Robotics :

towards Programming by Demonstration

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Robotix Academy Roadshow 2020, Sarrebrücken

Outline

1. From Robots to Cobots
2. Programming methods more and more intuitive
3. Programming by demonstration

From Robots to Cobots

Industry 4.0 :

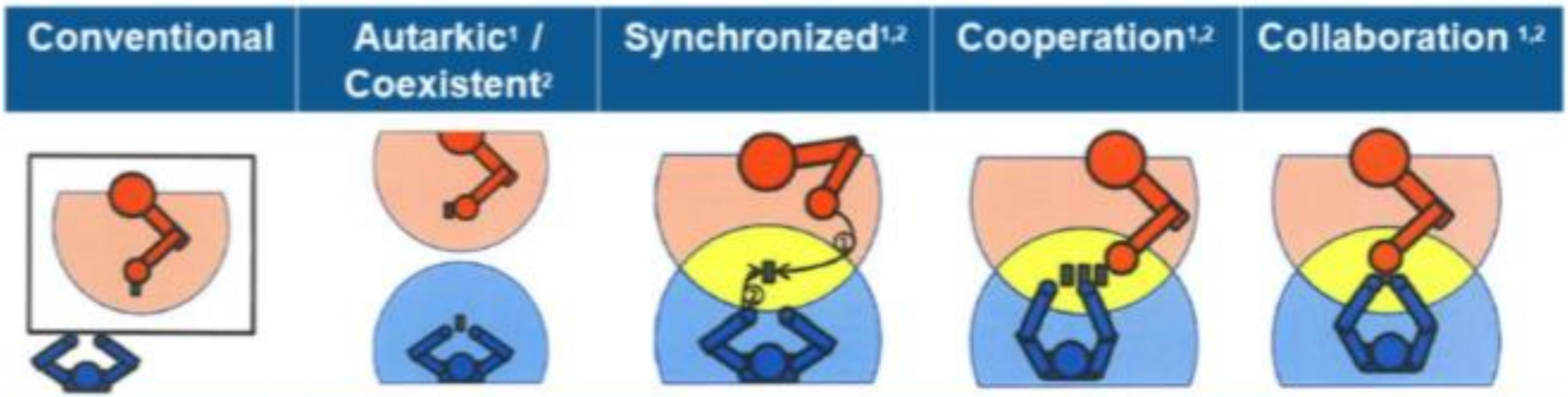
- Factory flexibility and personalized production
  - ➢ High numbers of product varieties
  - ➢ Small batch quantities

- Fully automated production : Highly productive BUT inflexible and capital-intensive
- Manual production : Flexible BUT less productive

Robot	Human
Accurate Endurance Repeatability High Load	Flexibility Learning / Adaptive Mobile

From Robots to Cobots

Human and robot working together



Spectrum	Description
Conventional	Strict separation of work space e.g. fences
Autarkic/ Coexistent	Human and robot are working without any fences, but have a separated work space
Synchronized	Only one is inside of the shared work space at a given time
Cooperation	Shared work space is used by both at the same time but the tasks are different
Collaboration	Shared work space and shared tasks

Reference : Müller, Robotix Academy, 2019

From Robots to Cobots

Example : Loading and unloading mechanical piece

https://www.youtube.com/watch?v=PtncirKiBXQ (Universal Robots, Xiamen Runner Industrial Corporation in China, 2017)

The robot and the human workspace are different without fences.

If the human moves in the robot workspace, the system performs a safety stop.

From Robots to Cobots

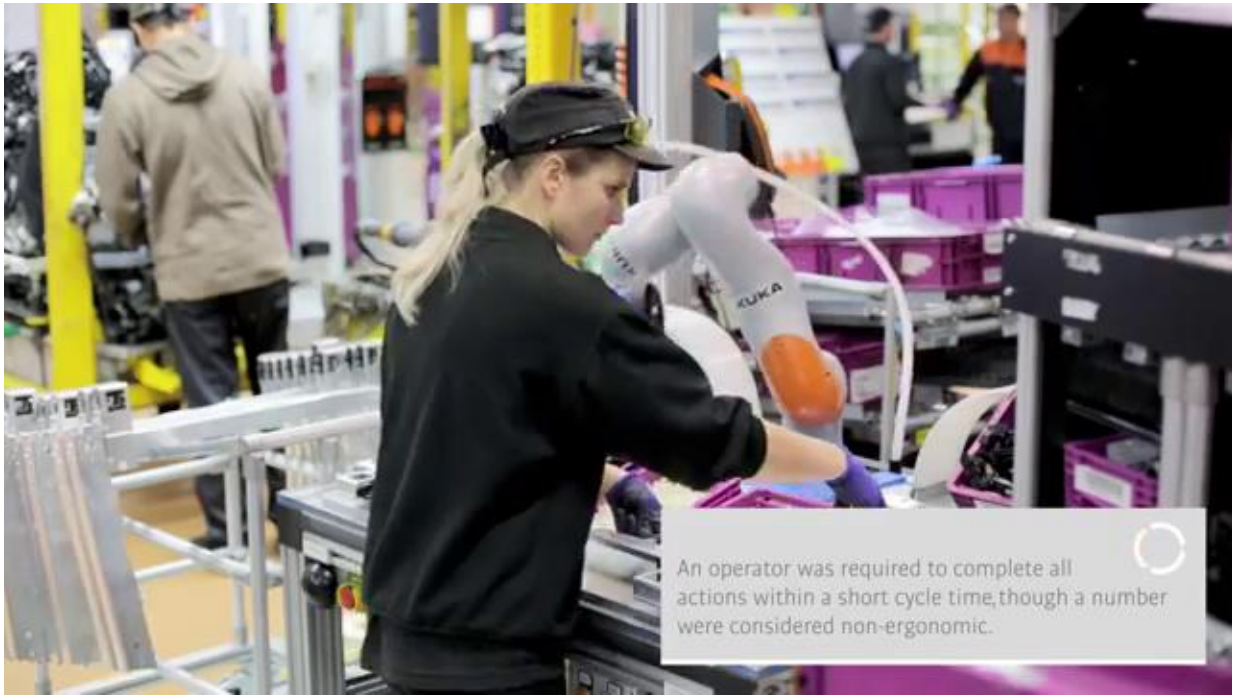
Example : Door car assembly

https://www.youtube.com/watch?v=684aq77gbGU&t=4s (CHARM project, 2013)

The human performs the complex assembly. At the end, he leaves the space and asks the automated inspection.

From Robots to Cobots

Example : Crash can structure assembly

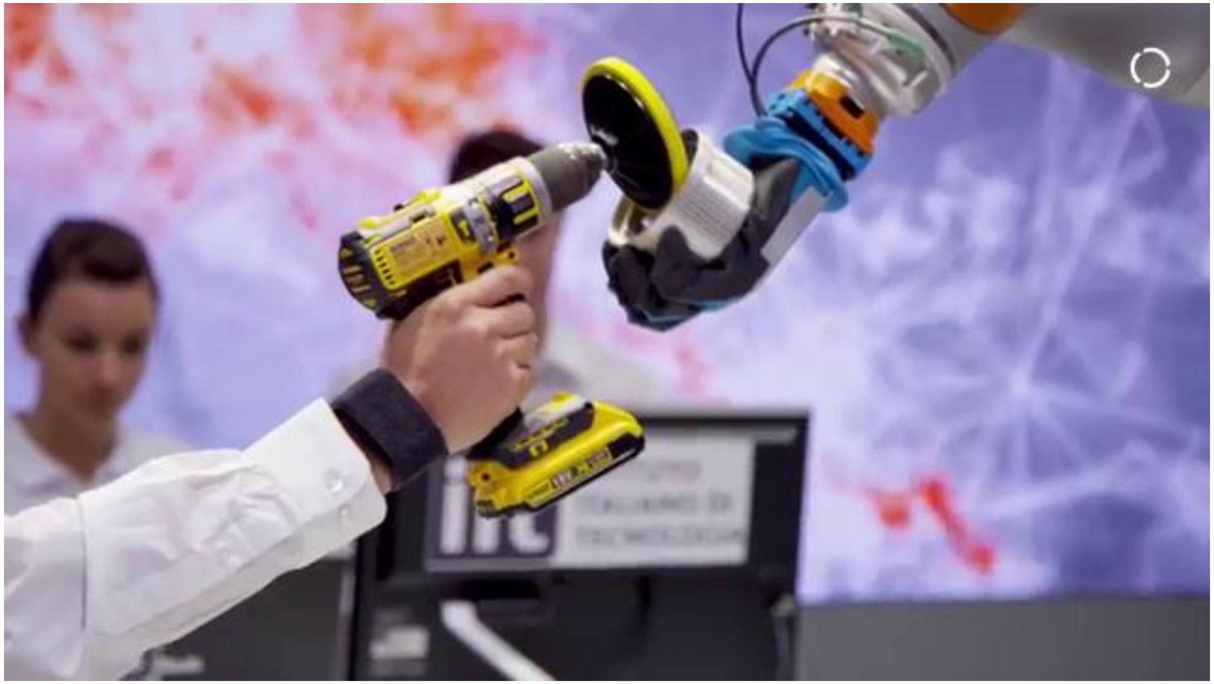


https://www.youtube.com/watch?v=keh99z1M5LI (Kuka, 2018)

The robot and the human work in the same space at the same time. The robot executes the non-ergonomic tasks.

From Robots to Cobots

Example : Robot adaptation for Ergonomic Human-Robot Collaboration



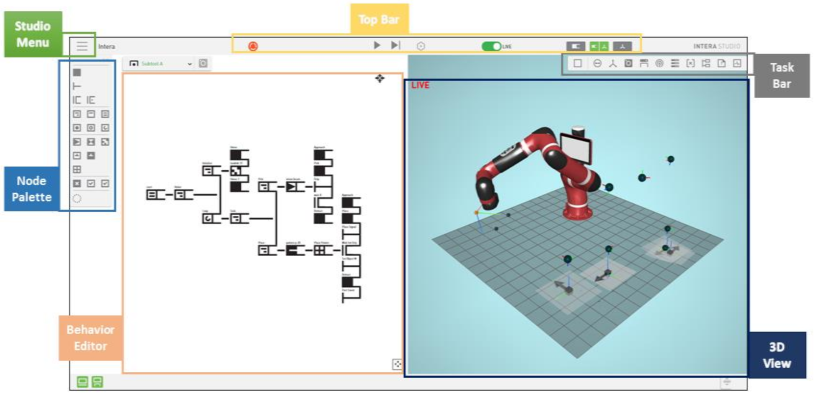
https://www.youtube.com/watch?v=XVGfBgOhaqw (KUKA Innovation Award, IIT Italy, 2018)

The robot and the human work for the same task and the robot adapts its position to help the human. Human-centered control of the robot.

From Robots to Cobots

Cobot features

- ➢ Low weight to payload ratio
- ➢ Easy installation and programming ➔Flexibility
- ➢ Integrated sensors
  - Forces/Torques
  - Cameras



- ➢ Conform to the safety standards
  - Low speeds
  - Limited forces
  - *EN ISO 10218* and *Machinery Directive*
  - *ISO/TS 15066* (Special cobots)

Outline

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2. Programming methods more and more intuitive
3. Programming by demonstration

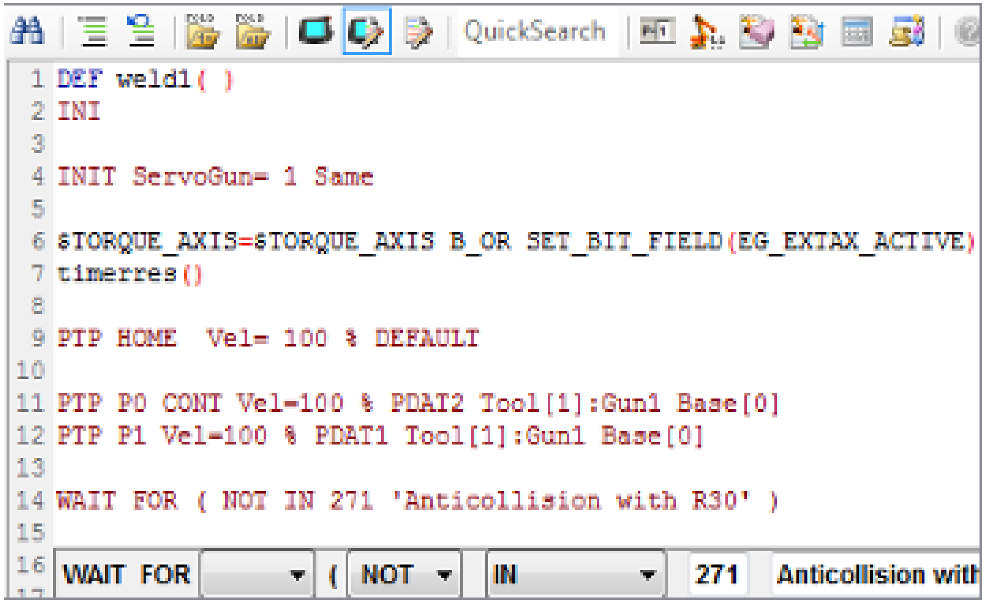
Programming methods

Programming language & Teach pendant

Robot motion is programmed with dedicated programming language.

The teach pendant is the only user interface

Example : Kuka KR 16

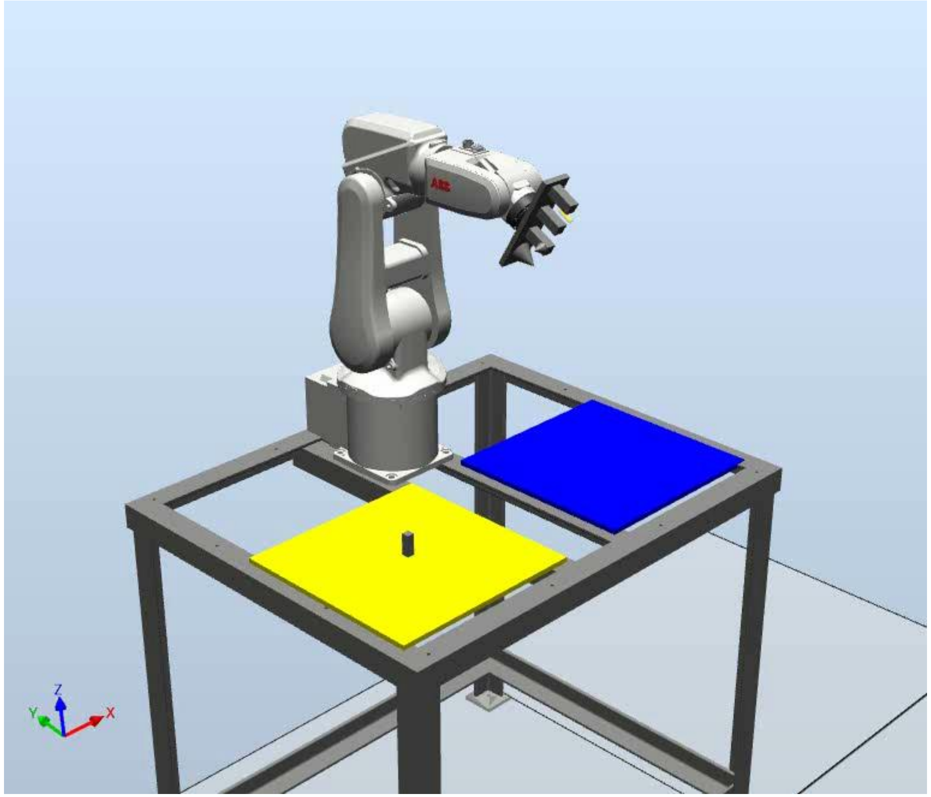


Programming methods

Programming language & Teach pendant & Virtual environment

The robot environnement and the tasks are modeled graphicaly

Example : ABB – RobotStudio



Programming methods

Cobots : Programming by blocks & Hand-guided robot

Robot can be moved directly by te user, programming method based on blocks

Example : Sawyer

Démo Sawyer :

- Programming pick and place task

- ***Example of vision task to show that it’s not limited***

Outline

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Programming by demonstration

- **Incremental** innovation in programming method so far

- PbD : potentially **disruptive** innovation

    - Inspired from human interaction. Aims at making programming easier, faster, more accessible.

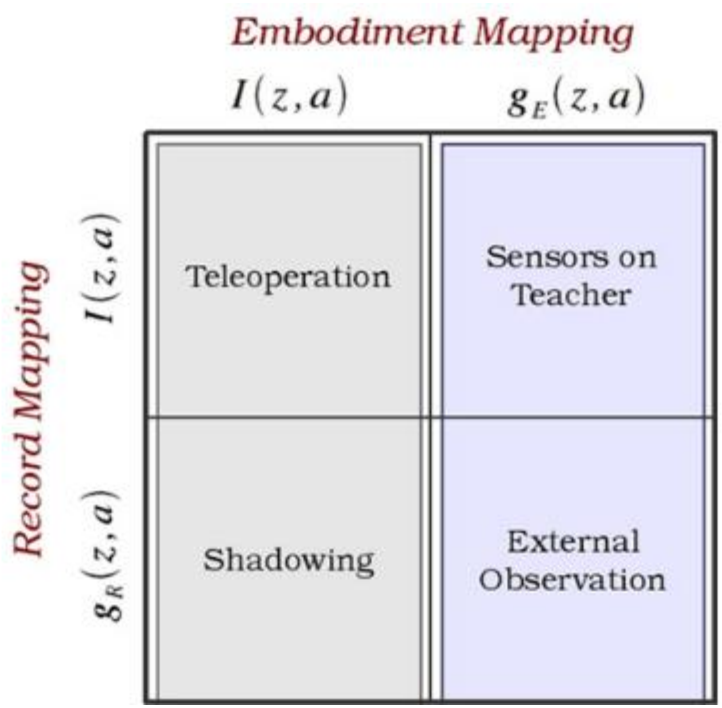
    - **Gathering data set** from demonstrations made by the operator (What to imitate ?)

    - **Extracting Policy** from demonstration : the robot « learns » how to reproduce the task and to adapt to new situations. (How to imitate ?)

Programming by demonstration

Demonstrations : correspondence issue

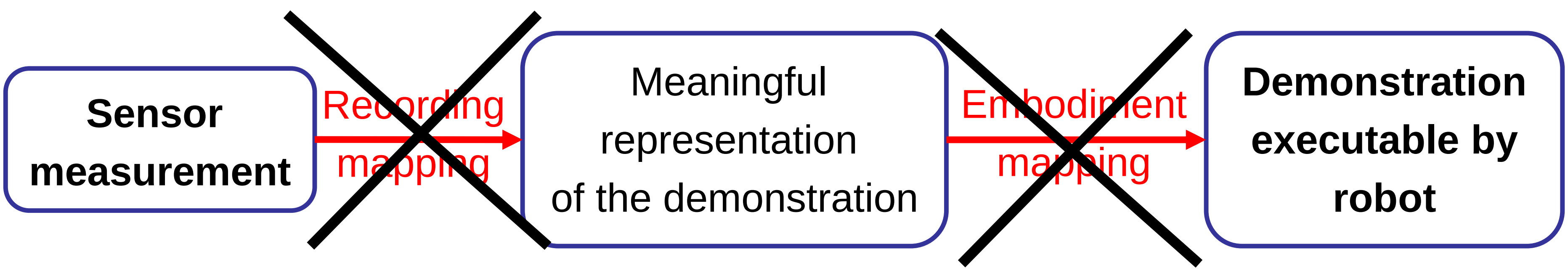
Sensor measurement → Recording mapping → Meaningful representation of the demonstration → Embodiment mapping → **Demonstration executable by robot**



Brenna D. Argall a, Sonia Chernovab, Manuela Velosob, Brett , A survey of robot learning from demonstration, Robotics and Autonomous Systems, 2009

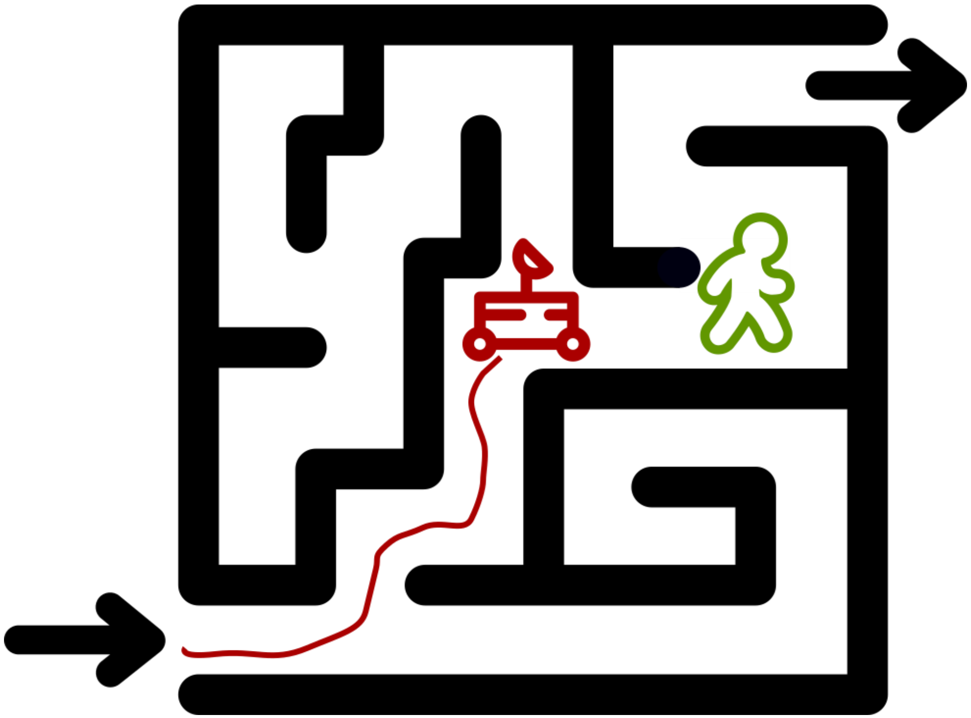
Programming by demonstration

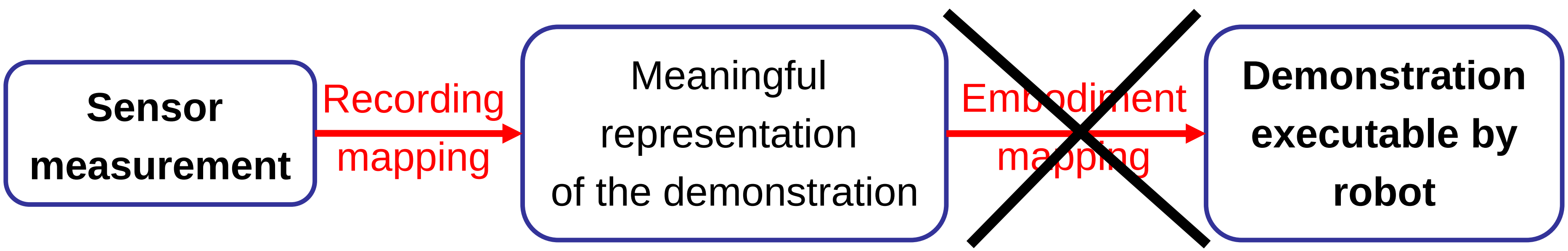
Demonstrations by teleoperation:



Programming by demonstration

Demonstrations by shadowing:





Programming by demonstration

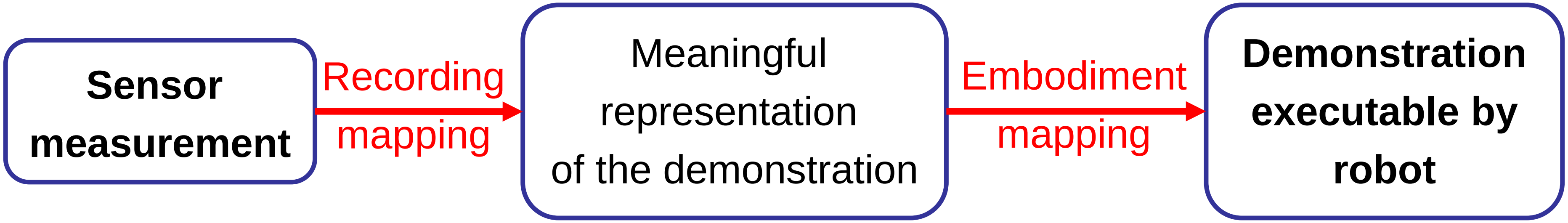
Demonstrations by sensor-on-instructor:

Source :
A.J. Ijspeert, un Nakanishi, Stefan Schaal, Movement imitation with nonlinear dynamical systems in humanoid robots, February 2002, in Proceedings - IEEE International Conference on Robotics and Automation 2:1398 – 1403, DOI: 10.1109/ROBOT.2002.1014739

Sensor measurement → ~~Recording mapping~~ → Meaningful representation of the demonstration → Embodiment mapping → **Demonstration executable by robot**

Programming by demonstration

Demonstrations by external observation:



- no constraint on robot

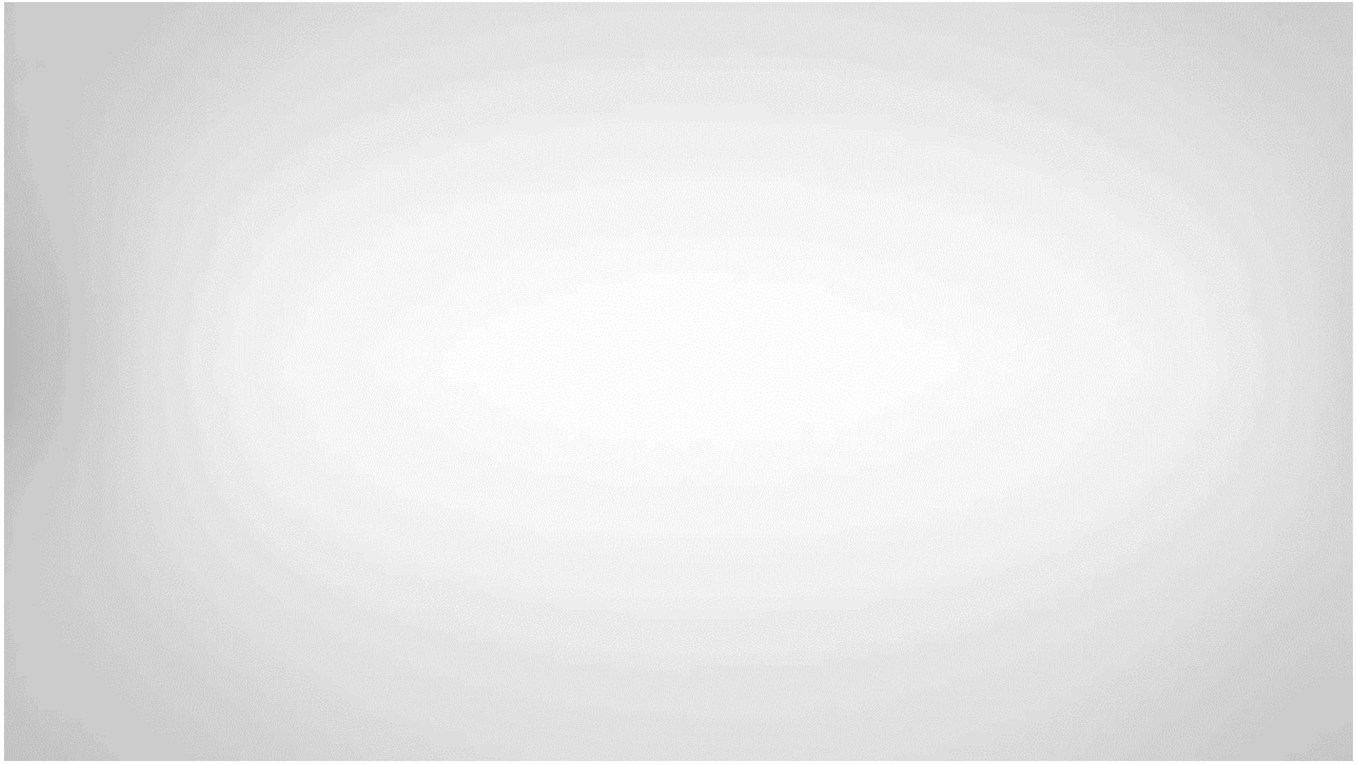
- no limitations on human motion (if appropriate recording method)

- requires **recording** and **embodiment** mapping identification

Programming by demonstration

Human motion measurement

Measurement by **exoskeleton** from research project in MIT



Melanie Gonick/MIT; MIT's Department of Mechanical Engineering; https://www.youtube.com/watch?v=2-5n2IsdCqU

Programming by demonstration

Human motion measurement

Vision-based human motion measurement

https://www.youtube.com/watch?v=k7AKpO6PkDU&t=

Programming by demonstration

Human motion measurement

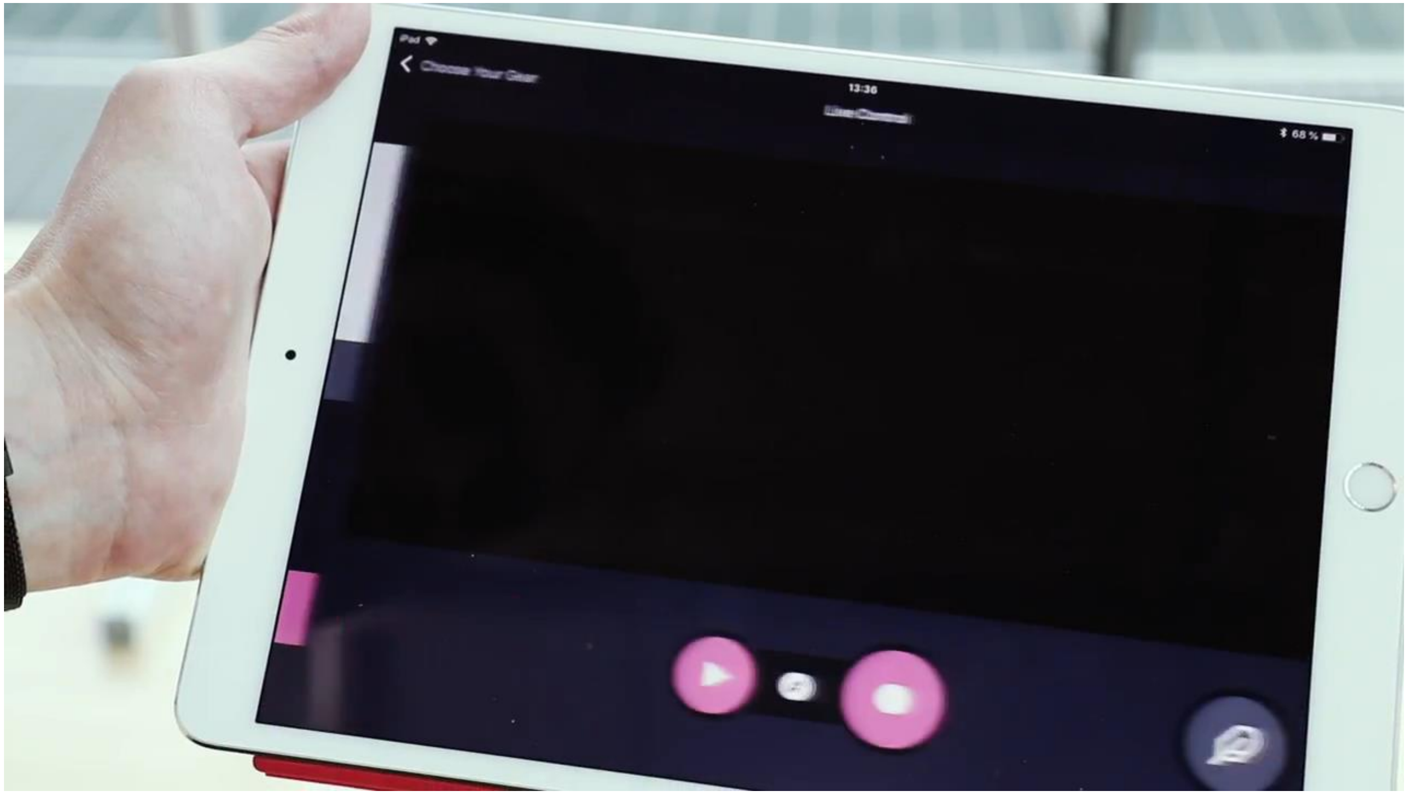
Vision-based human motion measurement: ArUCo marker

Demo Uliege

Programming by demonstration

Human motion measurement

- **inertial** human motion tracking : A step in the industrial world



http://www.wandelbots.com/

Programming by demonstration

Human motion measurement

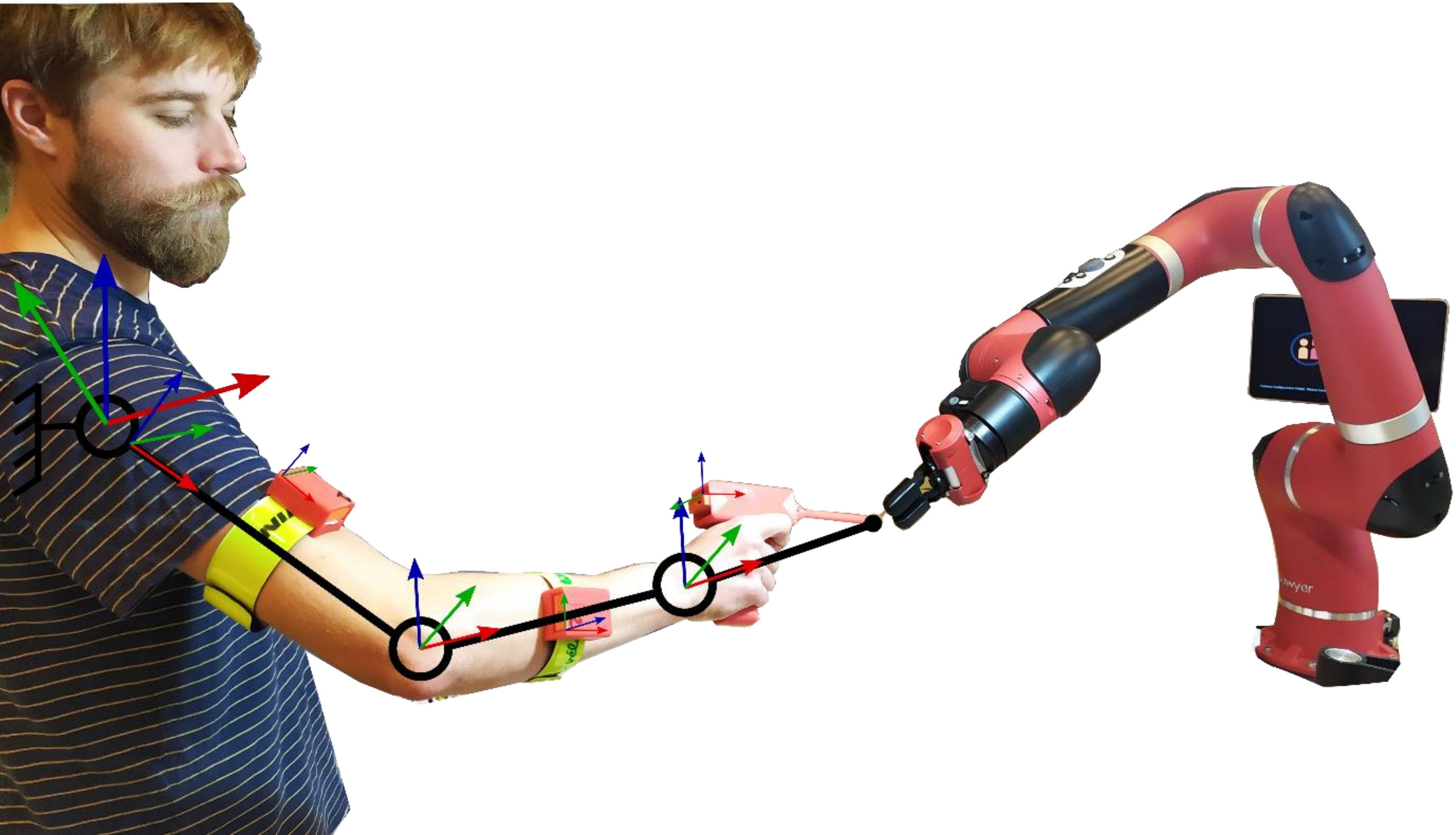
Inertial human motion tracking :

Demo Uliege : teleoperation of the Sawyer robot

Programming by demonstration

Our research :

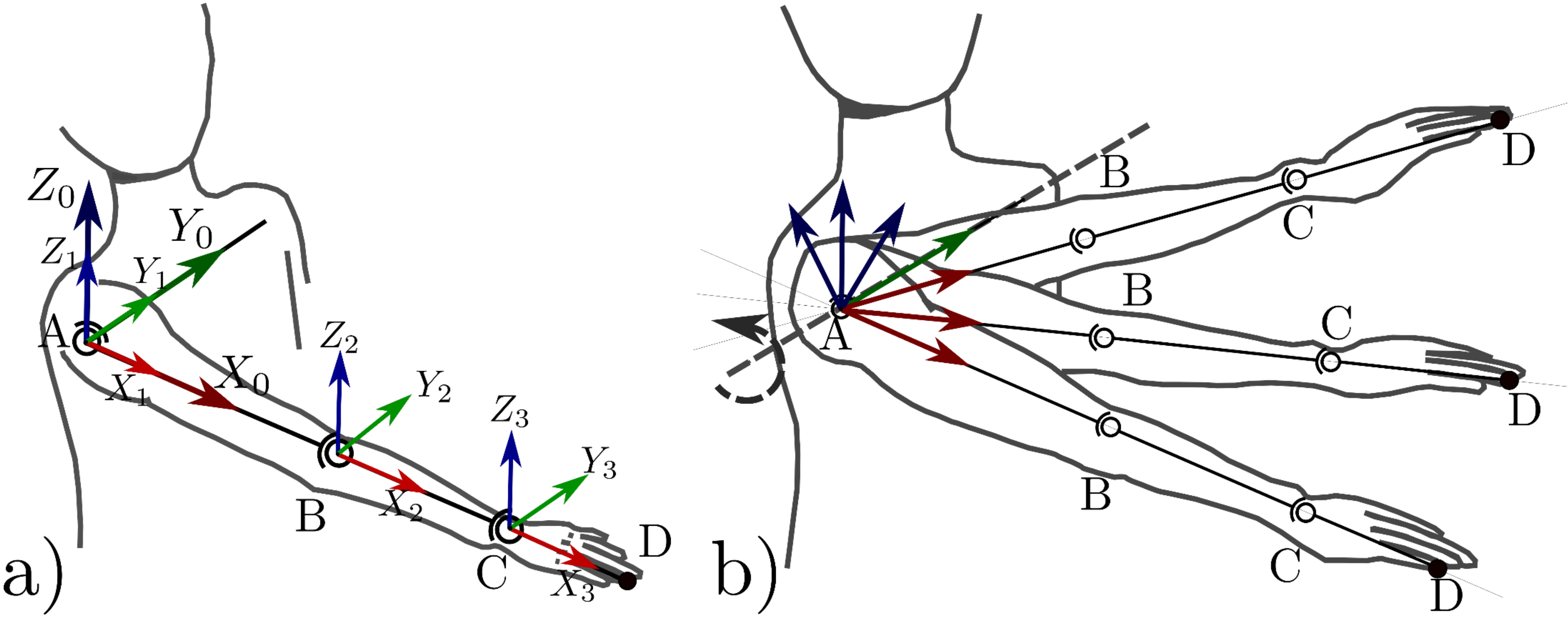
- An **IMU orientation estimation algorithm** based on human motion feature



Programming by demonstration

Our research :

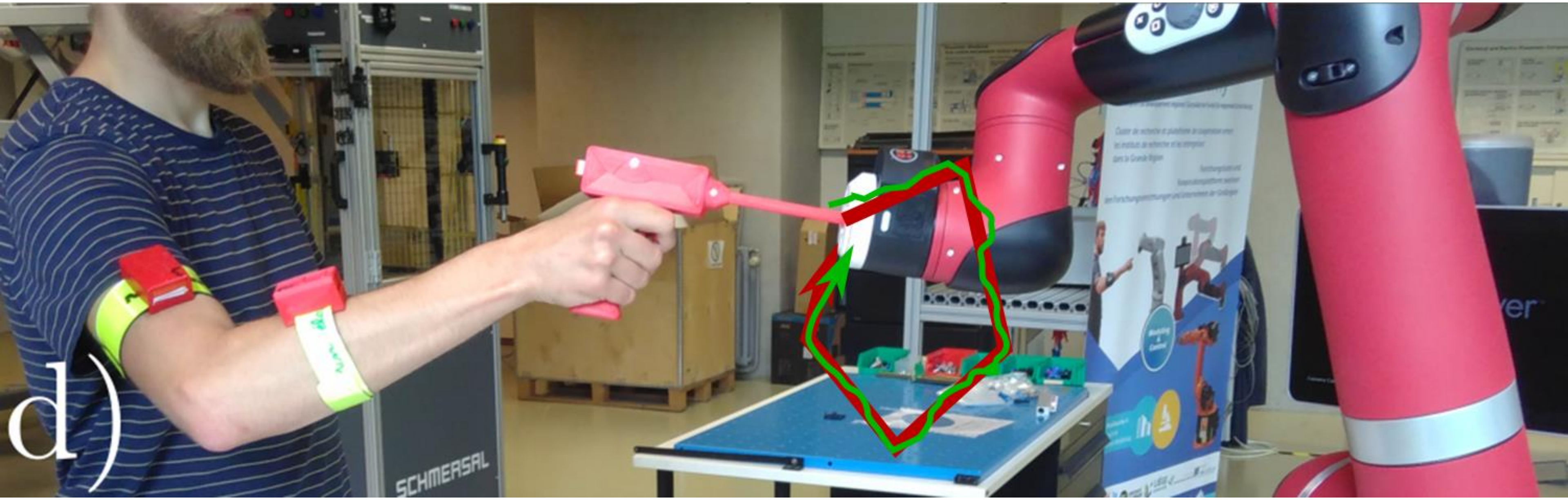
- **Recording mapping** : Algorithm + Initilialization procedure for sensor-to-segment estimation



Programming by demonstration

Our research :

- **Embodiment mapping** : procedure for human-robot transformation estimation
- **Optimization** step to better estimate parameters.



Programming by demonstration

Results :

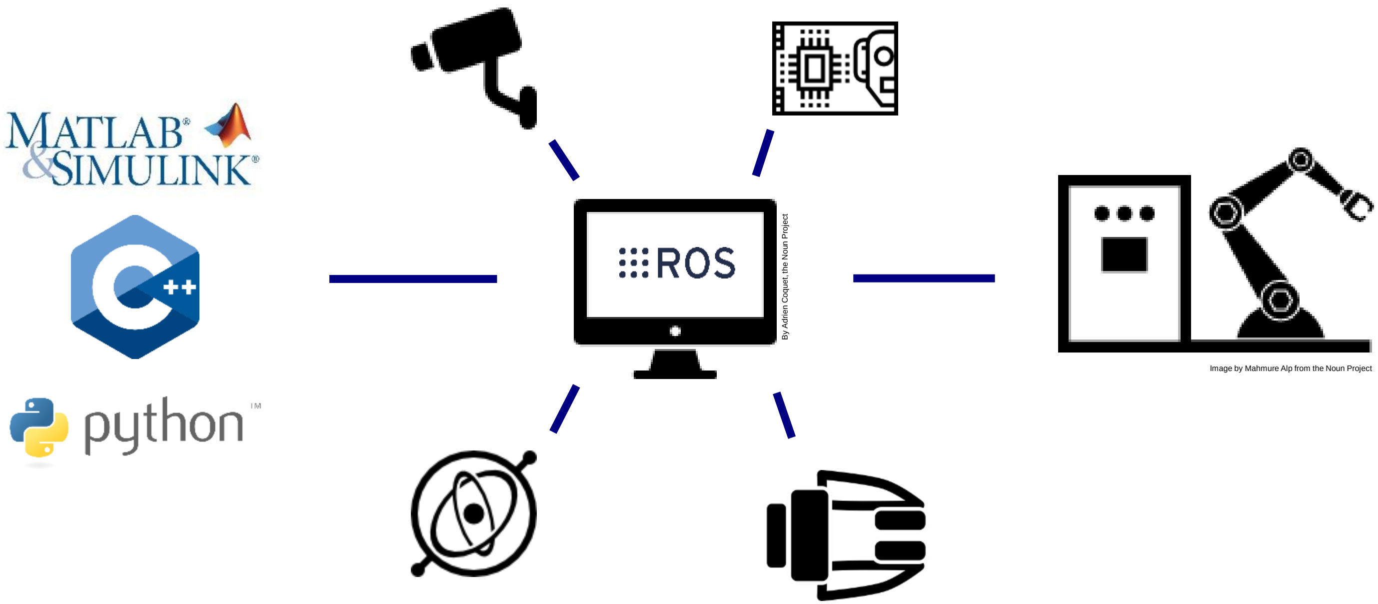
- Human hand trajectory with respect to robot for robot programming by demonstration.
- Lack of accuracy in case of complex tasks (parasitic motion, …).

Perspectives:

- Improve accuracy (using linear acceleration, kinematic constraint, …).
- Merging ArUCo markers and IMU-based tracking method.

ROS – Concept

- Based on **Linux** OS (interfaces with Windows).
- **Communication architecture** between systems (via « Subscriber/Publishers »).
- OpenSource, large community



- ROS-Industrial

Programming by demonstration

Extracting Policy

1) Mapping function
   - learning an approximation to the state-action mapping

2) System model
   - learning a model of the world dynamics and deriving a policy from this information

3) Planner

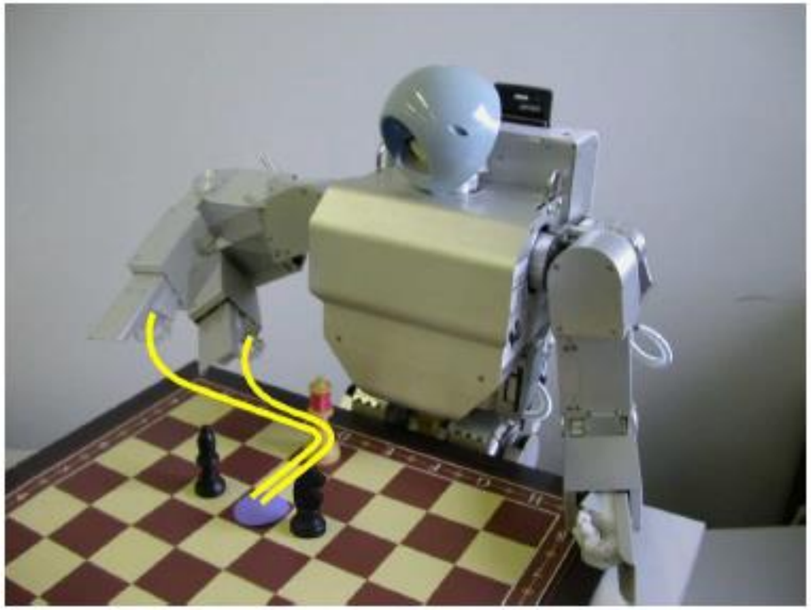
   - using a planner that produces the sequence of actions after learning the model of an action.

Programming by demonstration

Extracting Policy

Example: **A probalistic approach** from LASA in EPFL.

Task: move the white queen between two black bishops. Initial state of the setup is unknown



Calinon, S., Guenter, F., & Billard, A. (2006). On learning the statistical representation of a task and generalizing it to various contexts. *Proceedings - IEEE International Conference on Robotics and Automation*, *2006*(May), 2978–2983. https://doi.org/10.1109/ROBOT.2006.1642154

Programming by demonstration

Extracting Policy

Example: **A probalistic approach** from LASA in EPFL.

Data set from demonstrations :

n demonstrations made by kinesthesy

T measurement points by dmeonstration

The variable **{θ,x,y,h}** are measured at each **T**.

θ = { θt (time) θs (Robot joint angle of the robot) }
x = { xt (time) xs(Robot hand position) }
y = { yt (time) ys (Hand-Object vector) } By vision

h = { ht (time) hs (Robot hand state(close or open)) }

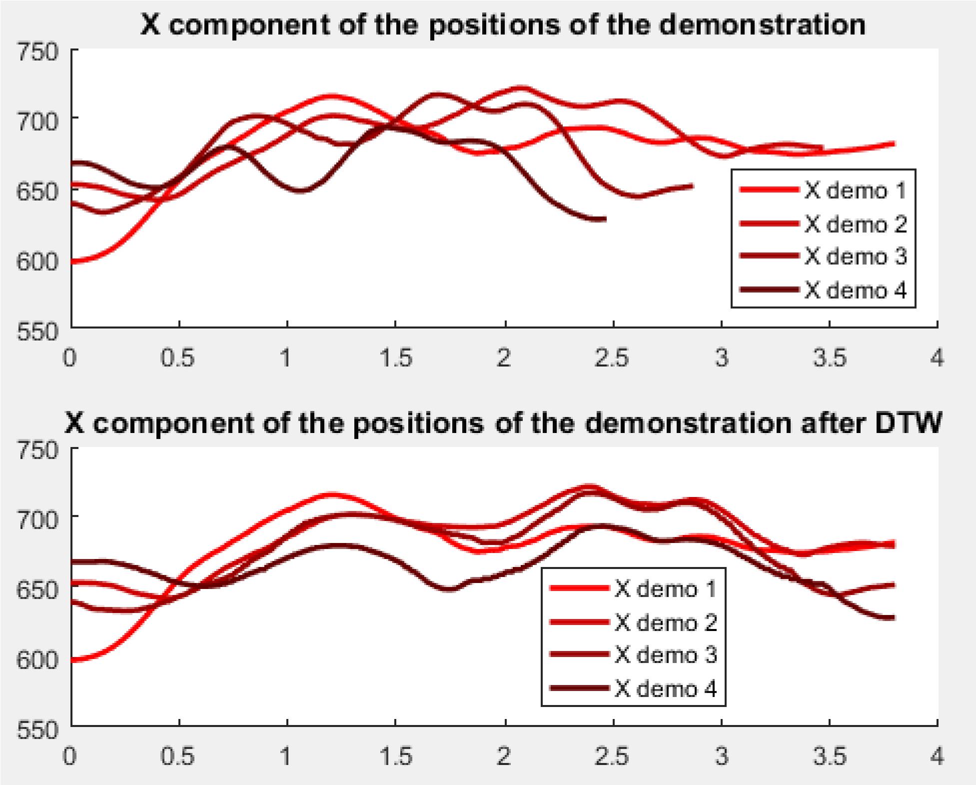
Programming by demonstration

Extracting Policy

Example: **A probalistic approach** from LASA in EPFL.

Process :

1 : DTW algorithm to « align » demonstration.



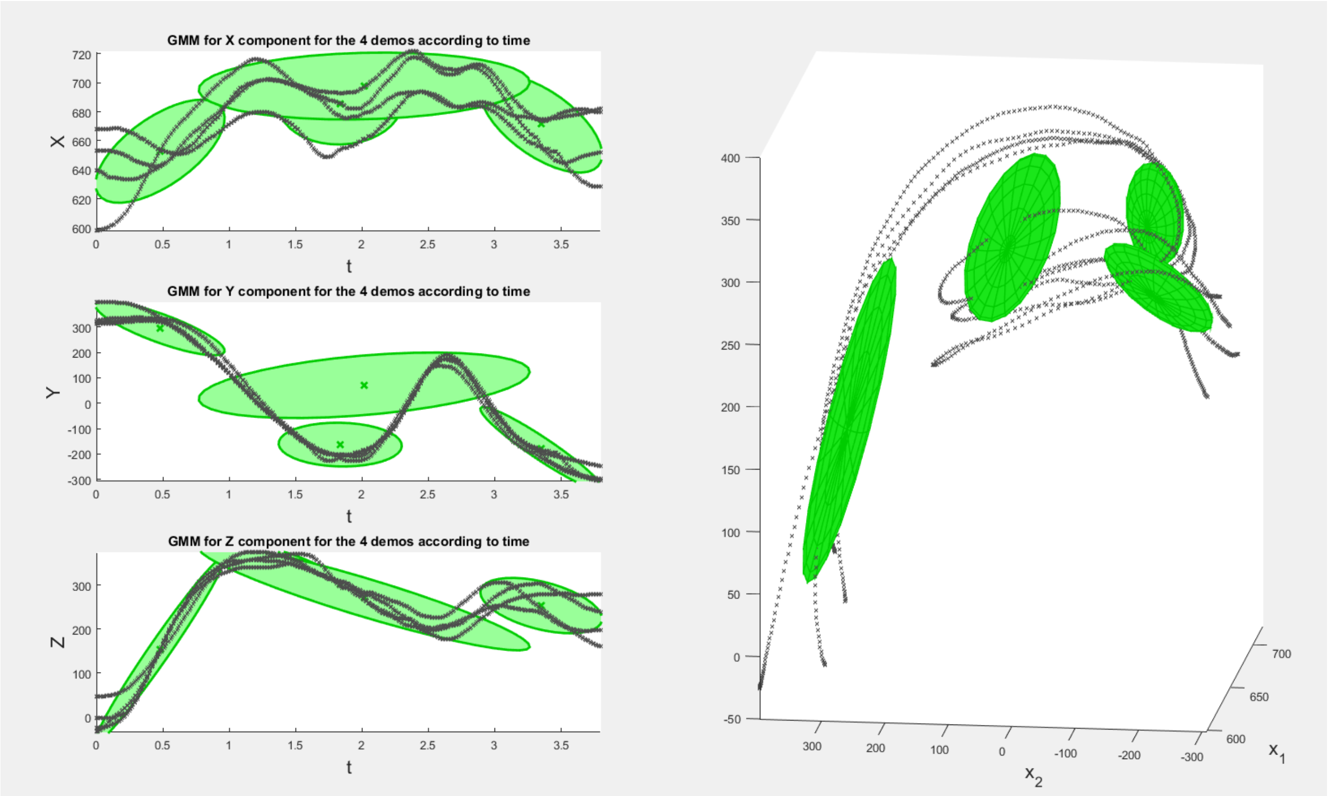
Programming by demonstration

Extracting Policy

Example: **A probalistic approach** from LASA in EPFL.

Process :

2 : Model of the data set with Gaussian Mixture Model



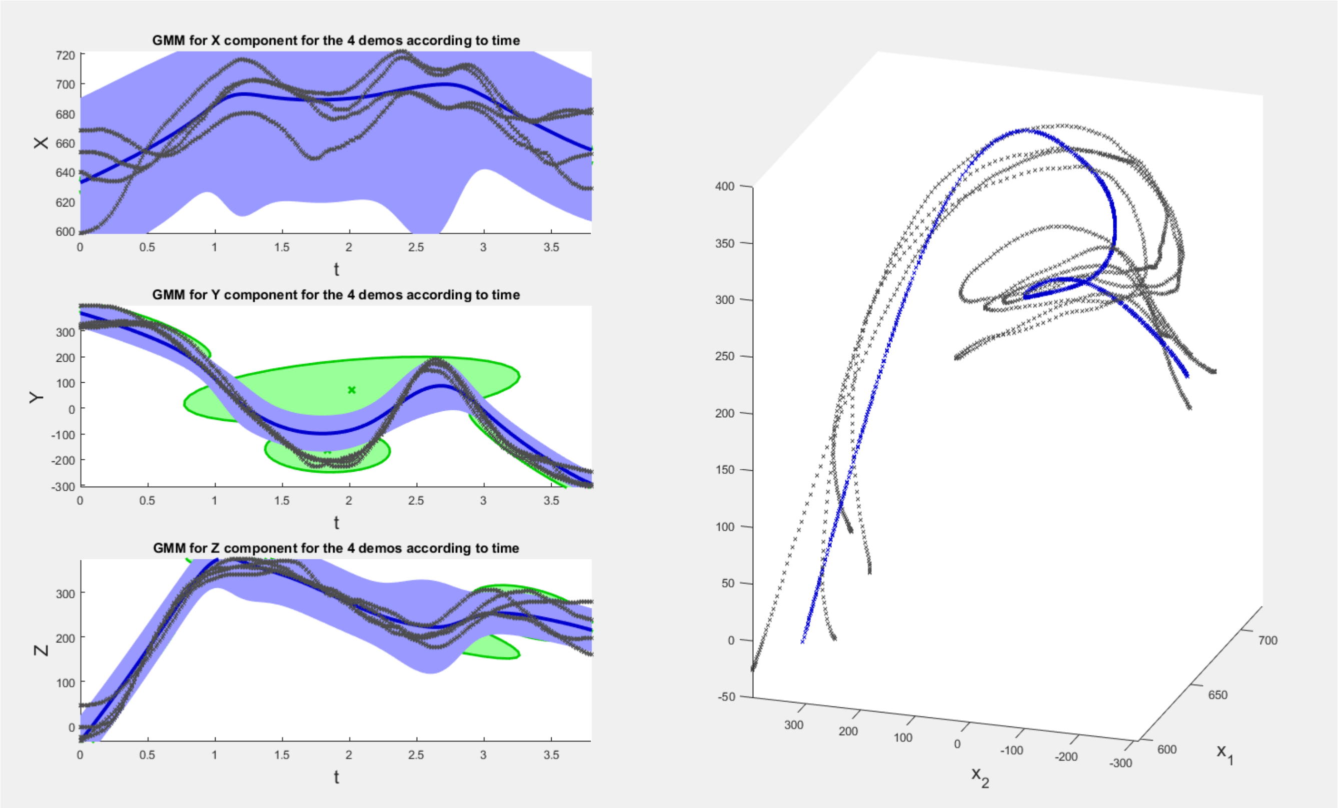
Programming by demonstration

Extracting Policy

Example: **A probalistic approach** from LASA in EPFL.

Process :

2 : Gaussian mixture regression

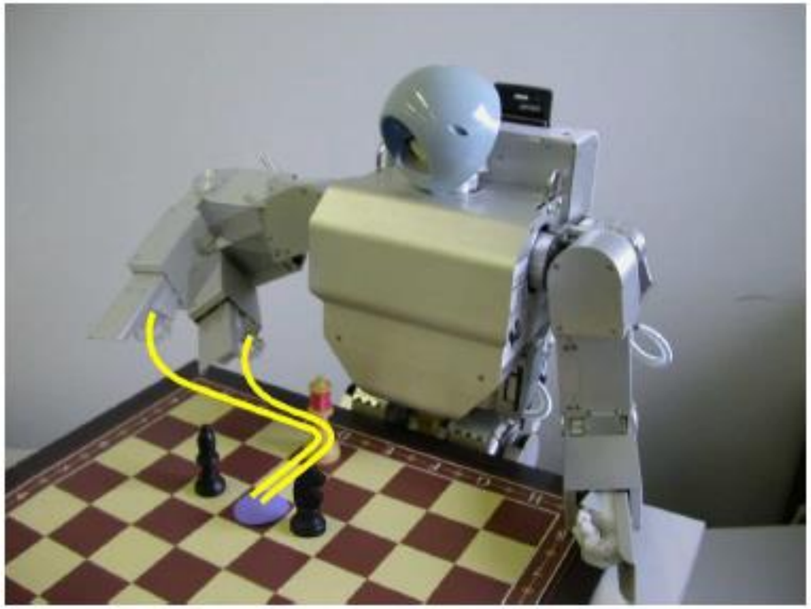


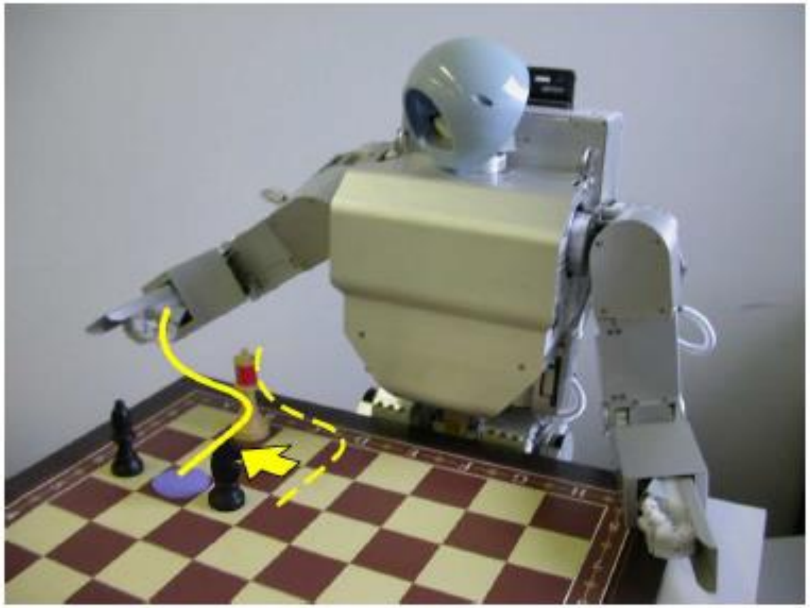
Programming by demonstration

Extracting Policy

Example : **A probalistic approach** from LASA in EPFL.

The task is reproduced succesfully even with an initial configuration different from the demonstration





Conclusion

- With 4.0 industry, robots tends to become cobots and programming method become more and more intuitive.
- Programming by demonstration is new programing method inspired from human interaction.
- In Uliege, we try to find a method for demonstrations :

  - IMU-based
  - new algorithm for IMU orientation estimation
  - Recording and embodiment mapping identification
  - Accuracy could be improved