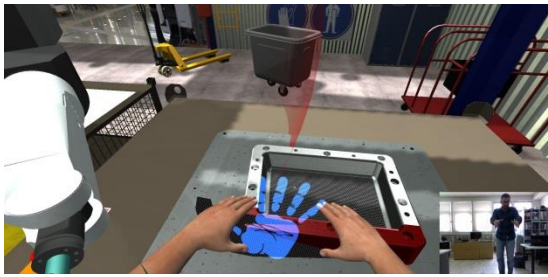
# 1st Experimental Setup

- **Objective**
  - investigate users' experience (presence) and performance
  - evaluate the effectiveness of the "emergencies"
  - test H-R interaction techniques' fluency and system usability
  - No HRC acceptability metrics
- **Set-up**
  - 30 senior students
  - 10 minutes - individual tests
  - Detailed protocol & oral instructions
  - Online questionnaire and discussions
  - A posteriori video recordings analysis

# User Experience

- **Presence by involvement**
  - human performance depends on presence
  - important measure for situation awareness in VEs
  - conditions: immersion and involvement

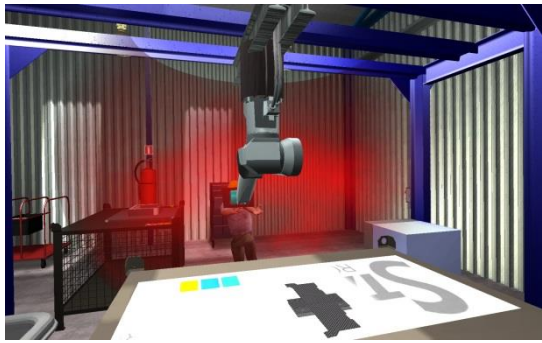

- **Immersion**
  - body proprioceptive feedback == HMD display info



- **Results**
  - 73% felt really “involved and present” in the virtual scene, as if manipulating an object with their hands
  - 77% felt really “immerged” in the virtual scene with the HMD
  - 93% did not loose their concentration at al
  - Only 50% felt like the avatar followed their body and head movements precisely

# Experimental Findings

- **Usability and tracking quality**
  - 86% felt like were really moving in the scene
  - Only 10% found difficult to move/navigate
  - 23% pointed out a slight vibration in movements
  - 53% sometimes lost control
- **Effectiveness**
  - 97% easily perceived the robot's workspace, the robot speed and the alarm events
  - 70% accomplished their tasks successfully
  - 93% favorably accepted that visual & auditory stimuli enhance awareness of hazard
- **User motivation**
  - 76%: as if they were participating in an amusing game
  - 90%: such HRC training tasks can be much attractive

# Discussion

- **Platform for experimentation**
  - Simple use case, scenario fidelity
  - Positive prospect, pertinent tool for HRC
  - Scored great in presence, motivation and navigation issues
  - Kinect tracking problems and limitations tackled

- **HRC Acceptability**
  - All mental safety and awareness issues have to be tackled
  - immersive experience combined with warning stimuli, can help the user to experience the feel of presence as a situation awareness phenomenon

- **Novelties**
  - Wide blending of interaction tasks and techniques
  - contactless interaction, head tracking and immersion quality

# Future work

- HRC acceptability metrics and testing
- Experiments with new 3D UIs (hybrid hands and finger tracking)
- consider new alarm and trigger types
- consider alternative scenarios of collaboration (e.g. collaborative laying in parallel)
- safety-based robot motion programming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# Annex A: Test results summary

**Table 1** Test results (SD: strongly disagree, D: strongly agree, N: neutral, A: agree, SA: strongly agree)

| Question | SD | D | N | A | SA |
|---|---|---|---|---|---|
| I feel like I was really moving in the scene | 0 | 1 | 3 | 5 | 21 |
| Wearing the HMD I feel present and involved in the virtual activity | 2 | 1 | 5 | 15 | 7 |
| I lost my concentration, even instantaneously, during the experiment | 28 | 0 | 0 | 2 | 0 |
| Wearing the HMD I feel immerged in the virtual environment | 1 | 0 | 7 | 13 | 9 |
| I feel like I was really moving an object with my hand, despite the fact that the object did not have physical mass | 1 | 7 | 8 | 12 | 2 |
| I did not easily perceive the red transparent surface that represented the robot workspace | 29 | 0 | 0 | 0 | 1 |
| Audiovisual stimuli (alarms) helped me being aware of a potentially hazardous workspace | 0 | 1 | 1 | 8 | 20 |
| I did not encounter any difficulties during the initial calibration process with the Kinect sensor | 0 | 3 | 3 | 6 | 18 |
| I feel like the avatar followed my body and head movements precisely | 1 | 2 | 12 | 14 | 1 |
| It was easy to take the patches form the robot's end-effector | 0 | 0 | 9 | 13 | 8 |
| It was easy to navigate/move in the virtual world (ease of movement, restraint) | 0 | 3 | 12 | 12 | 3 |
| I feel like my behavior in the virtual world didn't change, compared to my behavior in the real world | 3 | 10 | 9 | 8 | 0 |
| I feel more like I was participating in an amusing game | 0 | 2 | 5 | 10 | 13 |
| After the experiment I went through, I believe that H–R training tasks can be more attractive with the use of "serious games" | 1 | 0 | 2 | 8 | 19 |