Intent detection and somatosensory feedback

#04: Motion tracking (optical, IMU-based)

Claudio CASTELLINI, Sabine THÜRAUF

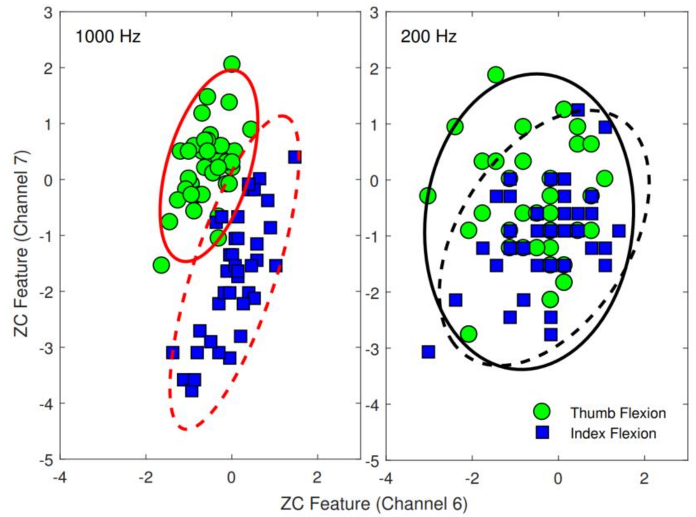


Figure 2. Differences in EMG patterns between using: (**left**) a 1000 Hz sampling rate; and (**right**) a 200 Hz sampling rate. ZC features are extracted from two different EMG channels (6 and 7) during thumb flexion (green circle markers and solid lines) and index flexion (blue square markers and dashed lines). Samples are from Subject 1 of Database 3.

EMG patterns related to two actions. Reproduced from Angkoon Phinyomark, Rami N. Khushaba and Erik Scheme, *Feature Extraction and Selection for Myoelectric Control Based on Wearable EMG Sensors*, MDPI Sensors 2018, 18, 1615

The *rubber hand illusion.* See Botvinick M, Cohen J., *Rubber hands 'feel' touch that eyes see.* Nature. 1998 Feb 19;391(6669):756. doi: 10.1038/35784. PMID: 9486643.

Lecture #04:

More signals for intent detection

- (optical) Motion tracking
- Gaze tracking
- Inertial Measurement Units (IMUs)
- Summary

Optical motion tracking

- does tracking a user‘s movements (motion) tell us anything about her intent?
  - in principle, of course it does
- OMT consists of tracking a person‘s movements by looking at her
  - either using standard cameras (visible light)
  - or specific cameras / emitters / triangulation setup (laser, structured light, near-infrared)
- uses active markers, passive markers or no markers
  - markers need be placed on the subject‘s body
  - and need react to the radiation emitted / detected by the cameras
  - markeless OMT relies on computer vision (very hard problem)
- problem: need bulky equipment all around the user.

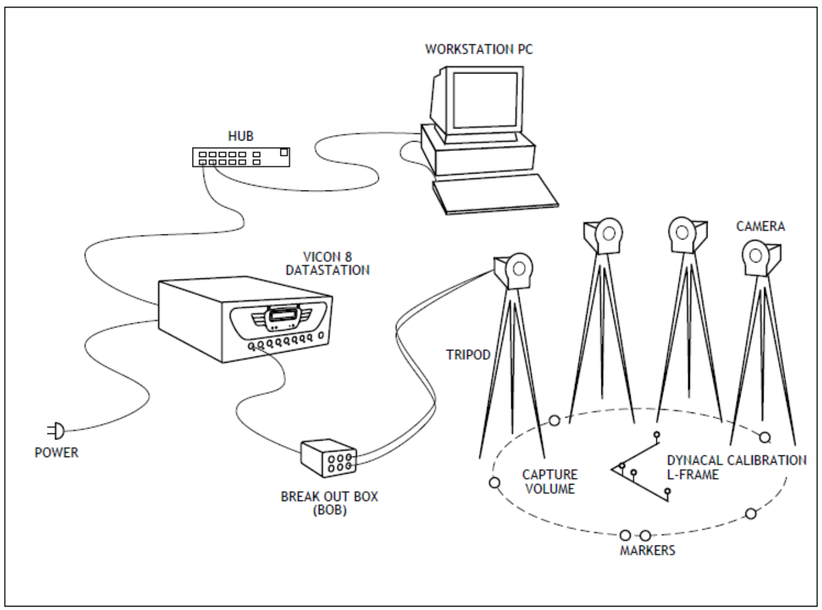
Intent detection and somatosensory feedback

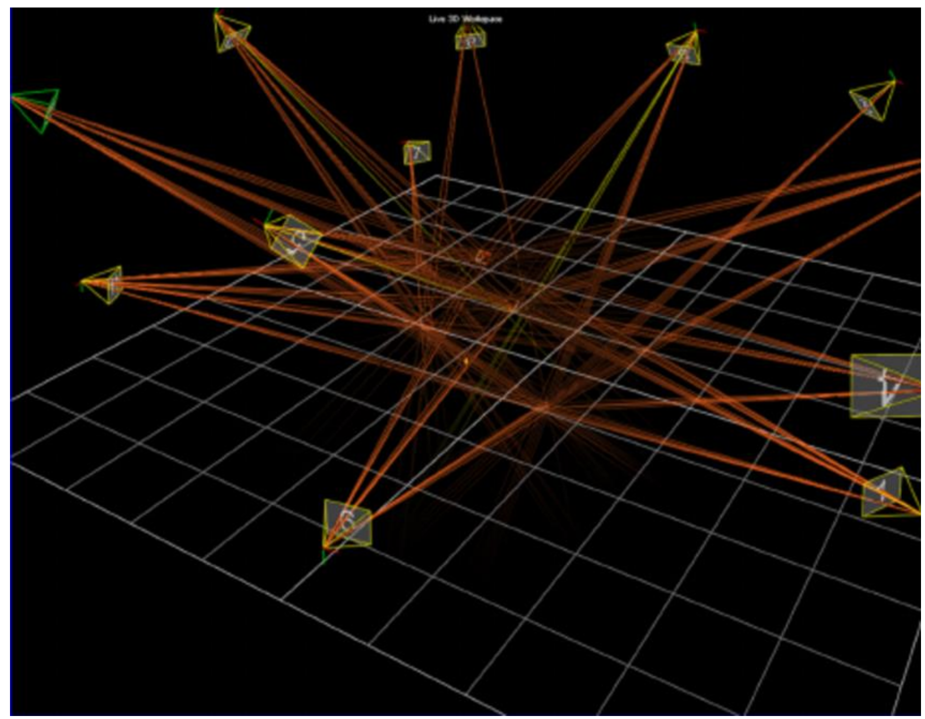
What is the need of the markers?

- To mark the body with dots – algorithm looks at how the dots move around and then reconstruct the posture of the body and motion of the body.
- In marker-based OMT, reflective or active markers are attached to specific points on the subject's body. These markers reflect or emit light, which is then detected by the optical sensors(cameras)
- By tracking the movement of these markers over time, the system can reconstruct the motion of the person's body in three-dimensional space
- Markers are made of adhesive tape that can reflect light
- Markers are so small - can even track single finger movements

Optical motion tracking

- a very popular system: the Vicon.





Optical motion tracking

- a very popular system: the Vicon.

Optical motion tracking

- a very popular system: the Vicon.

Optical motion tracking

- is this intent detection? Yes
- but useless in daily living
- but feasible in a clinic,
- and very useful to measure compensation movements!
  - less compensatory motion means motion more similar to able-bodied persons
  - so, better control and functional recovery
  - Compensation movements refer to adjustments or modifications in movement patterns made by an individual to compensate for limitations, weaknesses, or imbalances in their musculoskeletal system.
  - Identify the wrong movements patients do
  - understanding compensation movements is crucial for facilitating recovery, improving movement quality, and enhancing overall functional performance.
- therefore, used to enhance functional assessment
  - both in prosthetics and rehab

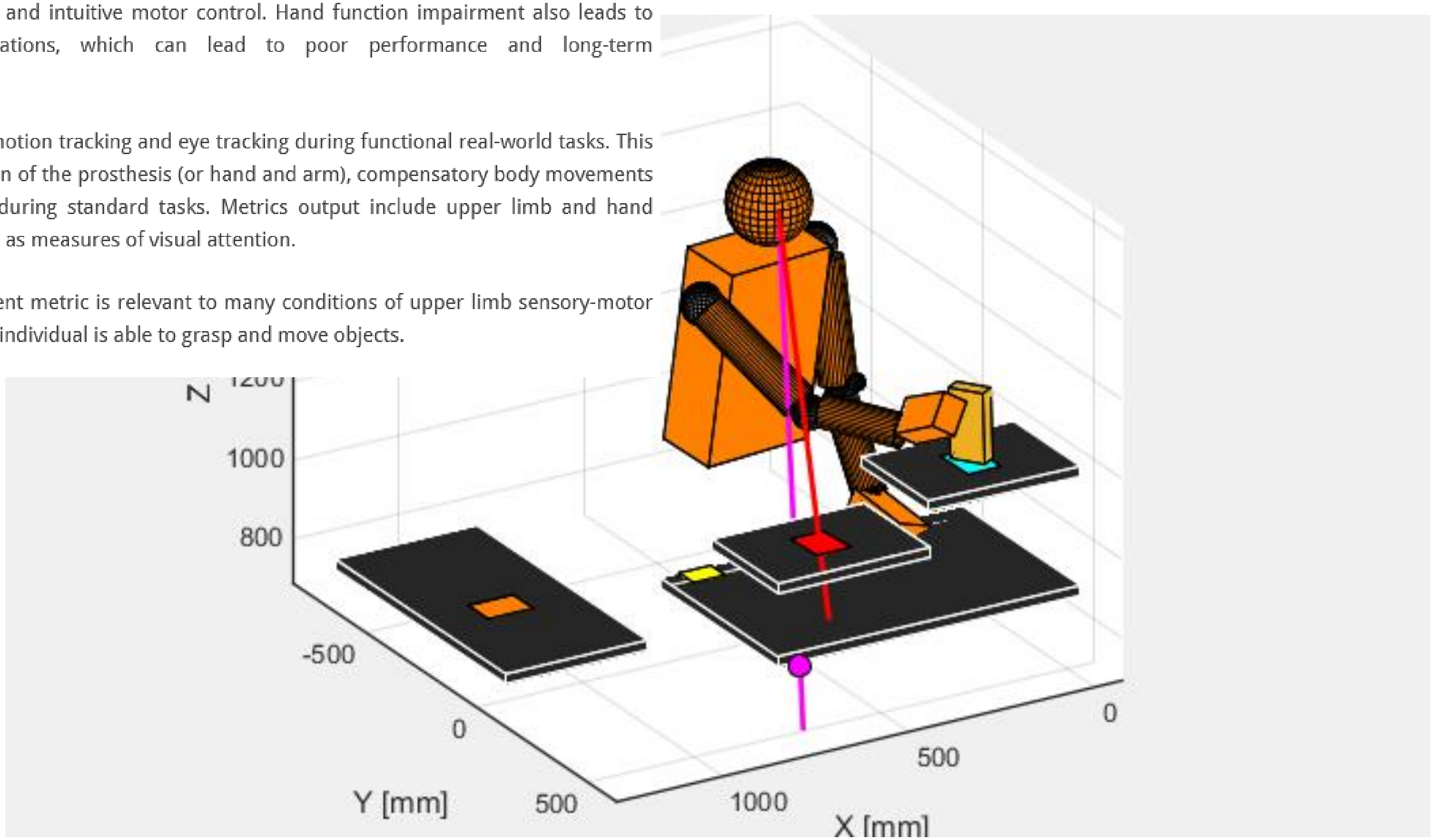
Optical motion tracking

Gaze and Movement Assessment (GaMA)

Rationale: The movement of our eyes to specific locations is intimately tied to the demands of a task. Visual attention is an integral component of motor performance expected to change with accurate sensory feedback and intuitive motor control. Hand function impairment also leads to proximal body compensations, which can lead to poor performance and long-term complications.

Method: GaMA combines motion tracking and eye tracking during functional real-world tasks. This metric quantifies the motion of the prosthesis (or hand and arm), compensatory body movements and visual gaze behavior during standard tasks. Metrics output include upper limb and hand kinematic measures as well as measures of visual attention.

Applicability: This assessment metric is relevant to many conditions of upper limb sensory-motor impairment, so long as the individual is able to grasp and move objects.



https://blinclab.ca/research/gama

Intent detection and somatosensory feedback

GaMA stands for Gaze and Movement Assessment. It's a method for evaluating how well someone with an upper limb impairment (arm or hand) can perform tasks. Here's a breakdown of the key points:

Why GaMA was developed (Rationale):

- Our eye movements are closely linked to what we're doing with our hands. This makes eye tracking a good way to assess how well someone controls their hand/arm.
- Good sensory feedback (feeling what your hand is touching) and smooth motor control (moving your hand/arm) are important for hand function. GaMA assumes these will influence how someone looks at objects during tasks.
- People with hand impairments may use other body parts (like their shoulders) to compensate, which can affect performance and cause problems in the long run.

How GaMA works (Method):

- GaMA combines two technologies:
  - **Motion tracking:** This tracks the movement of the impaired limb (prosthesis, hand, or arm) during tasks.
  - **Eye tracking:** This tracks where the person is looking as they perform the tasks.
- GaMA analyzes several things: is it similar to what normal people do?
  - How the impaired limb moves
  - How much the person uses other body parts to compensate
  - Where the person looks while doing the tasks

Who can benefit from GaMA (Applicability):

- GaMA is useful for anyone with an impairment affecting how they sense and move their upper limb (arm or hand).
- As long as the person can still grasp and move objects somewhat, GaMA can be used.

Overall, GaMA provides a more comprehensive picture of upper limb function than traditional methods that only look at movement. By including eye gaze and the potential for compensation, GaMA can be a valuable tool for:

- Assessing a person's current abilities
- Tracking progress over time
- Comparing different treatment options

Heather E. Williams , Craig S. Chapman, Patrick M. Pilarski, Albert H. Vette and Jacqueline S. Hebert, Williams *et al., Myoelectric prosthesis users and non-disabled individuals wearing a simulated prosthesis exhibit similar compensatory movement strategies,* J NeuroEngineering Rehabil (2021) 18:72

Optical motion tracking

Abstract

Background: Research studies on upper limb prosthesis function often rely on the use of simulated myoelectric prostheses (attached to and operated by individuals with intact limbs), primarily to increase participant sample size. However, it is not known if these devices elicit the same movement strategies as myoelectric prostheses (operated by individuals with amputation). The objective of this study was to address the question of whether non-disabled individuals using simulated prostheses employ the same compensatory movements (measured by hand and upper body kinematics) as individuals who use actual myoelectric prostheses.

Methods: The upper limb movements of two participant groups were investigated: (1) twelve non-disabled individuals wearing a simulated prosthesis, and (2) three individuals with transradial amputation using their custom-fitted myoelectric devices. Motion capture was used for data collection while participants performed a standardized functional task. Performance metrics, hand movements, and upper body angular kinematics were calculated. For each participant group, these measures were compared to those from a normative baseline dataset. Each deviation from normative movement behaviour, by either participant group, indicated that compensatory movements were used during task performance.

Results: Results show that participants using either a simulated or actual myoelectric prosthesis exhibited similar deviations from normative behaviour in phase durations, hand velocities, hand trajectories, number of movement units, grip aperture plateaus, and trunk and shoulder ranges of motion.

Conclusions: This study suggests that the use of a simulated prosthetic device in upper limb research offers a reasonable approximation of compensatory movements employed by a low- to moderately-skilled transradial myoelectric prosthesis user.

Intent detection and somatosensory feedback

1. Myoelectric prosthesis users and non-disabled individuals wearing a simulated prosthesis exhibit similar compensatory movement strategies – optical motion tracking was used to track this
2. Both group exhibited the same compensation movements - which are not good, they should be able to behave like normal people.
3. Eye tracking not done in this experiment
4. Grip aperture refers to the width of the opening between your thumb and fingers when you grasp an object.
5. Peak hand velocity refers to the maximum speed reached by the hand during a swinging or throwing motion.
6. Hand distance traveled would be the straight-line distance between the starting point (where your hand was before reaching) and the ending point (where your hand reaches the object)
7. The duration of a phase represents the amount of time it takes for a specific point on the wave (such as a crest or trough) to complete one full cycle.
8. Compared to a normal person, the phase durations for grasping is much higher for other partcipants
9. The grey line is for normal people – peak hand velocity is lower for other participants, whereas hand distance travelled is longer for the participants than normal people.

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Optical motion tracking

Functional task

The Pasta Box Task, developed by Valevicius et al. [46], validated by Williams et al. [51], and used in prior prosthesis user studies [2, 50], mimics the actions of reaching for a kitchen item and moving it to shelves of different heights – thereby including common prosthesis assessment requirements. In this task, the participant is required to perform three movements: *Movement 1* – moving a pasta box from a lower side table immediately to their right (height: 30 inches) to a shelf in front of them (height: 43 inches); *Movement 2* – moving the pasta box to a second shelf at a higher height across the body (height: 48 inches); and *Movement 3* – moving the pasta box back to the starting position on the side table. The

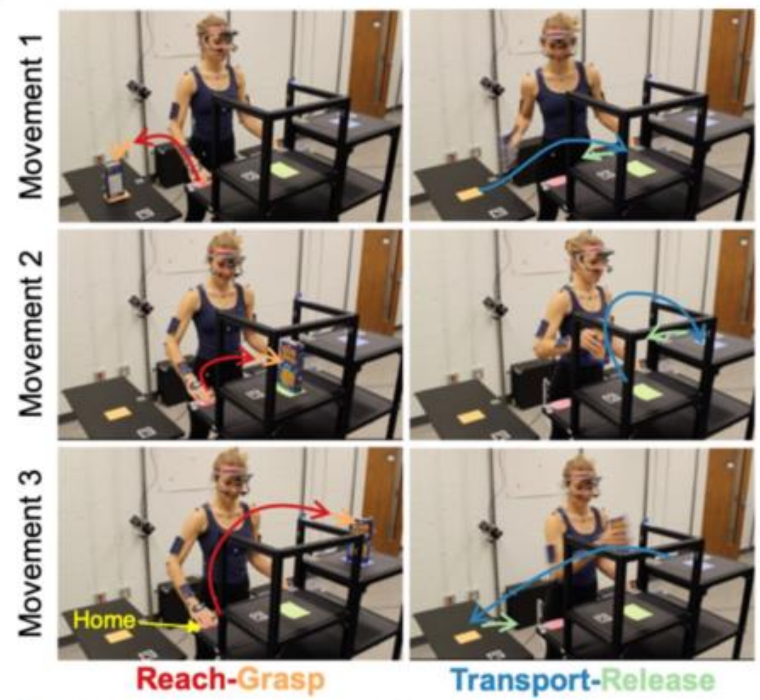

Fig. 1 Pasta Box Task. Sequence of the Pasta Box Task movements (Movements 1, 2, and 3) with the 'home' position labelled. Reach-Grasp and Transport-Release movement segments are colour-coded and illustrated with arrows to show direction. Although this figure shows a normative participant wearing an eye tracking device, eye gaze behaviour data were not analyzed in this study. Reproduced from Valevicius et al. [46] with permission

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Optical motion tracking

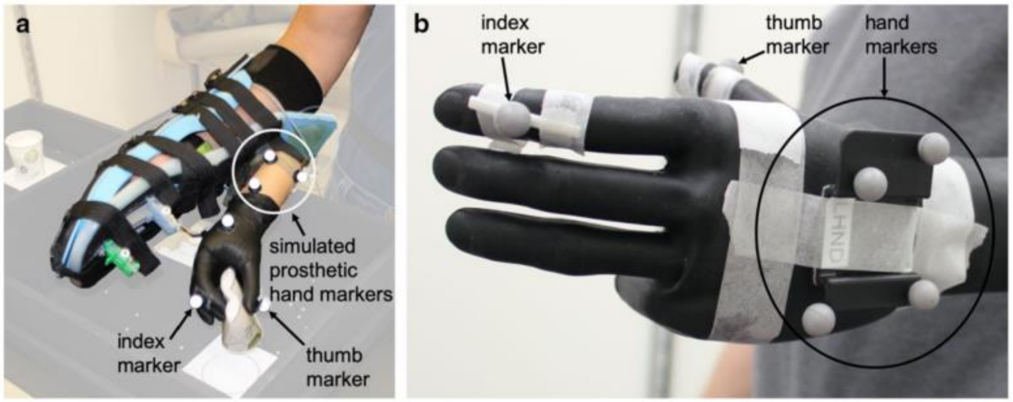

Fig. 2 Motion capture marker placement. Placement on the simulated prosthesis (**a**), and a myoelectric prosthesis (**b**). The unlabelled n
the simulated prosthesis in panel (**a**) was not used for analysis in this study

SP participant experimental setup

A 12-camera Vicon Bonita motion capture system (Vicon Motion Systems Ltd, Oxford, UK) was used to capture the three-dimensional trajectories of motion capture markers affixed to the SP participants at a sampling frequency of 120 Hz. Three individual motion capture markers were affixed to a rigid surface of the simulated prosthesis, along with additional markers on the index finger (middle phalange) and thumb (distal phalange), as shown in Fig. 2a. In accordance with Boser et al.'s *Clusters Only* model, rigid plates, each holding four markers, were placed on the participants' upper arm, trunk, and pelvis [52]. Additional individual markers were placed on the pasta box, shelving unit, and side table, as outlined in the supplementary materials of Valevicius et al. [46].

MP participant experimental setup

An 8-camera Optitrack Flex 13 motion capture system (Natural Point, OR, USA) was used to capture the three-dimensional trajectories of motion capture markers affixed to the MP participants at a sampling frequency of 120 Hz. While these data were collected at a later

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Optical motion tracking

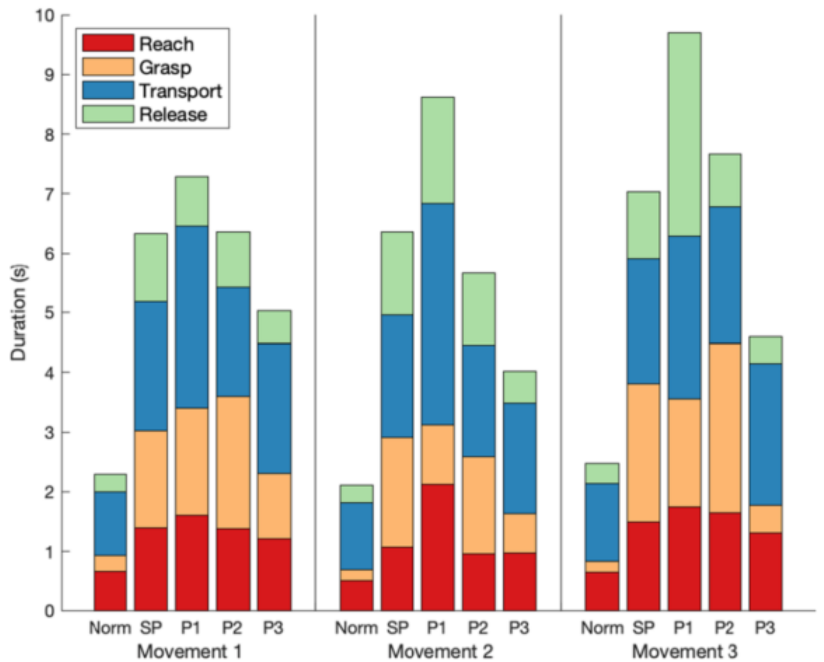

Fig. 3 Phase durations. Average Pasta Box Task durations of normative participants ('Norm'), SP participants, and the three MP participants (P1, P2, P3). These durations are presented for each movement of the task and are divided into Reach, Grasp, Transport, and Release phases, color coded as per legend

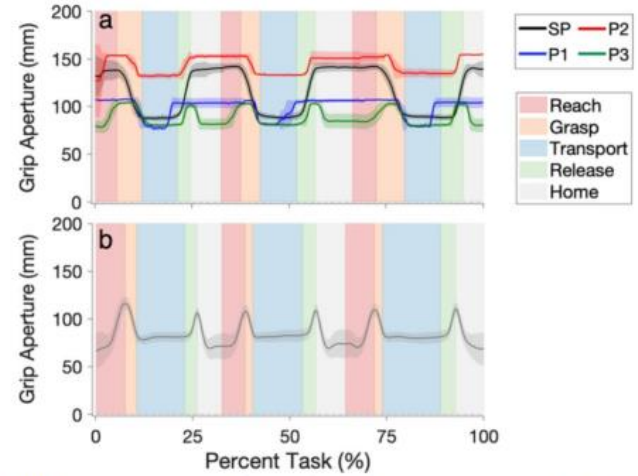

Fig. 5 Grip aperture profiles. Profiles of the SP participants (black) and of the MP participants (P1: blue, P2: red, P3: green) (**a**) and of the normative baseline [46] (grey, **b**) over the course of the Pasta Box Task (all 3 movements). The solid lines represent averages and the shading represents ± 1 standard deviation (between-participant standard deviation is presented for SP participants). The average (all SP and MP participants) relative durations of each phase (Reach, Grasp, Transport, Release, Home) can be inferred from the width of the corresponding colored bars. Grip aperture profiles were time normalized by phase and resampled using these average relative phase durations. Normative grip aperture plots are shown in a separate panel due to the differences between normative relative phase durations and those of the SP and MP participants

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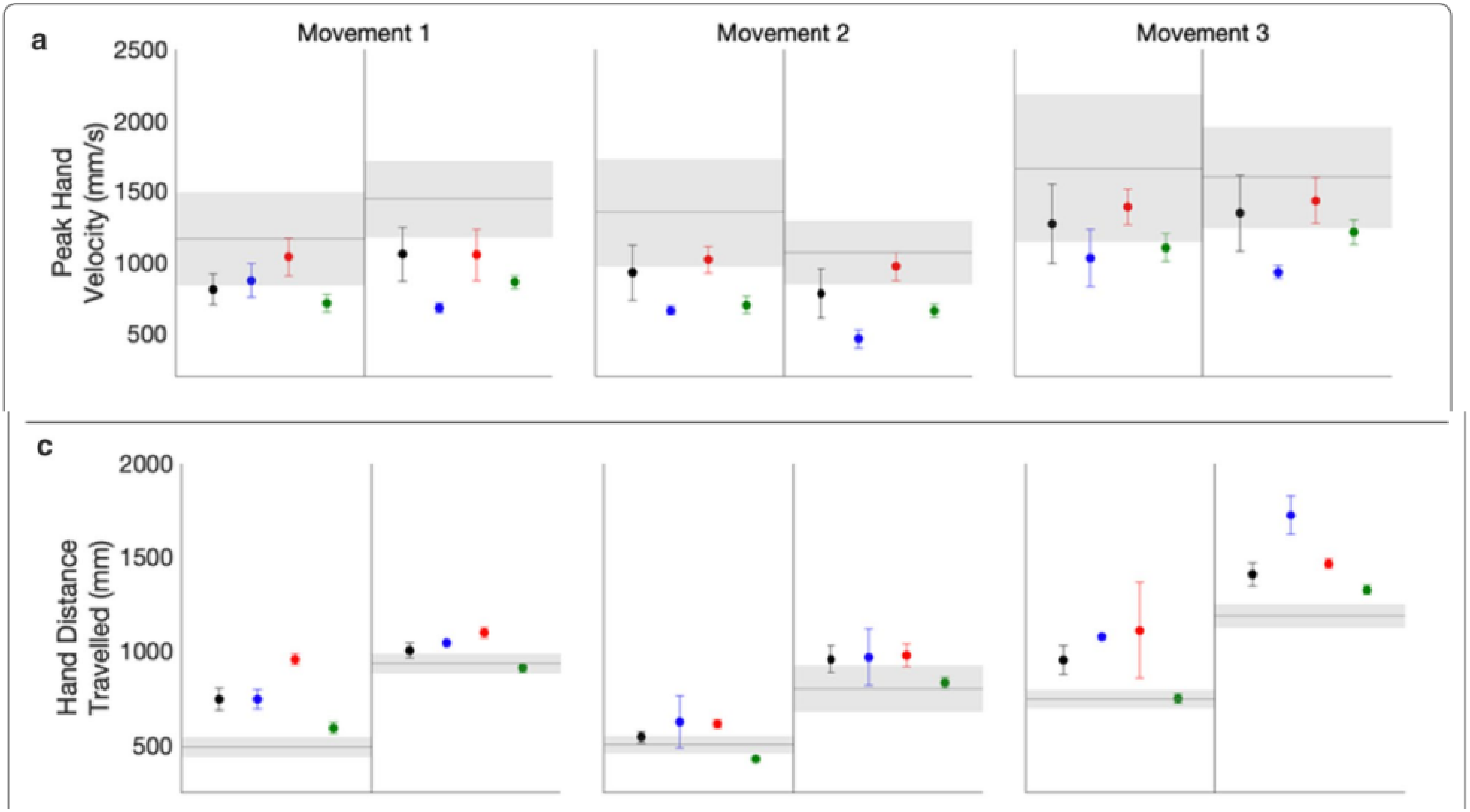


Optical tracking

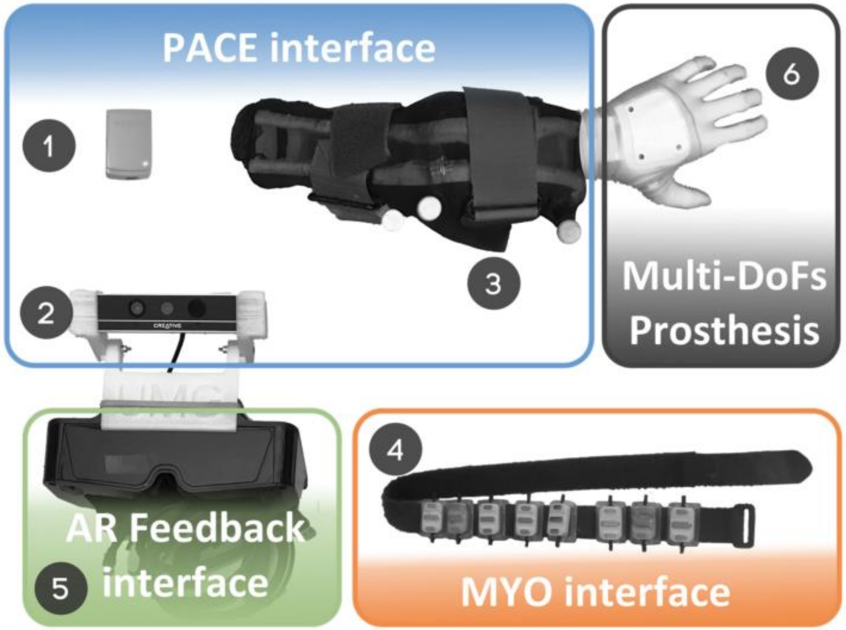
- for the purpose of intent detection, a more practical idea: *tracking the scene* the user is in!
- actually, this is no intent detection…
- …or is it?
- to some extent, it is:
  - if we know what‘s in front of the user,
  - we can have a rehab device autonomously reach and grasp!
- is this feasible at all?
  - inevitably suffers from all computer-vision related problems (illumination, perspective changes, etc.)
  - must be wearable and acceptable
  - must work in real-time and last long
  - must be affordable

Jeremy Mouchoux, Stefano Carisi, Strahinja Dosen , Dario Farina, Arndt F. Schilling and Marko Markovic, *Artificial Perception and Semiautonomous Control in Myoelectric Hand Prostheses Increases Performance and Decreases Effort*, IEEE Trans Rob 2020

Optical tracking

- using AR glasses,
  - identify the objects in the scene (in front of the user),
  - choose one according to proximity to the prosthesis,
  - decide whether to start an autonomous grasp or use sEMG to this purpose.

Abstract—**Dexterous control of upper limb prostheses with multiarticulated wrists/hands is still a challenge due to the limitations of myoelectric man–machine interfaces. Multiple factors limit the overall performance and usability of these interfaces, such as the need to control degrees of freedom sequentially and not concurrently, and the inaccuracies in decoding the user intent from weak or fatigued muscles. In this article, we developed a novel man–machine interface that endows a myoelectric prosthesis (MYO) with artificial perception, estimation of user intention, and intelligent control (MYO–PACE) to continuously support the user with automation while preparing the prosthesis for grasping. We compared the MYO–PACE against state-of-the-art myoelectric control (pattern recognition) in laboratory and clinical tests. For this purpose, eight able-bodied and two amputee individuals performed a standard clinical test consisting of a series of manipulation tasks (portion of the SHAP test), as well as a more complex sequence of transfer tasks in a cluttered scene. In all tests, the subjects not only completed the trials faster using the MYO–PACE but also achieved**



1. Man-machine interface called Myo-Pace. Myo-Pace is designed to assist users with upper limb prostheses that have multiple joints in the wrist and hand.
2. Traditional myoelectric interfaces use a process called pattern recognition to translate a user's muscle signals into specific movements. This can be difficult because it requires the user to consciously control each degree of freedom one at at time. Myo-Pace offers greater ease of use by employing artificial perception to anticipate the user’s goals and automate some aspects of prosthesis control.
3. The article describes a study that compared Myo-Pace to traditional myoelectric control methods. The study involved eight able-bodied subjects and two amputees. The subjects were asked to perform a series of tasks including grasping objects and moving them in a cluttered environment. The researchers found that Myo-Pace enabled subjects to complete the tasks more quickly.
4. The speciality of Myo-Pace as discussed in the paper is its use of artificial perception to anticipate the user's goals and automate some aspects of prosthesis control. This makes it different from traditional myoelectric interfaces that rely on conscious control of each movement. Myo-Pace aims to reduce the complexity of controlling a multi-jointed prosthesis by predicting user intent.
5. AR glasses to track the user's gaze and identify objects they're looking at.

Intent detection and somatosensory feedback

1. **Object Identification**: AR glasses equipped with cameras and computer vision algorithms can analyze the scene in front of the user and identify objects present. This involves recognizing objects based on their visual features, such as shape, color, and texture.
2. **Proximity Assessment**: Once the objects are identified, the system determines their proximity to the user's prosthesis. This may involve calculating the distance between the objects and the prosthesis or assessing their spatial relationship in the user's environment.
3. **Decision Making**:
   1. **Autonomous Grasp**: If an object is within close proximity to the prosthesis and meets predefined criteria (e.g., size, shape, weight), the system may initiate an autonomous grasp. This means that the prosthesis will automatically reach out and grasp the object without any explicit command from the user.
   2. **Volitional Grasp**: If the object is further away or if the user prefers manual control, the system may use sEMG to detect a "volitional" grasp. sEMG sensors attached to the user's residual limb or remaining muscles can detect electrical signals generated when the user intends to move or activate the prosthesis. These signals are then interpreted by the system as commands to initiate a grasp.

Intent detection and somatosensory feedback

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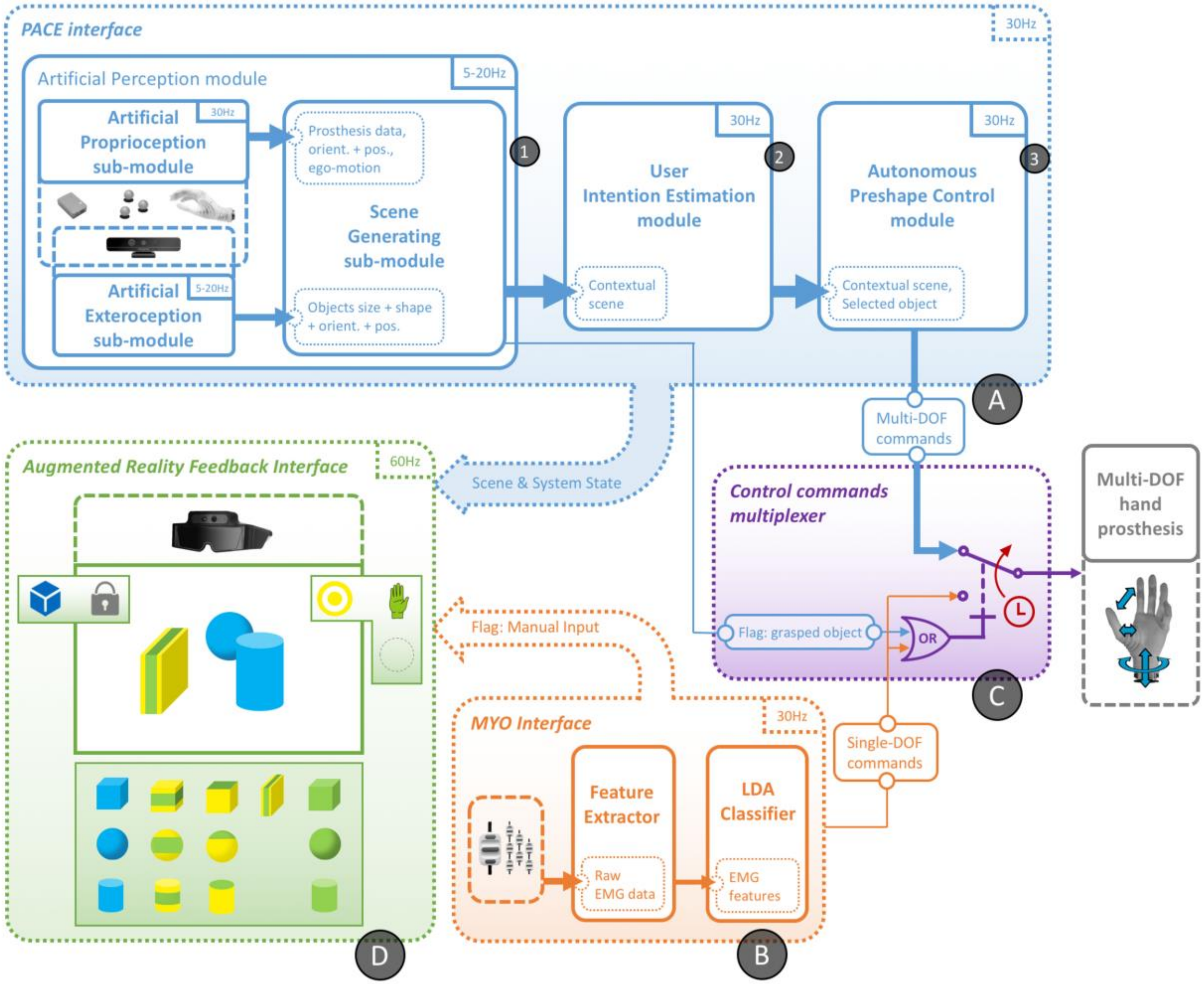
Optical tracking

- using AR glasses,
  - identify the objects in the scene (in front of the user),
  - choose one according to proximity to the prosthesis,
  - decide whether to start an autonomous grasp or use sEMG to detect „volitional“ grasp. (Volitional means done of one's own will or choosing.)



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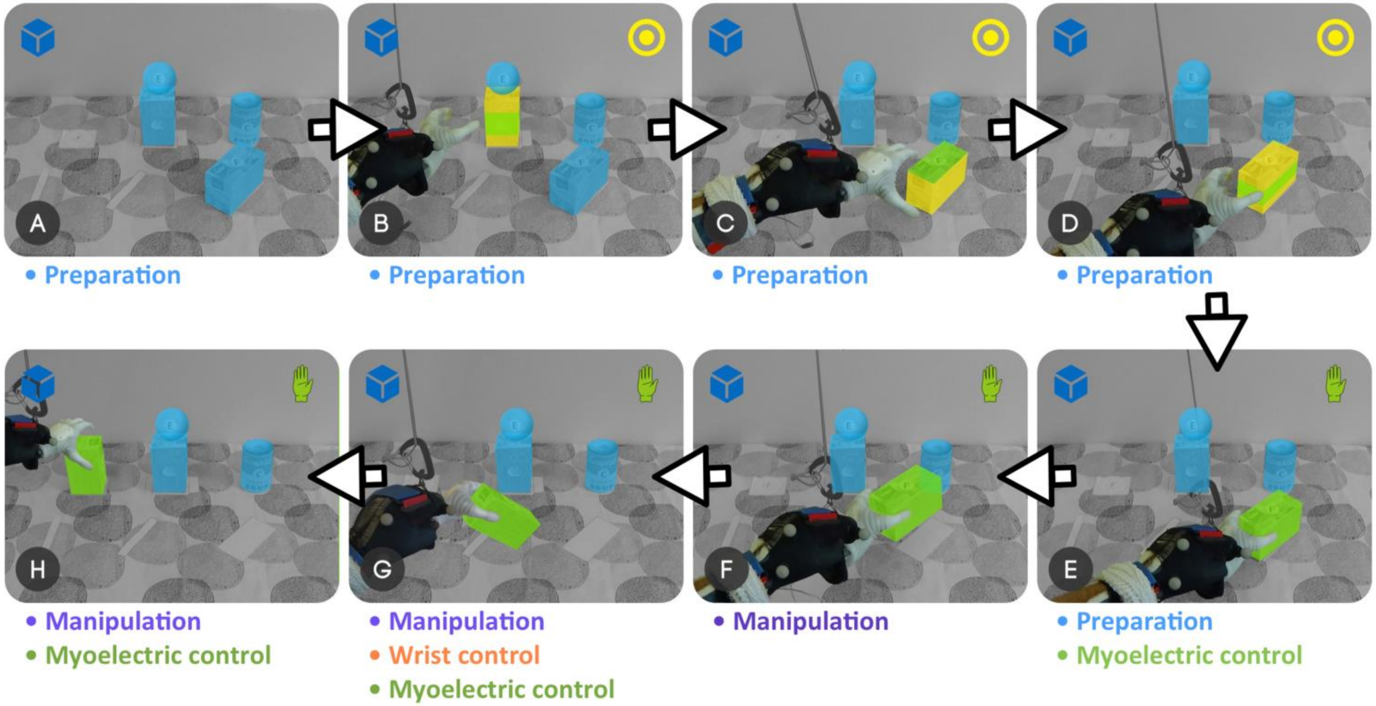

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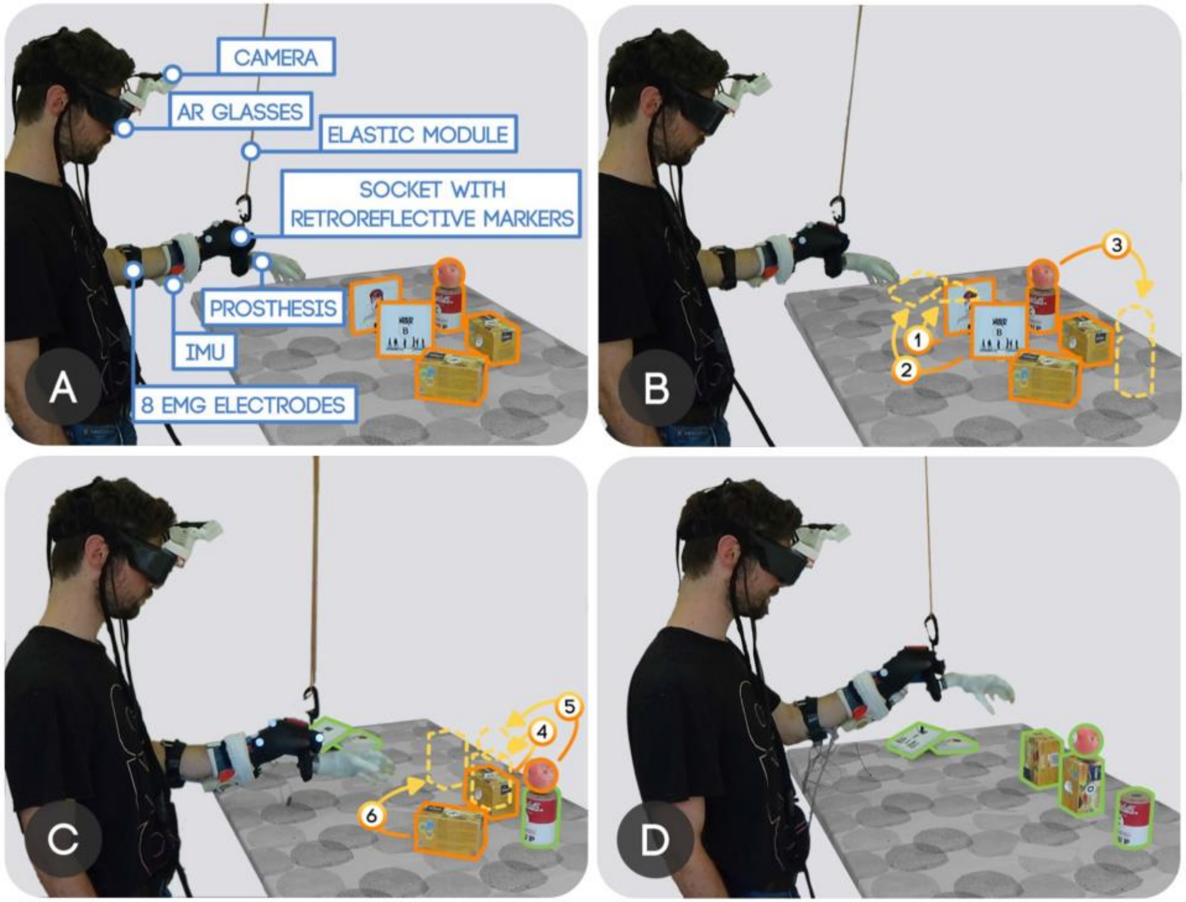

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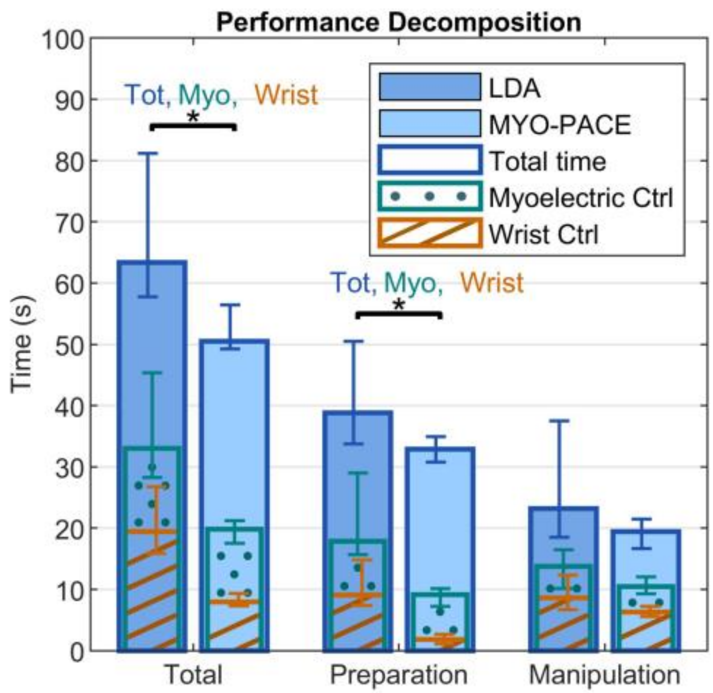
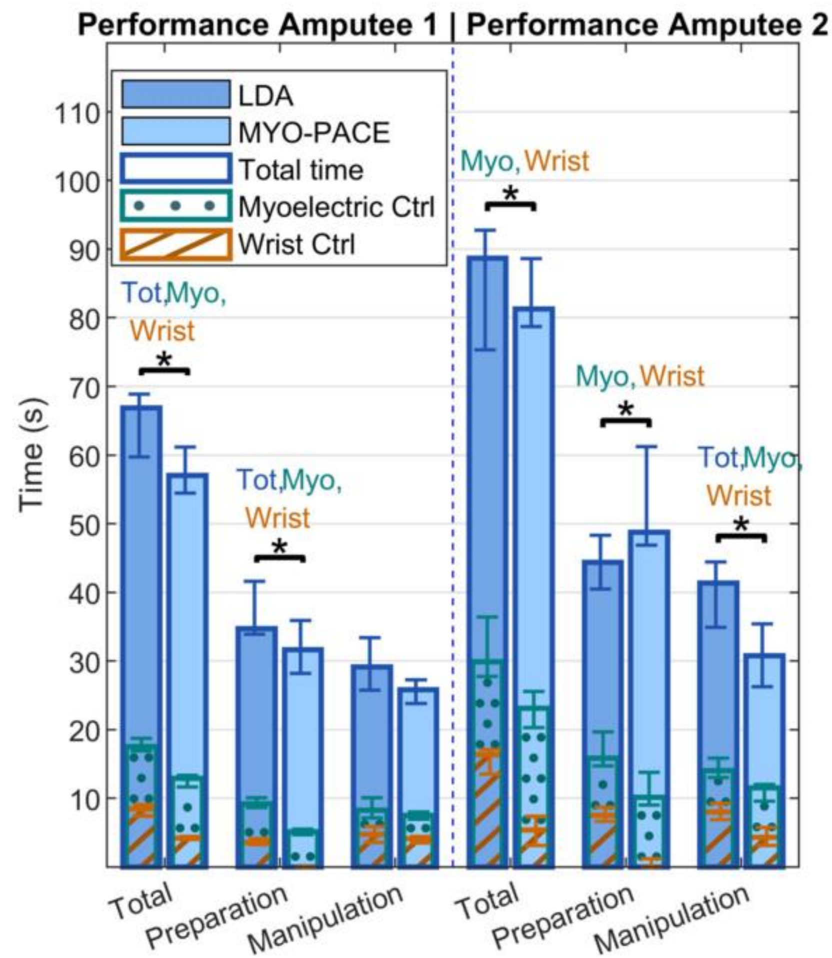


Fig. 7. Trial time decomposition for the cluttered scene interaction (CSI) test performed by able-bodied subjects. The trial execution time and the total time spent using myocontrol are decomposed in preparation and manipulation phases. The indications above the asterisks stand respectively for a significant difference ($p < 0.05$) in the total amount of time (Tot), the time spent controlling the prosthesis manually (hand and wrist; Myo), and time spent controlling the wrist manually (Wrist) for each phase of the task.



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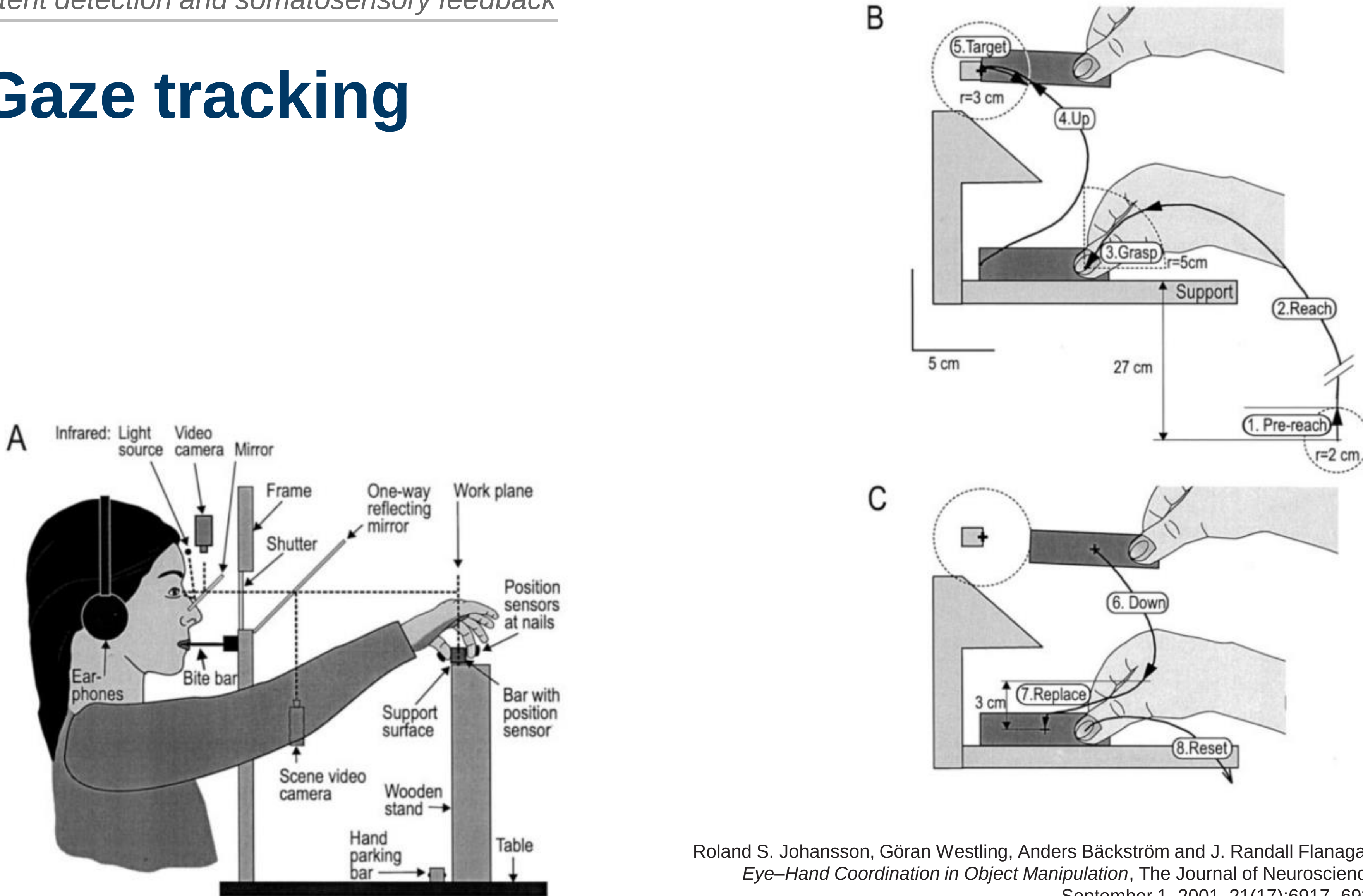
- is this then feasible?
  - inevitably **suffers from all computer-vision related problems** (illumination, perspective changes, etc.)
  - must be **wearable** and **acceptable**
  - must **work in real-time and last long – battery**
  - must be **affordable**
  - I think its better than vicon

Gaze tracking

- actually: detecting what you are looking at by looking at your eyes!
  - usually via near-infrared camera(s) – we cannot see them
- does tracking your gaze tell me anything interesting about your intent?
- - yes to some extent, also measure the trust that someone has on prosthesis
- it definitely does: while moving, *you seldom look at your own body.*
  - because you have *proprioception*, - It's the body's ability to perceive its own position in space without relying on vision.
  - and proprioception means *excellent body inverse kinematics*
  - which means you can *concentrate on your targets*.
  - Summary - we just need to focus on the goal, brain will take care of our movement - Because our brain can handle these complex calculations unconsciously, thanks to proprioception, we are free to focus our attention on what we are trying to achieve with our movements, rather than how to move our bodies themselves.
- a remarkable, foundational paper:

Roland S. Johansson, Göran Westling, Anders Bäckström and J. Randall Flanagan, *Eye–Hand Coordination in Object Manipulation*, The Journal of Neuroscience, September 1, 2001, 21(17):6917–6932

Gaze tracking



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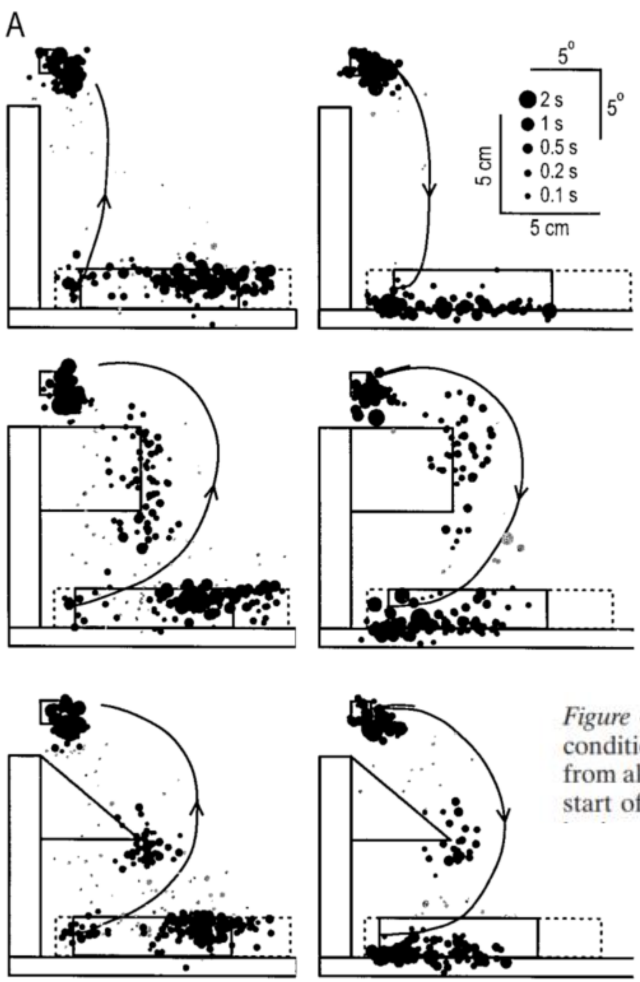

Fixation landmarks

Subjects thus directed gaze almost exclusively to objects involved in the task. Furthermore, gaze was directed to landmarks on these objects that were important in the task. These included the forthcoming grasp site on the bar, the left tip of the bar used to contact the target, the protruding point(s) on the obstacle, the target, and the support surface.

Figure 4. Gaze fixations in relation to landmarks for all three obstacle conditions. *A*, The *left panels* show the distribution of all gaze fixations, from all subjects and trials, from the time gaze left the fixation zone to the start of the target phase. The *right panels* show the corresponding distri-

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Gaze tracking

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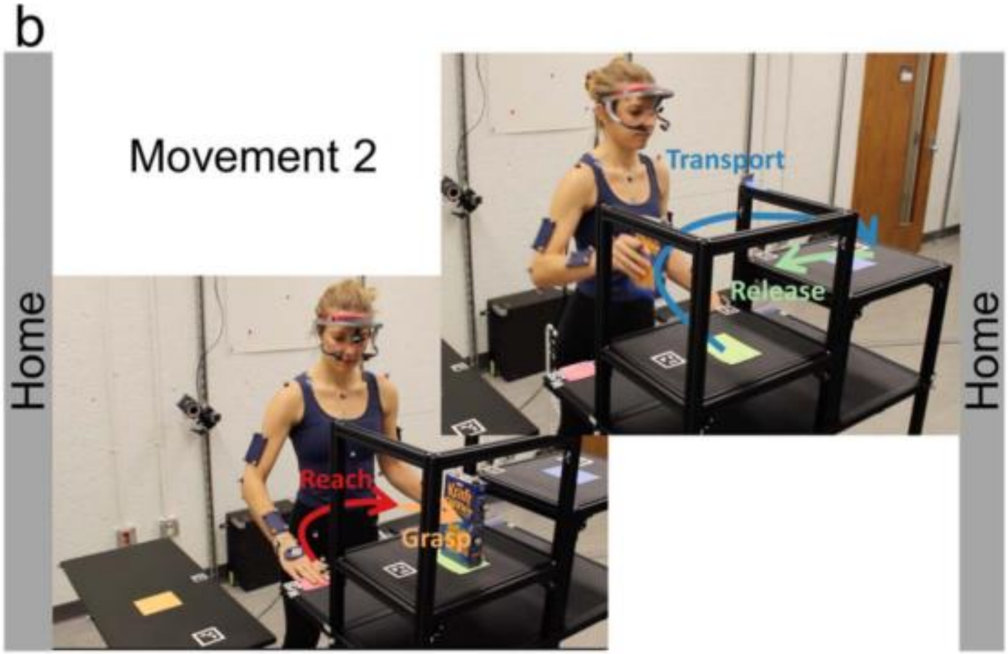
- does tracking your gaze tell me anything interesting about your intent?
- it definitely does: while moving, *you seldom look at your own body.*
  - because you have *proprioception*,
  - and proprioception means *excellent body inverse kinematics*
  - which means you can *concentrate on your targets*.
- in rehabilitation robotics: *if you trust your robot,* you won‘t look at it but at the targets!
  - e.g. upper-limb prosthetics: users should *not* be looking at the prosthesis,
  - but at the places where they want to grasp and release!
  - e.g. lower-limb prosthetics: users should *not* be looking at the leg prosthesis,
  - but ahead, at where they want to go!

Lavoie, E. B., Valevicius, A. M., Boser, Q. A., Kovic, O., Vette, A. H., Pilarski, P. M., Hebert, J. S., & Chapman, C. S. (2018). Using synchronized eye and motion tracking to determine high-precision eye-movement patterns during object-interaction tasks. Journal of Vision, 18(6):18

Gaze tracking

This study explores the role that vision plays in sequential object interactions. We used a head-mounted eye tracker and upper-limb motion capture to quantify visual behavior while participants performed two standardized functional tasks. By simultaneously recording eye and motion tracking, we precisely segmented participants' visual data using the movement data, yielding a consistent and highly functionally resolved data set of real-world object-interaction tasks. Our results show that participants spend nearly the full duration of a trial fixating on objects relevant to the task, little time fixating on their own hand when reaching toward an object, and slightly more time—although still very little—fixating on the object in their hand when transporting it. A consistent spatial and temporal pattern of fixations was found across participants. In brief, participants fixate an object to be picked up at least half a second before their hand arrives at the object and stay fixated on the object until they begin to transport it, at which point they shift their fixation directly to the drop-off location of the object, where they stay fixated until the object is successfully released. This pattern provides additional evidence of a common system for the integration of vision and object interaction in humans, and is consistent with theoretical frameworks hypothesizing the distribution of attention to future action targets as part of eye and hand-movement preparation. Our results thus aid the understanding of visual attention allocation during planning of object interactions both inside and outside the field of view.



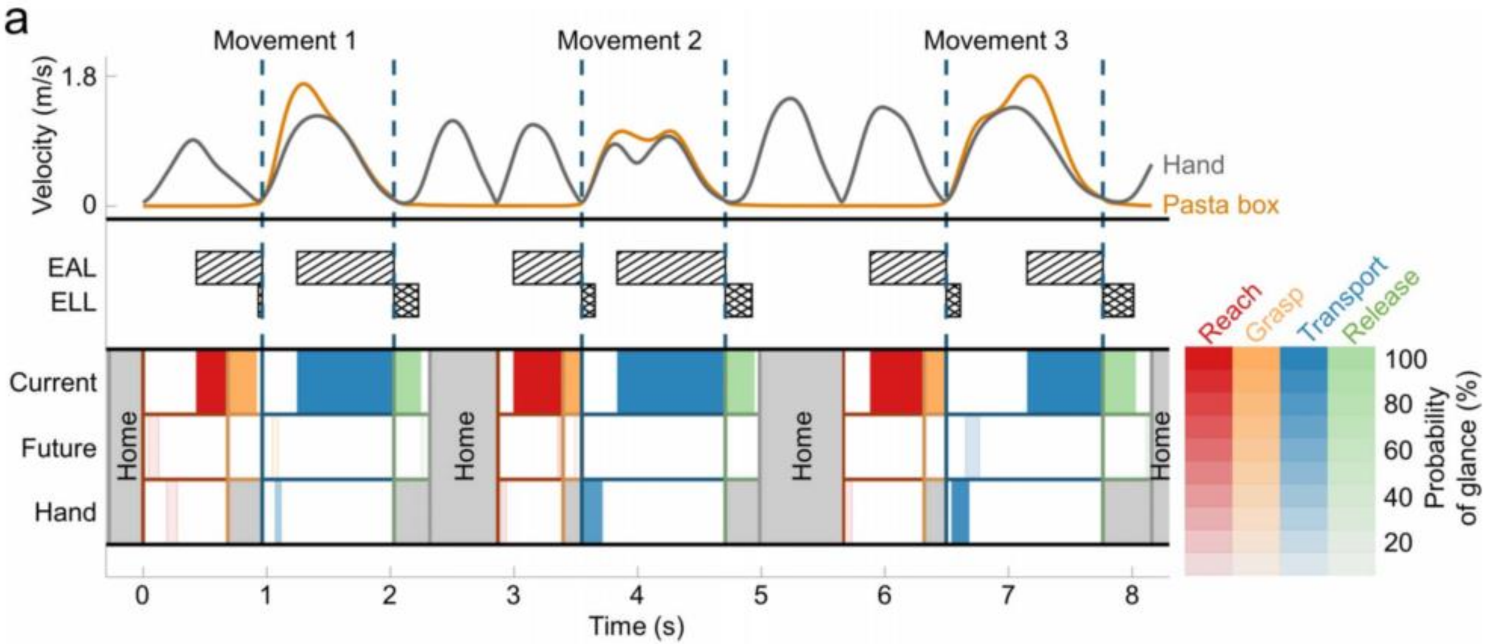
Lavoie, E. B., Valevicius, A. M., Boser, Q. A., Kovic, O., Vette, A. H., Pilarski, P. M., Hebert, J. S., & Chapman, C. S. (2018). Using synchronized eye and motion tracking to determine high-precision eye-movement patterns during object-interaction tasks. Journal of Vision, 18(6):18

Gaze tracking

Results

General normative eye behavior during sequential object movement

Here, we present the similarities of the eye-behavior measures during sequential object movements between the two tasks. Summarized statistical results can be found in Tables 2–4, containing (respectively) a summary of the comparison between Pasta and Cups tasks, the Pasta task analysis, and the Cups task analysis. Graphical visualization of percent fixation time, number of looks per phase, EAL/ELL measures is shown in Figure 4.



Gaze tracking

- is this then feasible?
  - must be **wearable** and **acceptable**
  - must **work in real-time and last long**
  - must be **affordable (?)**

Inertial Measurement Units

- originally conceived to establish a ship‘s position
  - main problem: the measurement tend to *drift*

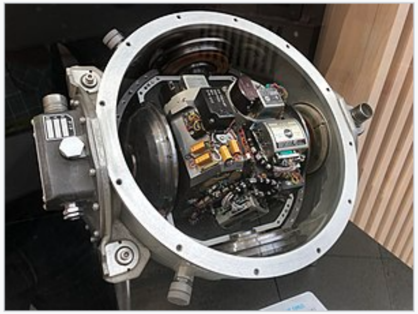
- nowadays integrate a magnetometer, an accelerometer and a gyroscope

Inertial measurement unit

From Wikipedia, the free encyclopedia

For broader coverage of this topic, see Inertial navigation system.

An **inertial measurement unit** (**IMU**) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers. IMUs are typically used to maneuver aircraft (an attitude and heading reference system), including unmanned aerial vehicles (UAVs), among many others, and spacecraft, including satellites and landers. Recent developments allow for the production of IMU-enabled GPS devices. An IMU allows a GPS receiver to work when GPS-signals are unavailable, such as in tunnels, inside buildings, or when electronic interference is present.[1]


Apollo Inertial Measurement Unit

Contents [hide]

Intent detection and somatosensory feedback

- Inertial measurement units (IMUs): are electronic devices that measure and report a body's specific force, angular rate, and sometimes the orientation of the body.
- originally conceived to establish a ship’s position: IMUs were originally designed to help determine the location of a ship at sea.
- main problem: the measurement tends to drift: Unfortunately, the accuracy of IMUs tend to drift over time, which can make them unreliable for long-term navigation.
- nowadays integrate a magnetometer, an accelerometer and a gyroscope: To improve accuracy, modern IMUs often combine three types of sensors:
    - Magnetometer: detects magnetic fields and helps determine direction or heading.
    - Accelerometer: measures acceleration.
    - Gyroscope: measures rotational motion.

1. By combining data from these sensors, IMUs can provide more accurate information about a device's orientation and movement.
2. However, there are some limitations to using an accelerometer alone to determine orientation:It cannot distinguish between acceleration due to gravity and acceleration due to motion. So, if the device is moving, it can be difficult to determine its orientation based on the accelerometer data alone.This is where other sensors in an IMU come into play:Gyroscopes can measure rotational motion. This information can be used to track the orientation of the IMU over time, even when it is moving.Magnetometers can measure magnetic fields. This information can be used to determine the compass direction of the IMU, which can be helpful for determining absolute orientation.
3. drift refers to the gradual deviation of the IMU's measured position, velocity, or orientation from the true values over time. This deviation occurs due to the accumulation of small errors in the sensor readings.

Inertial Measurement Units

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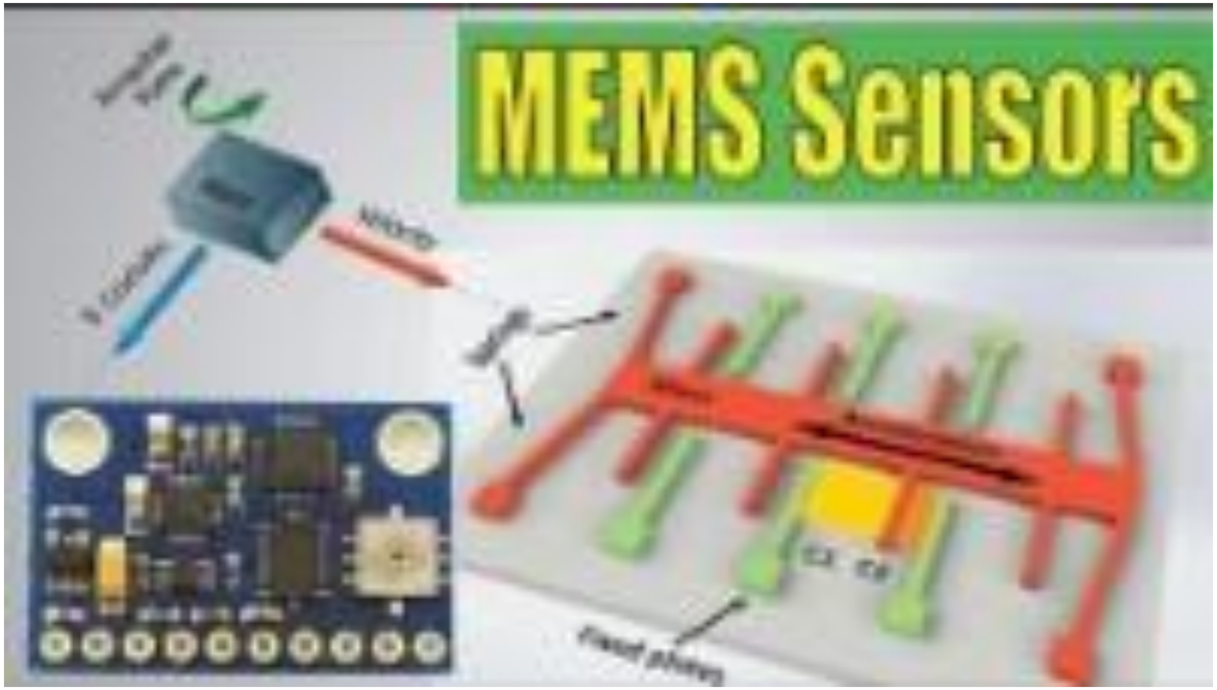

Inertial Measurement Units

- originally conceived to establish a ship's position
    - main problem: the measurement tend to *drift*
- nowadays integrate a magnetometer, an accelerometer and a gyroscope
- as a result, you get the *orientation* w.r.t. the gravity vector
- available as miniaturised chips with custom data-fusion algorithm
    - e.g., the BNO055 by Bosch

Inertial Measurement Units

- originally conceived to establish a ship's position
  - main problem: the measurement tend to *drift*
- nowadays integrate a magnetometer, an accelerometer and a gyroscope
- as a result, you get the *orientation* w.r.t. the gravity vector
- application:
  - direct kinematics - also known as forward kinematics, is a concept used in robotics to determine the position and orientation (pose) of the end effector (the gripper or tool at the tip of the robot's arm) given the specific joint angles or joint positions of the robot's arm.
  - body posture (kinematic configuration) detection
  - This is werable and cheaper than any kind of optical motion tracking to track the motion/orientation – eg BodyRig
  - A BodyRig is a wearable motion capture system designed to track the movement and orientation of a person's body. Unlike traditional optical motion tracking systems, which use cameras and markers to capture motion data, BodyRigs typically use a combination of sensors such as accelerometers, gyroscopes, and magnetometers.

Inertial Measurement Units

- the DLR BodyRig: low cost body tracking device

Sierotowicz, Marek / Connan, Mathilde / Castellini, Claudio, **Human-in-the-loop assessment of an ultralight, low-cost body posture tracking device**, 2020, *MDPI Sensors* , Vol. 20, No. 3

Inertial Measurement Units

- the Riablo by Corehab:

https://www.corehab.it/en/riablo-bf

Intent detection and somatosensory feedback

TCP/IP:

1. Characteristics:
2. Reliable: Ensures all data packets are delivered and in the correct order.
3. Overhead: More overhead due to error checking, acknowledgments, and retransmissions.
4. Latency: Higher latency due to the need for establishing connections and ensuring reliable delivery.
5. Usage: Suitable for applications where data integrity is critical, such as transferring files or command/control data for prosthetics.

UDP:

1. Characteristics:
2. Unreliable: No guarantee of packet delivery or order.
3. Overhead: Lower overhead, resulting in less latency.
4. Latency: Lower latency, suitable for real-time applications.
5. Usage: Suitable for applications where speed is critical, and occasional data loss is acceptable, such as streaming real-time sensor data.
6. Wi-Fi:
7. Higher data rates (up to several hundred Mbps).
8. Suitable for high-density sEMG data transmission.
9. Wider range than Bluetooth.

10. Wired Connection (e.g., USB):
11. Reliable and high data rate.
12. Eliminates issues with wireless interference.
13. Limits mobility compared to wireless solutions.

Intent detection and somatosensory feedback

1. Sensor fusion involves combining data from multiple sensors to provide a more accurate and comprehensive representation of a system's state
2. Different Sampling Rates:
3. Timestamp Misalignment: sensors have different clocks
4. Noise and Artifacts: Both EMG and IMU data can be noisy. EMG signals can be affected by muscle crosstalk, motion artifacts, and electrical interference. IMUs can be influenced by magnetic interference and sensor drift.
5. Data Latency: Different sensors may have different latencies, which can cause misalignment in the data streams.

To handle different sampling rates, consider the following methods:

1. Resampling: Upsample the lower frequency signal (e.g., IMU data) and/or downsample the higher frequency signal (e.g., EMG data) to a common rate. Linear interpolation or more sophisticated methods like spline interpolation can be used for resampling.
2. Time Alignment: Use the timestamps to align data points. When combining the data, align the higher frequency data (e.g., EMG) to the nearest timestamp of the lower frequency data (e.g., IMU).

To handle timestamp differences, you can:

1. Synchronization Protocols: Ensure that both sensors are synchronized using a common time source before starting data acquisition. For example, use a shared clock or a synchronization pulse.
2. Post-Processing Synchronization: Use algorithms to align timestamps after data acquisition. Methods like dynamic time warping (DTW) or correlation-based techniques can help adjust the time series to align data points correctly.
3. Interpolation: If there are small discrepancies in timestamps, interpolation can be used to estimate the data values at common timestamps.

To handle missing data:

1. Interpolation: Use interpolation techniques to estimate missing values. Linear interpolation, spline interpolation, or more advanced techniques like Kalman filtering can be used depending on the nature of the missing data and the requirements for accuracy.
2. Discard Incomplete Data: In some cases, it might be acceptable to discard incomplete data segments if they constitute a small fraction of the dataset and do not significantly impact the overall analysis.

Summary

- today:
  - muscle activity – detecting motion induced by it – track motion
  - using optical tracking – track scene also posture
  - using gaze tracking – track eye
  - using IMUs – detect orientation,cheaper than O
- feasible, affordable, acceptable in practice?
- IMU,G,O

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