Automation, Robotics and System Control lab

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Survey on Human-Robot Interaction for Robot Programming in Industrial Applications

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Robot programming

☞ **Intuitive ways to interact with robots and program them**
as a key enabler for a pervasive diffusion of robotics in industries

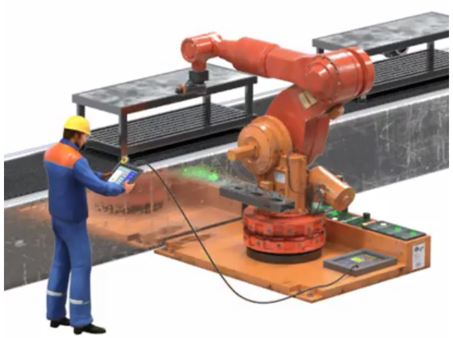
- A robot cannot be instructed in the same way that we would instruct a skilled human worker how to carry out a task
- Humans have knowledge about motion, physical effects, cause-effect relationships and learned procedures, and are able to reuse such knowledge in the future
- Robots are not able to perform such knowledge-based behaviours in a productive manner
- Instructions have to be explicit and motion oriented

Robot programming approaches

ROBOT PROGRAMMING

- **On-line programming**
  - **Teach pendant programming**
  - **Walk-through programming**
  - **Programming by demonstration**
- **Off-line programming**

+ multi-modal interaction



Traditional teach pendant programming

- Task trajectories are taught to the robot specifying a **set of points** that the robot must pass through
- **The operator moves the robot from point to point, using the buttons on the pendant to move it around and save each position individually**
- When the whole program has been learned, the robot can play back the points at full speed

Traditional teach pendant programming

PROs	CONs
Necessary in some specific situations • when it is needed to *in situ* verify and manually adjust programs generated off-line • when 3D models are unavoidable • in presence of complex tasks that can be only be programmed by the human operator close to the robot	**Tedious and time-consuming task** • As shown in several usability assessments (e.g., Gray, 1992; Morley, 1995)
	Technical expertise in programming required
	Suitable for simple tasks and workpieces with simple geometry
	Reprogramming required for each new task, even in case of small changes • Not suited for small and medium sized enterprises: small production batches require frequent task reprogramming

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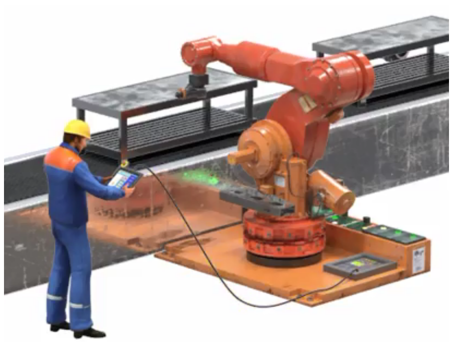
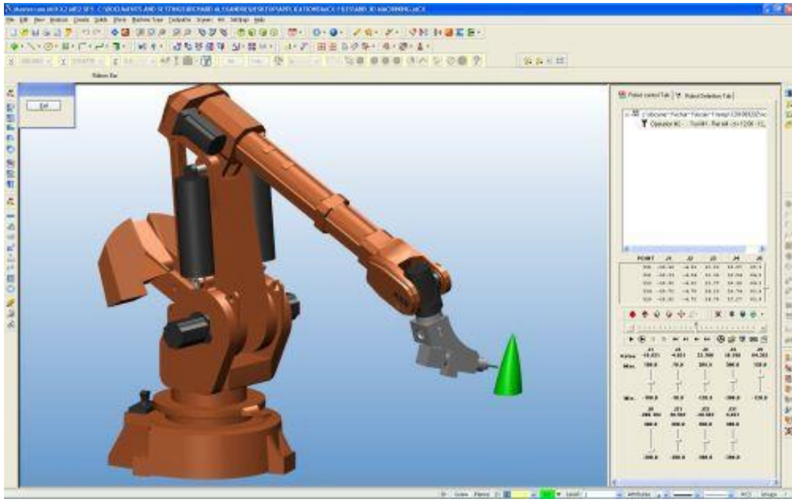


+ multi-modal interaction

Off-line programming

- Accomplished on remote computers located far from the robot station
- Using simulation software, the movements of the robot are simulated in a virtual 3D environment
- Modeling and simulation allow for graphical representation of the robot cell, automated program generation and simulation of the robot tasks
- Possible collisions can be detected directly in the simulation
- When the program is ready, it is loaded to the robot controller



Off-line programming

PROs	CONs
It reduces downtime required for robot programming • Programs are developed offline, so the robot only has to be halted while the new program is being downloaded and tested. • The burden of programming is moved from the robot operator in the shop floor to the software engineer in the office.	**It might take longer overall** • Although offline programming reduces the downtime of the robot, extra time is required to develop the simulation and test it on the robot.
It can be quite intuitive • The robot can be moved around in a 3D CAD environment with drag and drop techniques.	**Virtual models do not represent the real world with 100% accuracy** • Programs may still need to be altered after they are applied to the real robot.
Most advanced tools offer modules for specific processes, such as coating, welding or polishing	**A robot calibration step is needed when off-line program is transferred onboard the robot to compensate for positioning error due to a mismatch of coordinate systems between real and virtual world**

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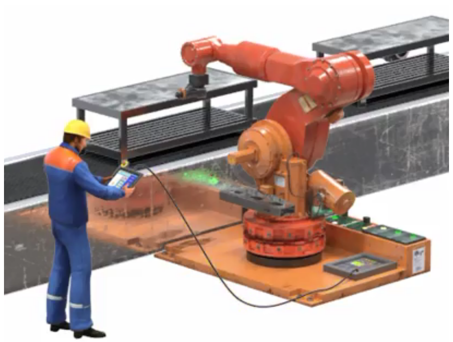

+ multi-modal interaction

Walk-through programming

- The operator manually guides the robot in a free way to the positions of interest, or along the desired paths or trajectories
- Safety issues are critical
- Different control schemes are possible
  - Force/torque sensor on the wrist of the robot
  - Vision-based systems
  - Virtual tool, for heavy and stiff robots
  - Others…
  - *References in the paper*

Walk-through programming

- STEP 1: Teaching
  - The user grabs the tool to move the robot through the desired positions
  - The robot controller records all the significant poses of the trajectory followed by the human operator
- STEP 2: Execution
  - The robot controller interpolates the saved poses and plays the trajectory back

Walk-through programming

PROs	CONs
Quicker than traditional teach pendants • It removes the need for multiple button pressing, allowing the operator to simply move the robot to the desired position.	**Robot downtime** • The method uses the physical robot for programming.
More intuitive than both traditional teach pendants and simulation programs • The task is programmed in almost the same way a human operator would perform it. This makes it simple for operators to learn. • This method requires no knowledge of programming concepts or being familiar with 3D CAD environments (as simulation does).	**Moving the robot to precise coordinates is not as straightforward as with the other methods** • This is especially true with some joystick based systems, where there is no way of entering a numerical value.
Useful for detailed tasks which would require many lines of code to achieve the same effect • E.g. Welding or painting of intricate shapes	

Walk-through programming

Pick and place

https://www.youtube.com/watch?v=n2OnnVHrAMU

Walk-through programming

Painting

https://www.youtube.com/watch?v=mxvThq_-r40

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  - **Walk-through programming**

  - **Programming by demonstration**

  + multi-modal interaction (linked to Walk-through programming and Programming by demonstration)

- **Off-line programming**

Programming by demonstration

HRI approach that allows a non-expert user to teach complex skills to a robot

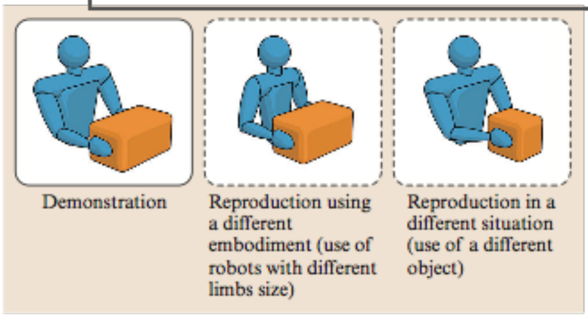
Varying scenarios

DEMONSTRATIONS OF EXAMPLE TASKS

ABSTRACTION

GENERALIZED TASK MODEL

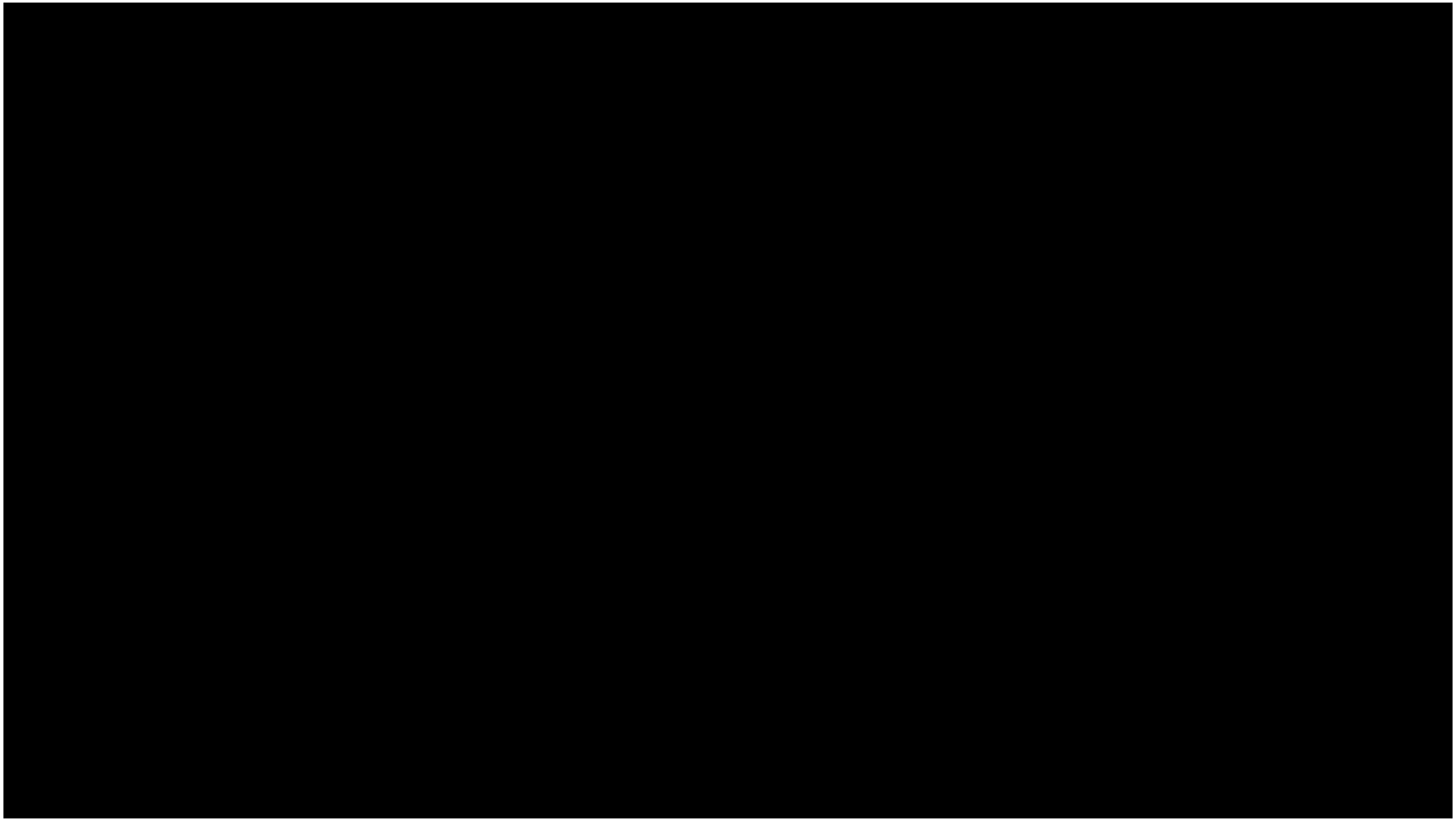
REPRODUCTION OF THE LEARNED TASK



Learning, non pure imitation

Programming by demonstration

Tennis table



https://www.youtube.com/watch?v=SH3bADiB7u

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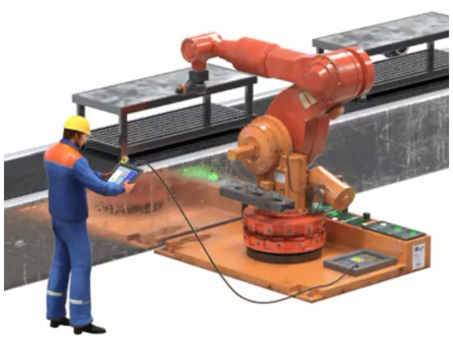
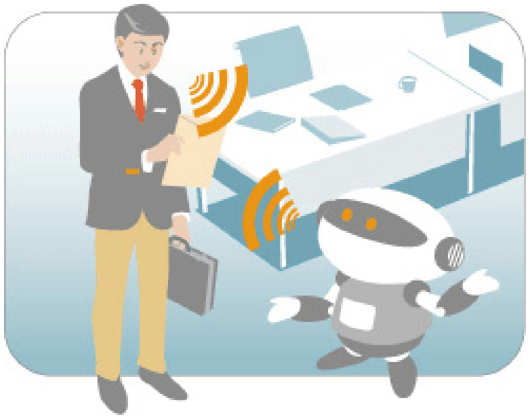


+ multi-modal interaction

Interaction modes

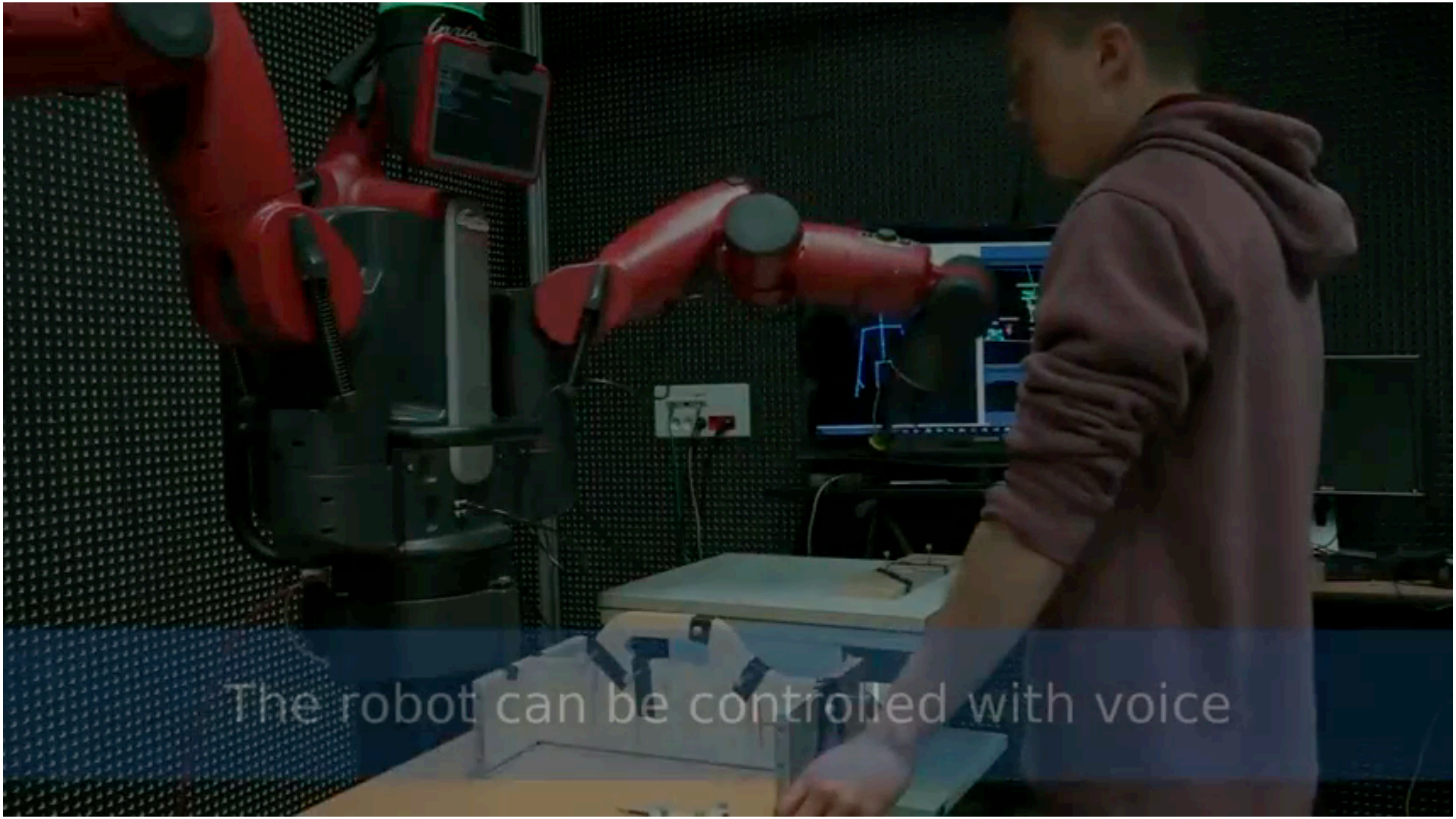
"*User-oriented*" interaction modes

- 6 main types of ***natural* interaction modes**
    - Speech
    - Gestures
    - Facial expressions
    - Eye tracking
    - Haptics
    - Kinesics and proxemics



- **Multimodal interfaces**
    - Redundancy
    - Higher perceptibility
    - Higher accuracy
    - Synergic effect

Speech interfaces



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