



Introduction to Robotics

Lecture 11

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Technical Aspects of Multimodal Systems

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Introduction

Spatial Description and Transformations

Forward Kinematics

Robot Description

Inverse Kinematics for Manipulators

Instantaneous Kinematics

Trajectory Generation 1

Trajectory Generation 2

Dynamics

Robot Control

Task-Level planning and Motion planning

Telerobotics

Introduction

Teleoperation classification by input devices





Outline (cont.)

Bilateral control and force feedback

Go beyond teleoperation

Architectures of Sensor-based Intelligent Systems

Summary

Conclusion and Outlook

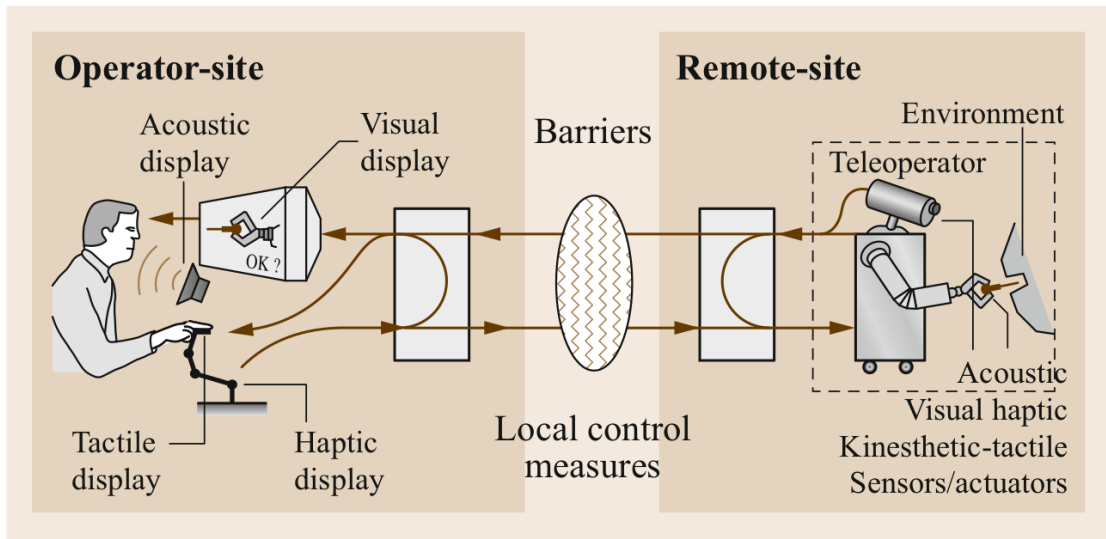






- ▶ Human-in-the-loop
- ▶ Handle unknown and hazardous environments
- ▶ Take fast decisions and dealing with corner cases

Telerobotics is perhaps one of the earliest aspects and manifestations of robotics.[16]



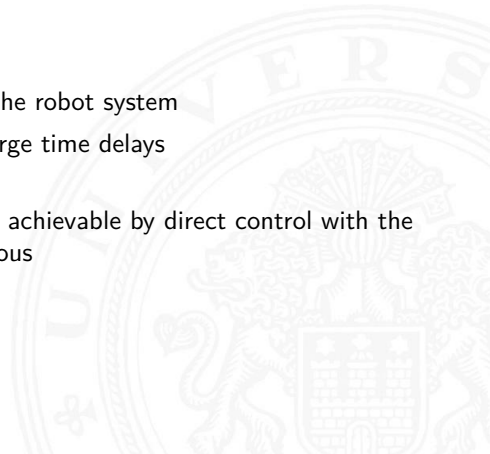


- ▶ *Telerobotics*
- ▶ *Teleoperation*
 - ▶ task-level operations
- ▶ *Telemanipulation*
 - ▶ object-level manipulation
- ▶ *Master-slave systems*
- ▶ *Telepresence*
 - ▶ an ultimate goal of master–slave systems and telerobotics in general
 - ▶ Bilateral telemanipulation





- ▶ *Direct control/manual control*
 - ▶ the user is controlling the motion of the robot directly
- ▶ *supervisory control*
 - ▶ the users only provide high-level commands
 - ▶ allow more autonomy and intelligence to shift to the robot system
 - ▶ is advantageous to the telerobotic systems with large time delays
- ▶ *shared control*
 - ▶ combine the basic reliability and sense of presence achievable by direct control with the smarts and possible safety guarantees of autonomous



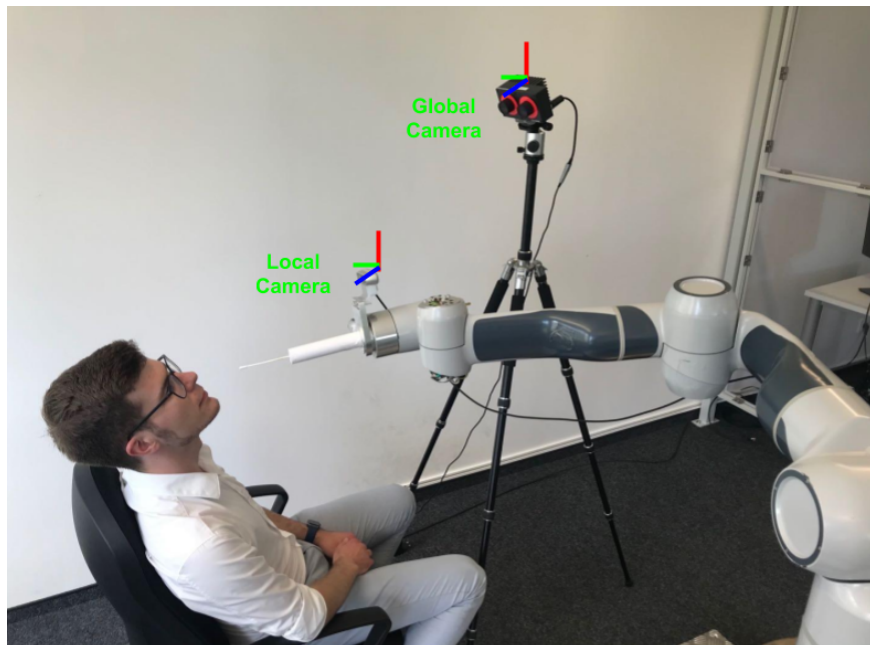
Swab sampling robot – shared control



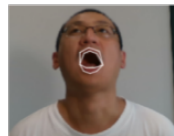
Automatic swab robot



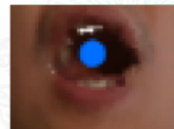
Automatic swab robot



Global Camera



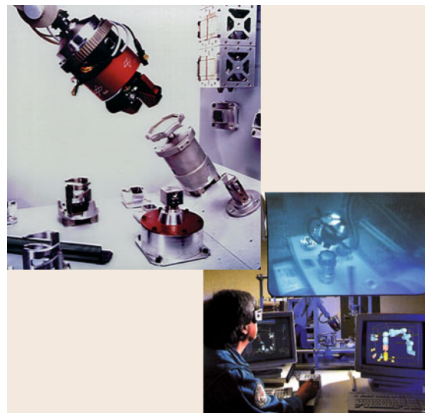
Local Camera



- ▶ Robots in hazardous/unstructured workplaces
 - ▶ Nuclear robots – where telerobotics starts
 - ▶ Space robots
 - ▶ Rescue robots



Raymond C. Goertz



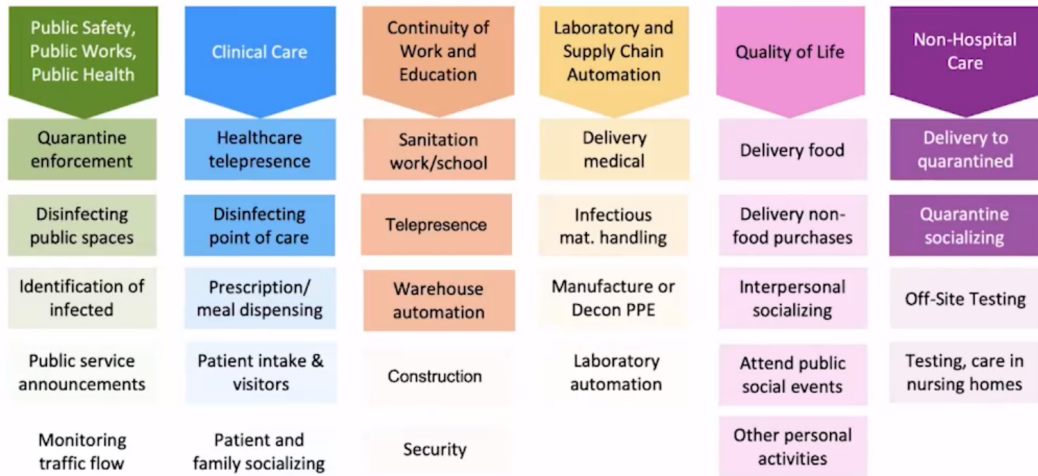
ROTEX

the first teleoperated space robot

- ▶ Medical robots – Da vinci robots

► ICRA2020 Plenary Panel - COVID-19 : How Robotist Can Help?

Applications by Categories

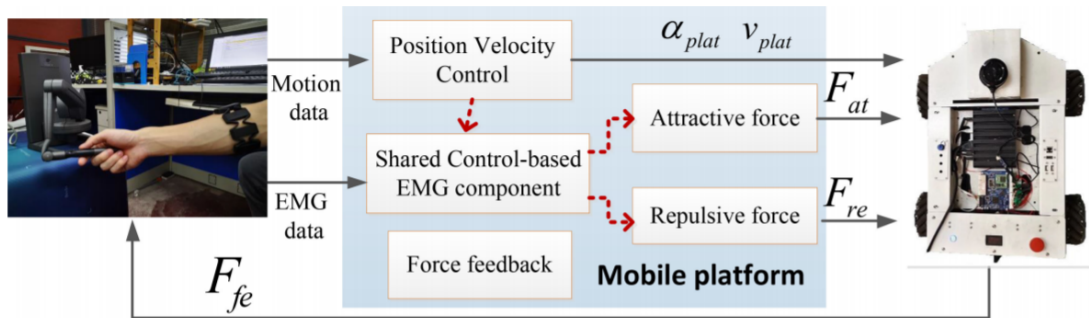


Inventory

- ▶ Surgical robots
- ▶ Incorporate haptic feedback
- ▶ Multisensory (image (endoscopy), haptic, IMU) fusion
- ▶ most are shared control

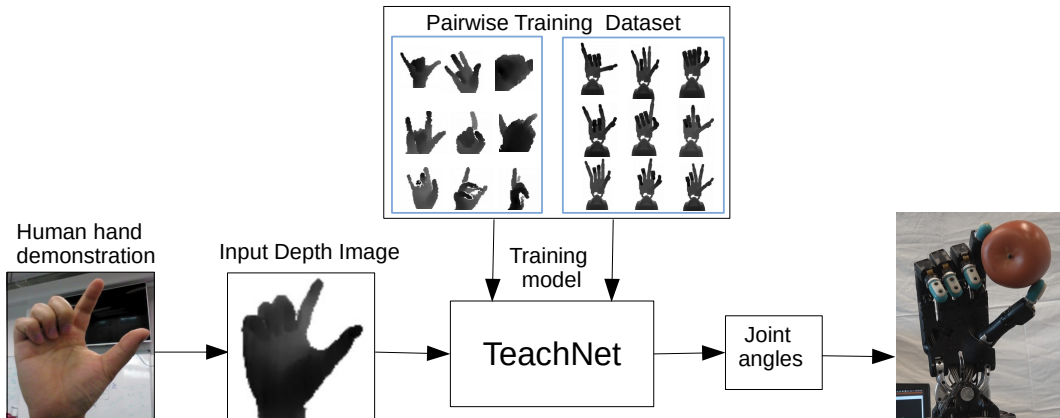


- ▶ Shared control
- ▶ Obstacle avoidance



Teleoperation in a dexterous robotic hand

- ▶ Direct control
- ▶ An end- to-end fashion



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²⁵Li, et al. TeachNet: Vision-based Teleoperation for Shadow Hand. ICRA2019

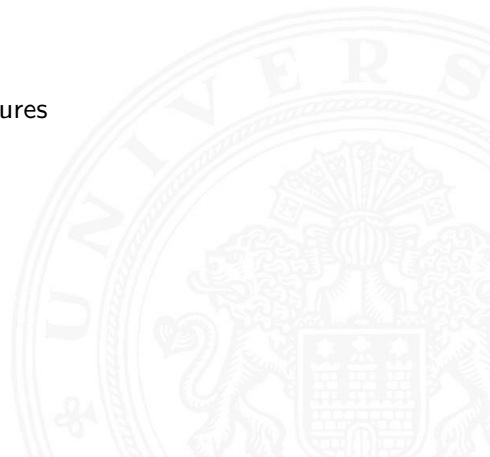


- ▶ joint mapping
- ▶ fingertip mapping
- ▶ pose mapping





- ▶ Time delay
- ▶ Force feedback
- ▶ Teleoperation between dissimilar kinematic structures
- ▶ Multilateral Telerobotics



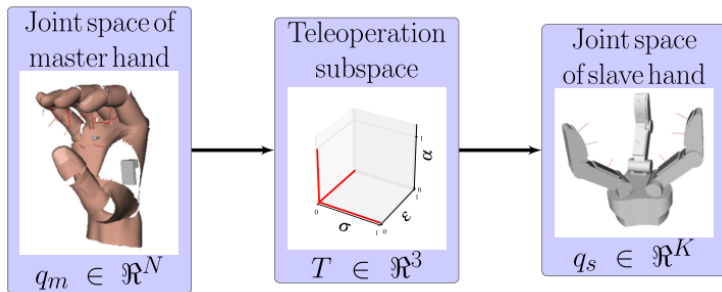


- ▶ Contact devices
 - ▶ Joystick
 - ▶ Apriltags
 - ▶ wearable gloves/suits/glass
 - ▶ Data glove
 - ▶ Optical markers
 - ▶ IMU (Inertial and magnetic measurement unit)
 - ▶ EMG (Electromyography)
 - ▶ VR/AR device
 - ▶ Haptic devices
- ▶ Contactless devices
 - ▶ Depth camera(s)
 - ▶ Ultraleap





- ▶ Cyberglove or wired glove
- ▶ Intuitive Hand Teleoperation
 - ▶ a low-dimensional and continuous teleoperation subspace
 - ▶ mapping between different hand pose spaces



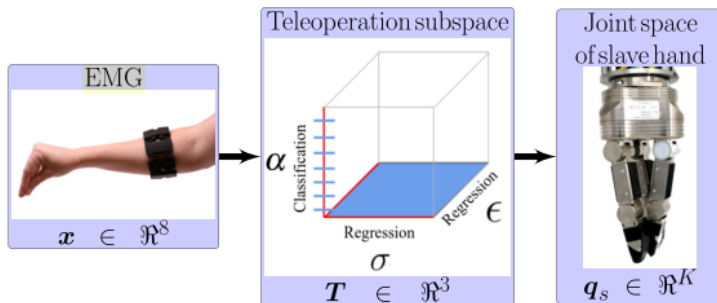
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¹Meeker, et al. Intuitive Hand Teleoperation by Novice Operators Using a Continuous Teleoperation Subspace. ICRA2018

- ▶ Multi-camera motion capture systems, such as PhaseSpace, OptiTrack
 - ▶ accurate point tracking solutions
 - ▶ suits must be customized and easily obstruct natural joint motions
 - ▶ the correspondence problem between markers on the fingers and cameras



- ▶ Commercial devices, such as Myo Armband
- ▶ EMG-controlled hand teleoperation
 - ▶ extracted force information from skeletal muscles through surface EMG
 - ▶ mapping forearm EMG into a subspace relevant to teleoperation



1 2

¹Meeker, et al. EMG-Controlled Hand Teleoperation Using a Continuous Teleoperation Subspace. ICRA2019

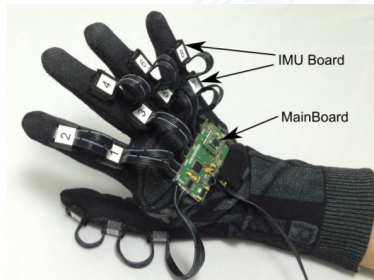
²Wen, et al. Force-guided High-precision Grasping Control of Fragile and Deformable Objects using sEMG-based Force Prediction. ICRA2020

IMU-based teleoperation

- ▶ Commercial devices, such as PerceptionNeuron
- ▶ Sensitive to magnetic/metal environments
- ▶ Convert the orientation, angular velocity and acceleration information of human into the control instruction flow of the robotic hand-arm



PerceptionNeuron



Cie-dataglove



Advantages:

- ▶ Inexpensive
- ▶ Easy to setup and use

Disadvantages:

- ▶ Provide less versatility and dexterity
- ▶ Necessary calibration before start to use it
- ▶ More suitable for robotic arms





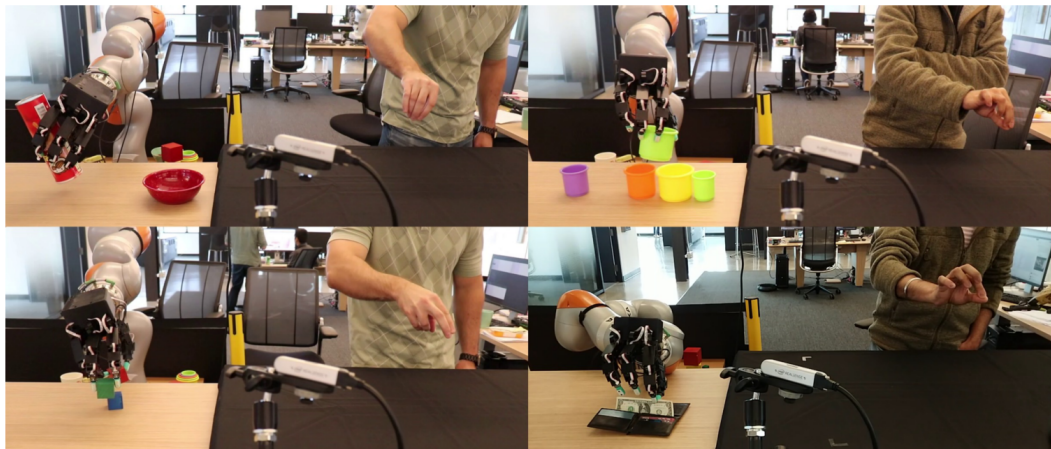
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²⁶Krupke, et al. Comparison of Multimodal Heading and Pointing Gestures for Co-Located Mixed Reality Human-Robot Interaction. IROS2018

DexPilot: Vision Based Teleoperation of Dexterous Robotic Hand-Arm System

Telerobotics - Teleoperation classification by input devices

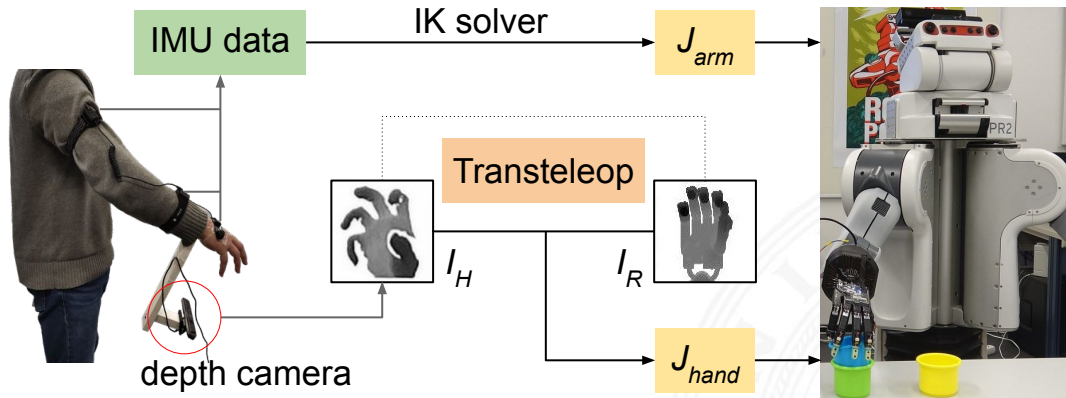
Introduction to Robotics



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²⁷Handa, et al. DexPilot: Vision Based Teleoperation of Dexterous Robotic Hand-Arm System. ICRA2020

A Mobile Robot Hand-Arm Teleoperation System by Vision and IMU



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²⁸Li, et al. A Mobile Robot Hand-Arm Teleoperation System by Vision and IMU. IROS2020



Advantages:

- ▶ Inexpensive
- ▶ Easy to setup and use
- ▶ Allow natural, unrestricted limb motions and be less invasive

Disadvantages:

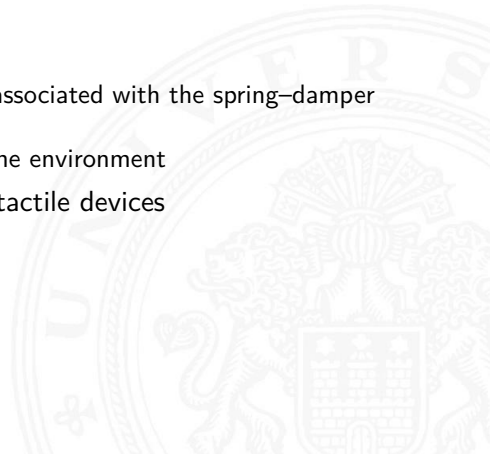
- ▶ Highly based on human cognitive
- ▶ Open-loop control

Future research:

- ▶ Real-time hand tracking to achieve an unlimited workspace for the novice
- ▶ Closed-loop control (slip detection and force estimation)

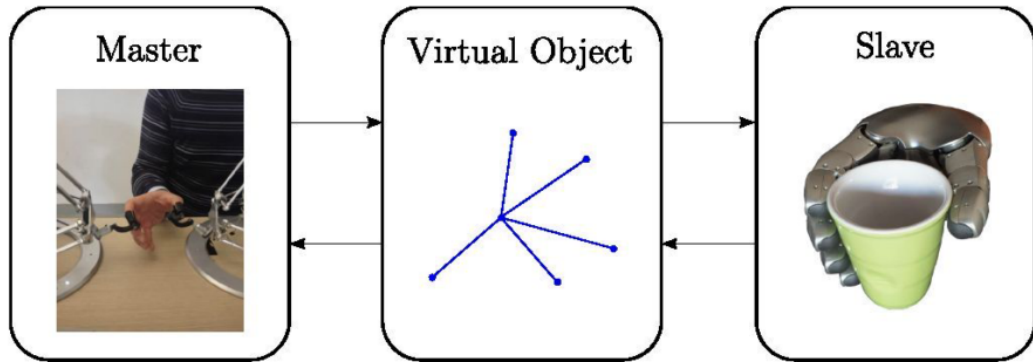


- ▶ Provide both forward and feedback pathways from the user to the environment and back
- ▶ Explicit force feedback
 - ▶ the slave's controller forces, which include forces associated with the spring–damper and slave inertia
 - ▶ the external forces acting between the slave and the environment
- ▶ Also can use alternate displays, such as audio or tactile devices



Object-based Bilateral Telemanipulation

- ▶ The master sub-system setup has two Omega.3 haptic devices
- ▶ The slave robot is a DLR-HIT II Hand.



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²⁹Salvietti, et al. Object-based Bilateral Telemanipulation Between Dissimilar Kinematic Structures. IROS2013

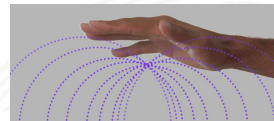
- ▶ CyberTouch (<http://www.cyberglovesystems.com/cybertouch>)
- ▶ HaptX gloves (<https://haptx.com/technology>)
- ▶ Ultraleap (<https://www.ultraleap.com/haptics>)



Cyber Touch



HaptX Gloves



Ultraleap



Imitation learning



Telerobotics

Given demonstrations or demonstrator

demonstrations or demonstrator

Goal train a policy to mimic demonstrations

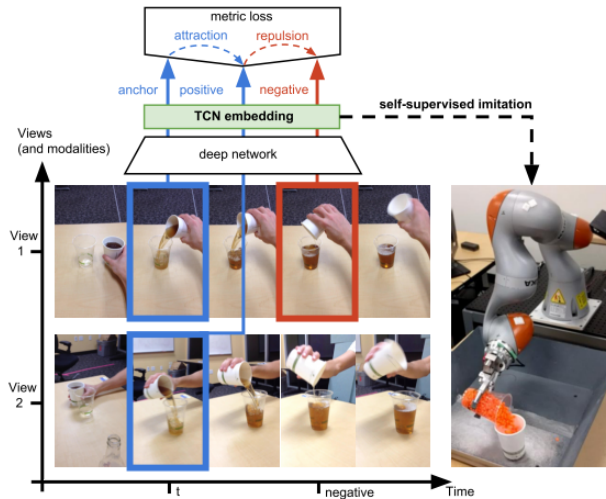
repeat/copy demonstrations

Research goals

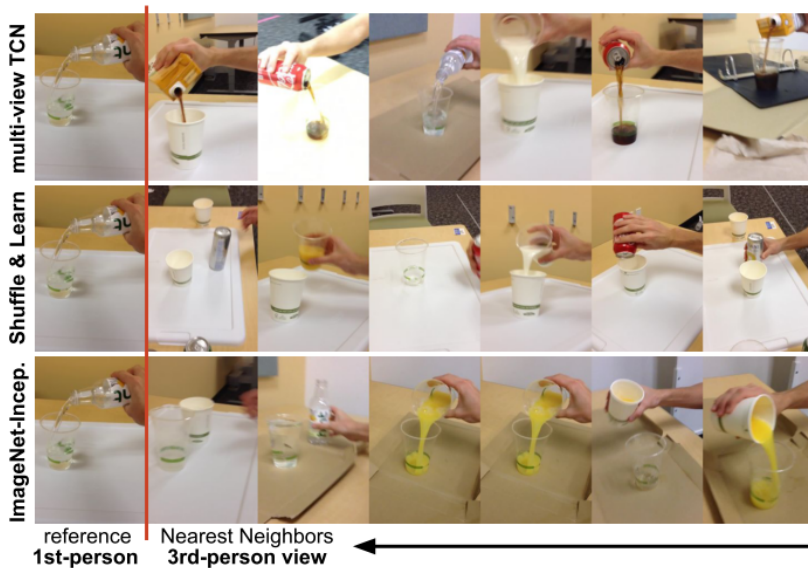
1. Learn suitable representations for understanding object interaction and enabling robotic imitation of a human
2. One-shot/few-shot learning
3. ...

Time-Contrastive Networks (TCN)[17]

- ▶ learn robotic behaviors from unlabeled videos recorded from multiple viewpoints
- ▶ Anchor, positive, negative



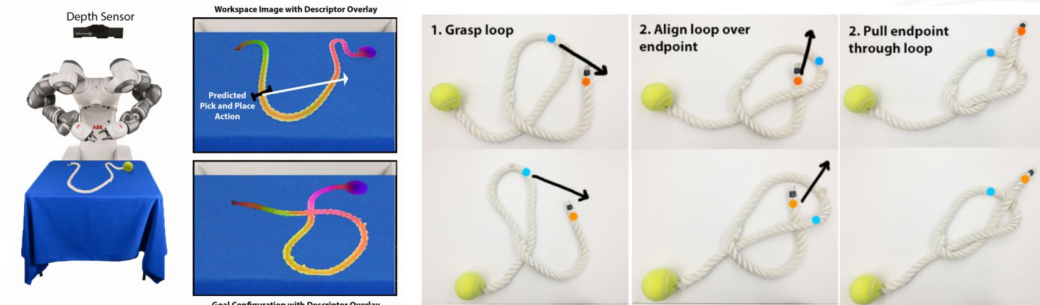
Label-free pose imitation by TCN



Label-free pose imitation by TCN



- ▶ Dense depth object descriptors
- ▶ Learn from video demonstrations
- ▶ Trained on synthetic depth Data

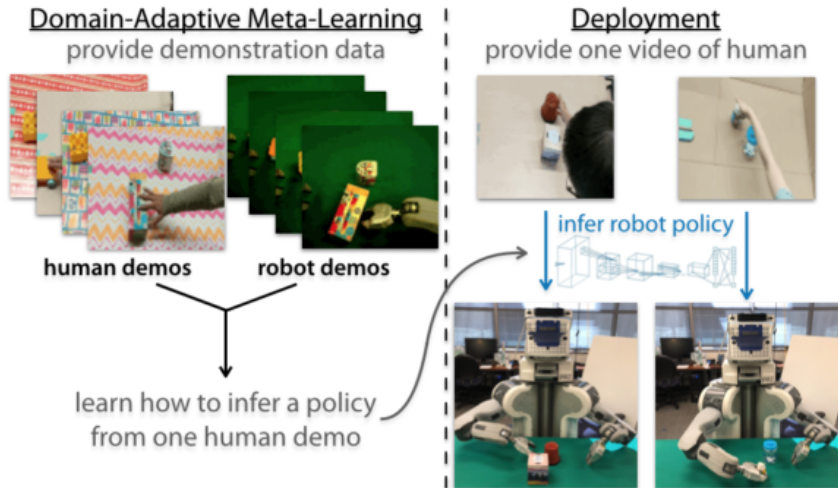


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³⁰Sundaresan, et al. Learning Rope Manipulation Policies Using Dense Object Descriptors Trained on Synthetic Depth Data. ICRA2020

One-shot/few-shot imitation learning

- ▶ quickly learn a new task from a small amount of demonstrations
- ▶ Model-Agnostic Meta-Learning (MAML)[18]





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