Multitouch Robot Control

Bachelor Thesis

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Technical Aspects of Multimodal Systems

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Outline

Outline (cont.)

Merlin Steuer

- Part-time student
- B.Sc. Informatik since WiSe13
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- Questions? Make some noise!

Motivation & Objective

- Robots get more and more ubiquitous
- Robots enter domestic space[5]
- Interfaces have to be easy and intuitive

$\Rightarrow$ A simple, intuitive remote control interface to complex robots shall be developed.

- Multitouch gestures well known
- Android tablet computer

Grasp Synergies

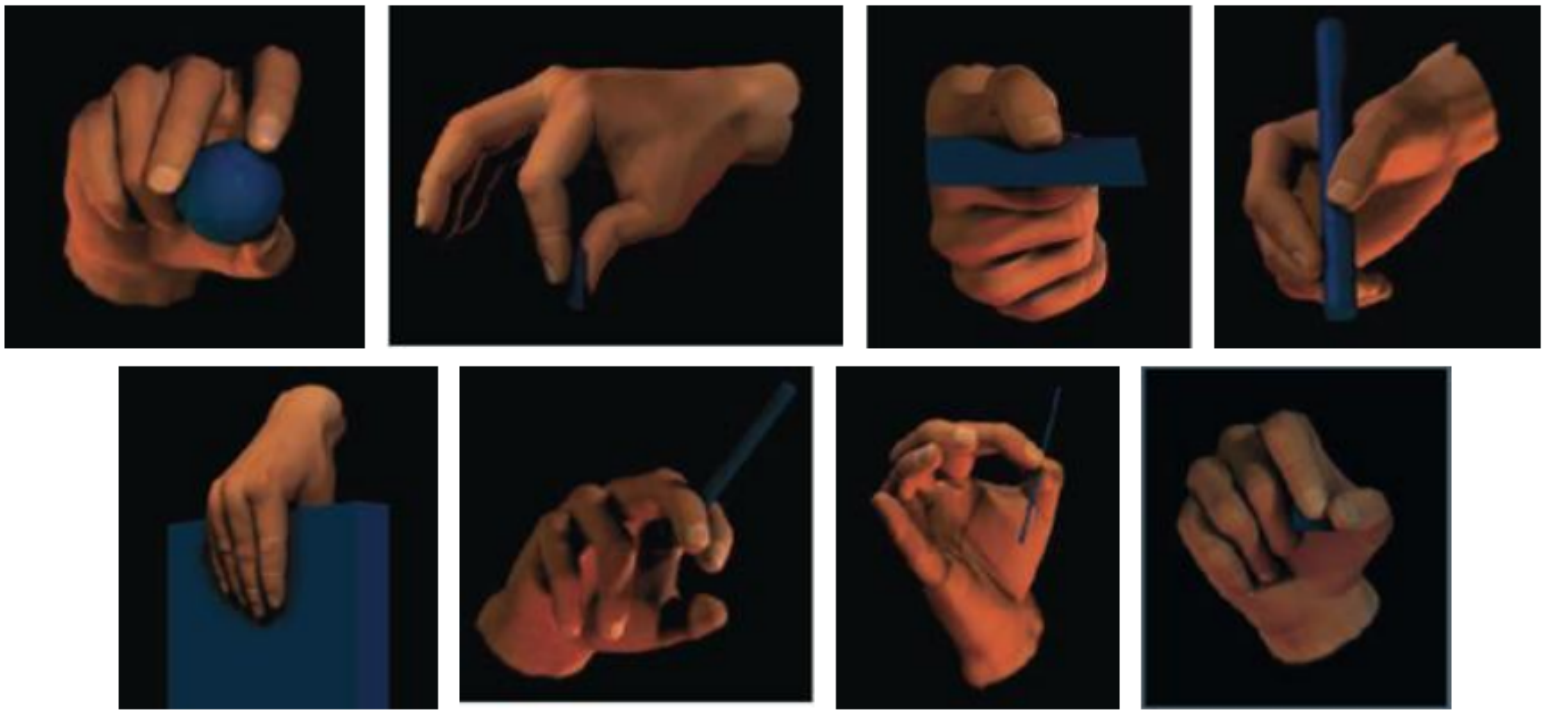
- Research at the TAMS group [2]
- PCA on human grasp postures
- Eigenvectors in matrix S (called *Synergy* here)
- Offset s_0 = mean joint values

$$\theta = s_0 + S\alpha \tag{1}$$

- $\alpha \in \mathbb{R}^{21}$ input amplitudes
- $\theta \in \mathbb{R}^{21}$ joint angles of the hand

$\Rightarrow$ Map properties of gestures to α (Absolute and relative)

Grasp Synergies



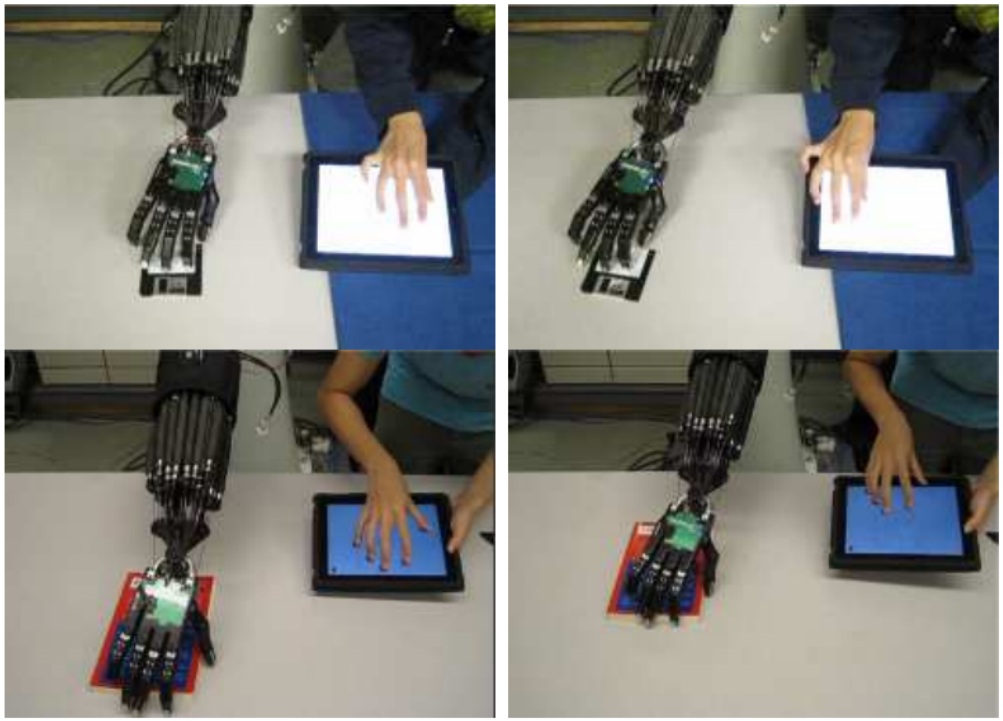
Grasp synergies recorded by Bernardino et al.[2]

Direct Fingertip Mapping

- Research done by Toh et al. [13]
- Grasp actions $\rightarrow$ fingertip movements in a plane

$\Rightarrow$ Map fingertips on touch screen to a plane in $3D$ space

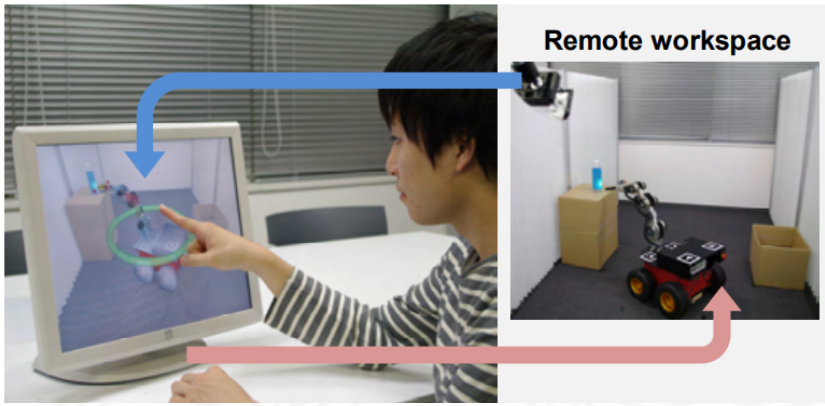
Direct Fingertip Mapping



Examples from Toh et al.[13]

Other Approaches

Controlling a robotic car with an Android phone, research by Akupati[1]



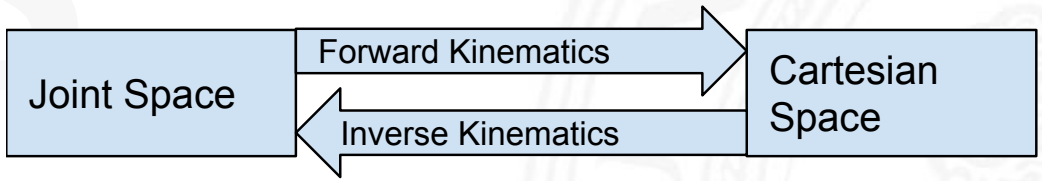
TouchMe! Controlling a robot with touch actions on an AR display. Research by Hashimoto et al.[8]

ROS

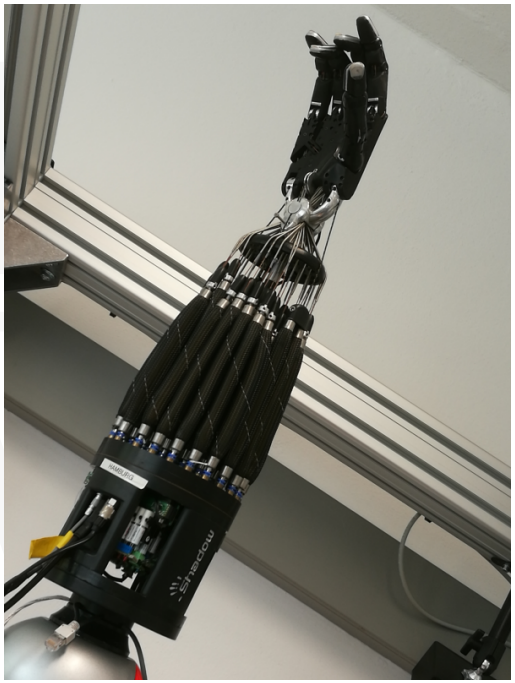
- Robot Operating System
- Software Framework to develop robots
- Communication Framework
- Publisher/Subscriber Pattern
- Services

Inverse Kinematics

- Joint Space θ
- Cartesian Space x
- Forward Kinematics: $x = f(\theta)$
- Inverse Kinematics: $\theta = f^{-1}(x)$



Shadow C5 Hand



The Shadow C5 Robotic Hand

- by *The Shadow Robot Company* [3]
- 24 DOF
- Pneumatic muscles
- Designed after human forearm

Kuka LWR 4+

The Kuka LWR robotic arm

- by *KUKA Roboter GmbH* [6]
- 7 DOF
- Integration into ROS over FRI (*Fast Research Interface*)[7]

Samsung Galaxy Tab S3

The used Android tablet

- by *Samsung* [10]
- 10 inch screen
- 2048x1536 px
- 2.15GHz Quad-Core CPU
- *rosjava* / *rosandroid*

BioIK

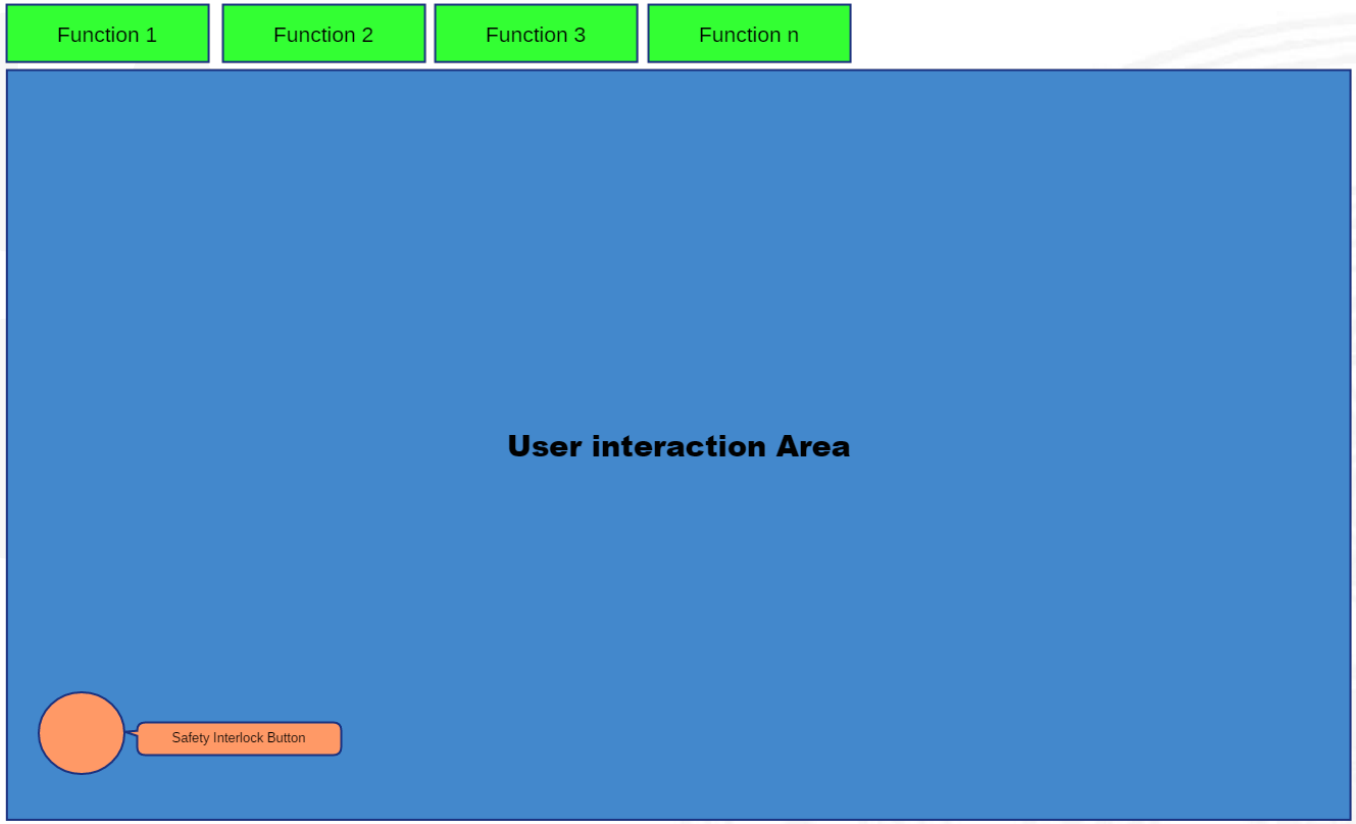
- Evolutionary, multi-goal algorithm for inverse kinematics
- Developed at the TAMS group [11, 12]
- Integrated into ROS by Philipp Ruppel [9]
- Philipp also provided the BioIK ROS service[1]

[1] Found at Philipp's GOGS

User Interface

- Most area reserved for touch interaction
- Functionality interchangeable by tab pages
- Safety interlock button
- **Interlock button does not replace hardware safety measures!**

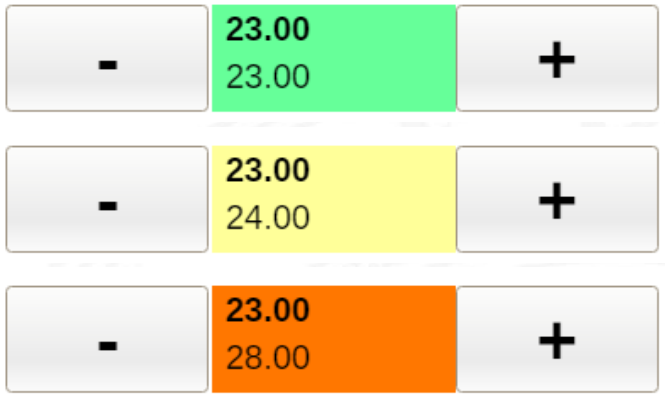
User Interface



General screen layout

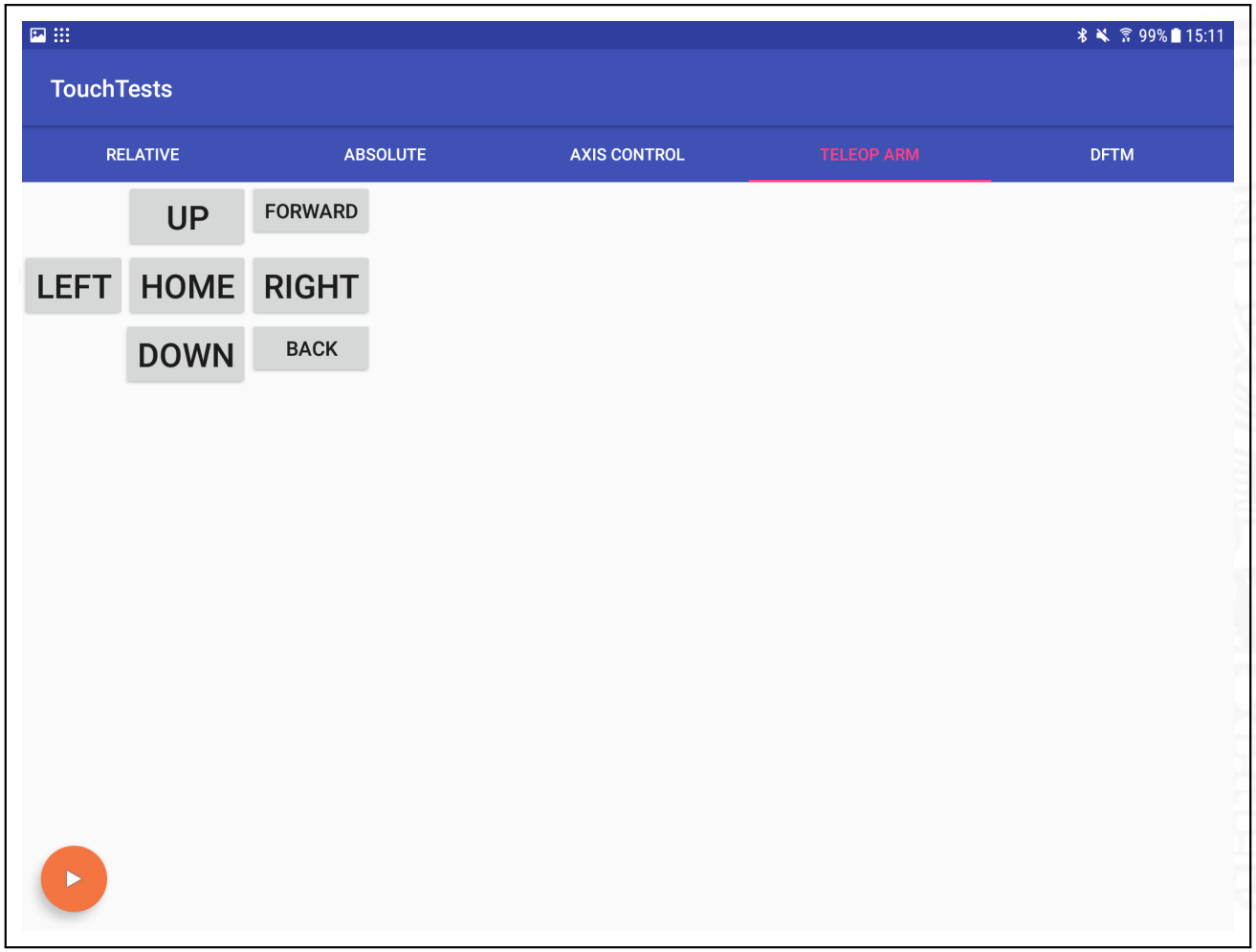
Axis Control Page

- One control for every joint
- +/- buttons to set joint angle
- Display of target value and current value
- Coloured indication of angle error



Axis Control Page

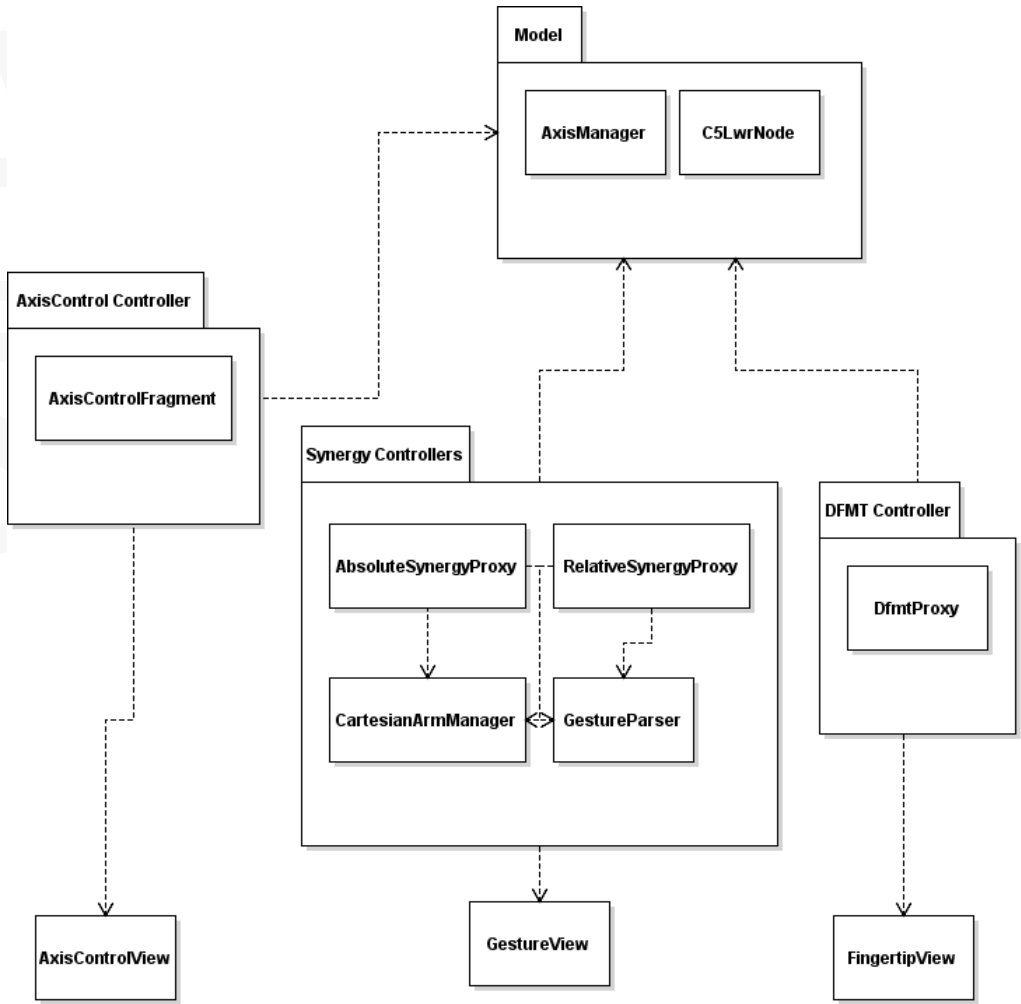
Arm Teleop


99% 15:11
TouchTests
RELATIVE
ABSOLUTE
AXIS CONTROL
TELEOP ARM
DFTM
UP
FORWARD
LEFT
HOME
RIGHT
DOWN
BACK

Software Architecture

- *Model-View-Controller* [4]
- Model: *AxisManager*, *C5LwrNode*
- View: **View*
- Controller: **Proxy*, **Fragment*, *CartesianArmManager*

Model-View-Controller



AxisManager

- *Model* $\Rightarrow$ responsible for all joint data and movement
- Enable / Disable (Safety Interlock)
- Joint Movements
- Target Values
- Maximum Speed

C5LwrNode

- Interface to ROS
- Receives joint information
- Sends joint information from AxisManager
- Methods to call the BioIK service

GraspSynergy

- $\theta = s_0 + S\alpha$
- s_0 and S provided as data files
- Functionality to load data files and calculate joint angles in *GraspSynergy* class (provided by Norman)
- Amplitudes range from -50 to 50

```
1  class GraspSynergy {
2    public void parseMatlabSynergyMean(InputStream is);
3    public void parseMatlabSynergyVecs(InputStream is);
4
5    public double[] toJoints(double[] amplitudes);
6  }
```

Touch Gestures

- Gesture property $\Rightarrow$ amplitude (relative or absolute)
- Position (Center)
- Size
- Orientation

Definitions:

- $p = (p_x, p_y) \in \mathbb{R}^2$ is a **Pointer** on a touch screen
- $G = \{p_1, \ldots, p_n\}$ for pointers p_i, $1 \leq i \leq n$ and $|G| \geq 1$ is a **Gesture**

Gesture Properties

For a gesture $G = \{p_1, \ldots, p_n\}$

- Position:

$$c(G) = \frac{1}{|G|} \sum_{i=1}^{|G|} p_i \qquad p_i \in G \tag{2}$$

- Size:

$$s(G) = \frac{2}{|G|} \sum_{i=1}^{|G|} d(c(G),\, p_i) \tag{3}$$

with $d(x, y) = \sqrt{(y_1 - x_1)^2 + (y_2 - x_2)^2}$ for $x, y \in \mathbb{R}^2$

Gesture Properties

For a gesture $G = \{p_1, \ldots, p_n\}$

- *Thumb Pointer*:

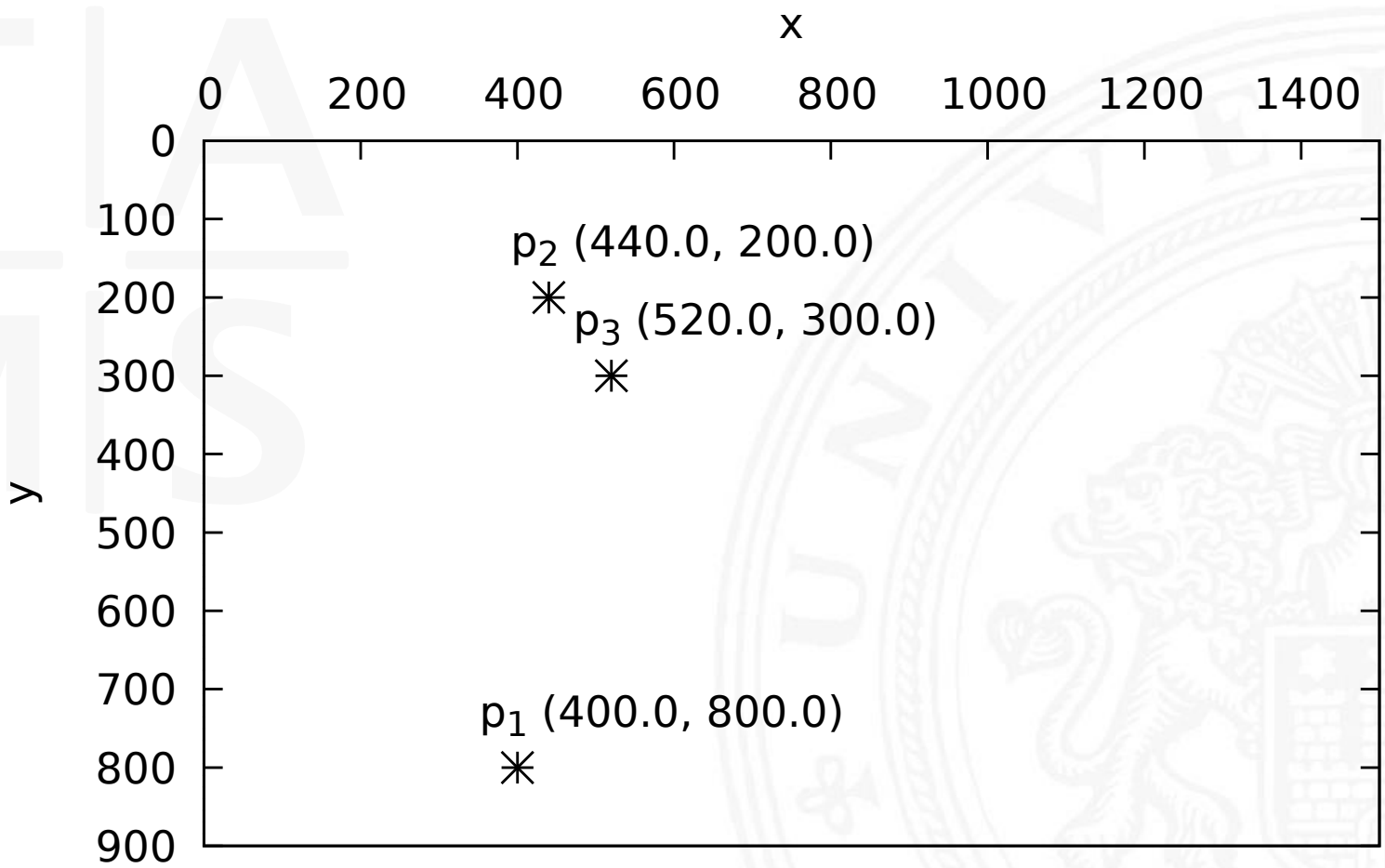
$$th(G) = \begin{cases} p_1 & |G| = 1 \\ p_n \text{ with } p_{n,y} = max\{p_{i,y} : p_i \in G\} & |G| = 2 \\ p_n \text{ with } d(c(G), p_n) = max\{d(c(G), p_i) : p_i \in G\} & |G| > 2 \end{cases} \tag{4}$$

- Orientation, for $v = c(G) - th(G)$, $b_y = \begin{pmatrix} 0 \\ -1 \end{pmatrix}$:

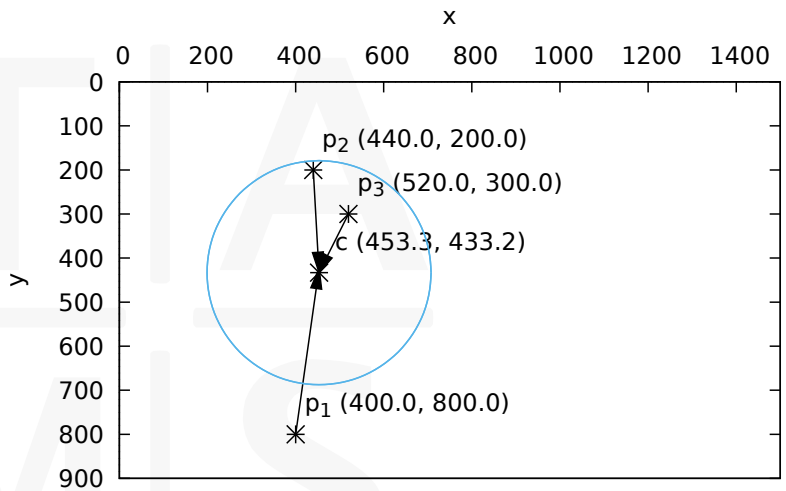
$$o(G) = \text{sign}(\det(b_y\ v)) \cdot \arccos\left(\frac{v \cdot b_y}{|v| \cdot |b_y|}\right) . \tag{5}$$

- $-\pi \leq o(G) \leq \pi$

Gesture Example



Gesture Example



- $c(G) \approx \begin{pmatrix} 453.3 \\ 433.2 \end{pmatrix}$
- $s(G) \approx 508.8$
- $o(G) \approx 0.141398 \,\widehat{\approx}\, 8.101°$

Implementation

- *Location* is a 2D vector
- *Pointer* has a *Location* and ID
- *Gesture* has multiple *Pointers*

```
1  public class Location {
2    public Location(float x, float y);
3
4    public float getX();
5    public float getY();
6
7    public Location add(Location loc);
8    public Location substract(Location loc);
9    public Location multiply(float c);
10   public Location divide(float c);
```

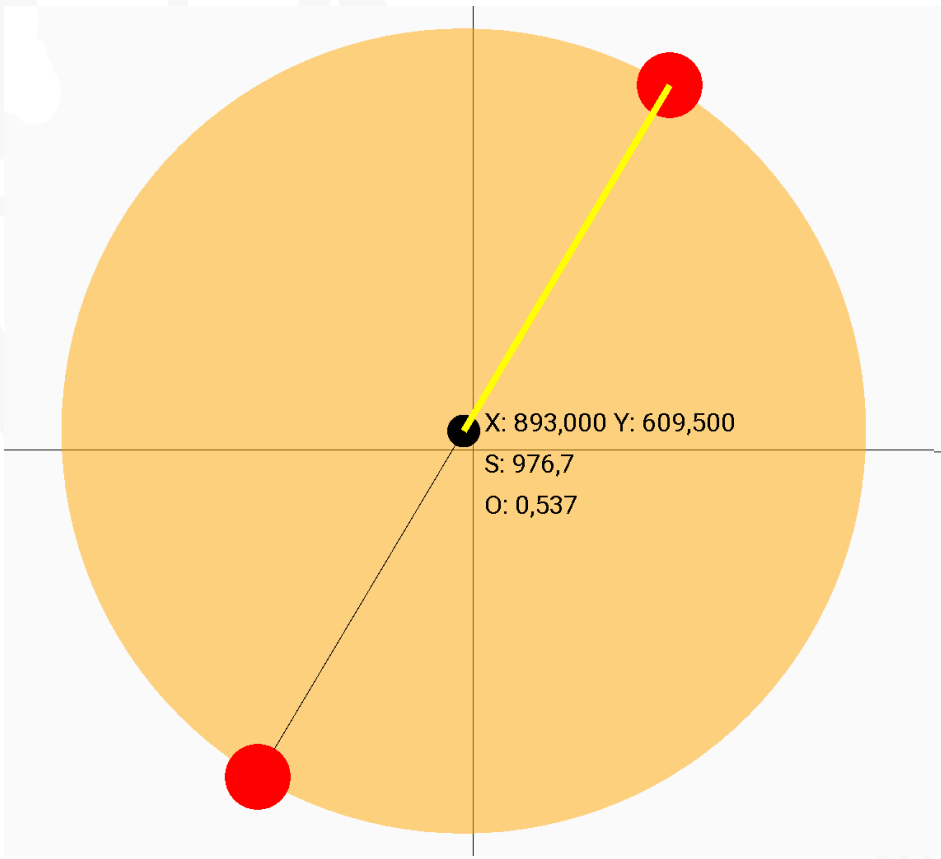
Implementation (cont.)

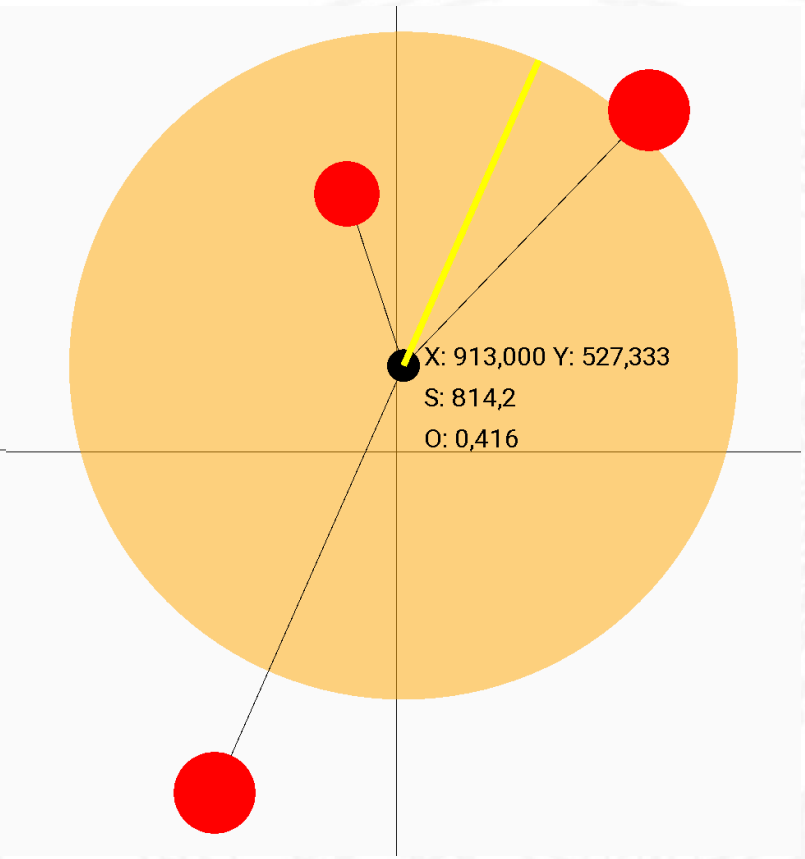
```
11
12    public double scalarProduct(Location loc);
13
14    public double getVectorLength();
15    public double distanceTo(Location loc);
16    public double getAngleTo(Location loc);
17    public Location getTurned(double angleRad);
18  }
```

Implementation (cont.)

```
1  public class Gesture {
2    public void addPointer(Pointer p);
3    public void removePointer(Pointer p);
4    public int getPointerCount();
5
6    public Location getCenter();
7    public float getSize();
8    public double getOrientation();
9  }
```

Gesture Visualization





AbsoluteSynergyProxy

- Maps gesture properties linearly ti amplitude values
- Maps gesture properties to robot palm position
- Gesture with two pointer used for amplitude control

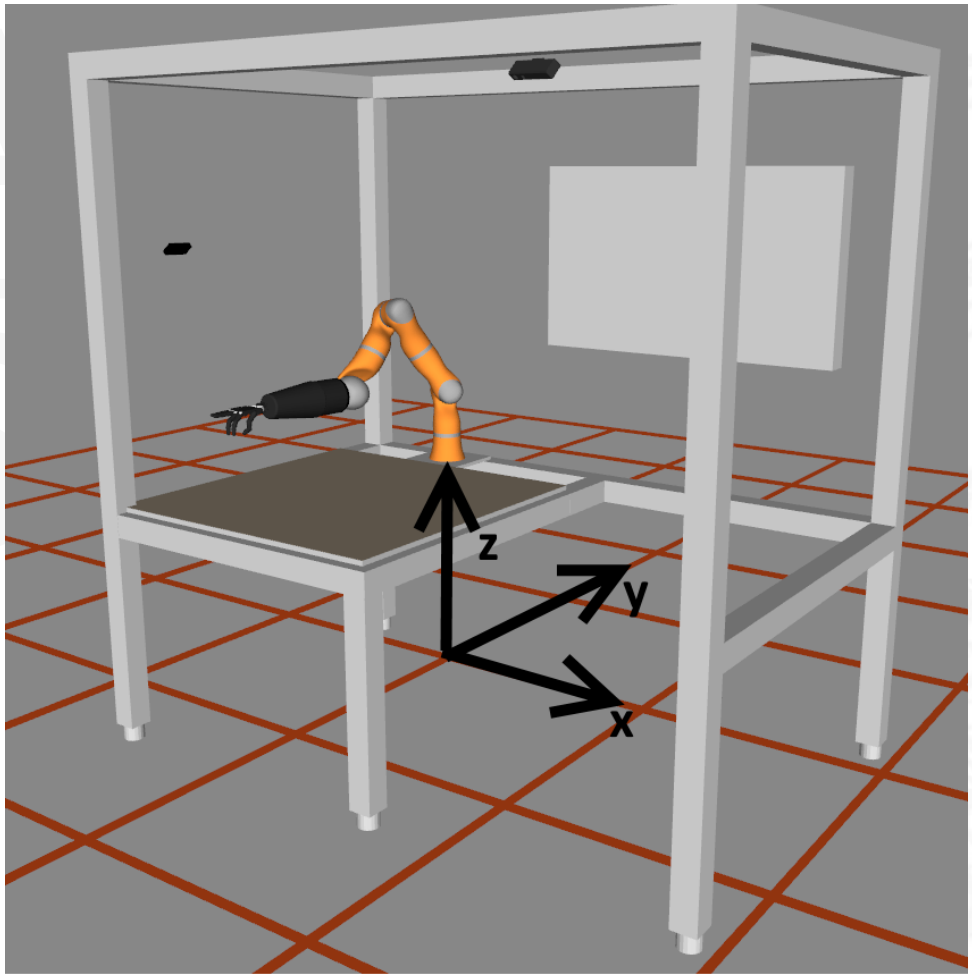
#	**Property**	**50 at**	**-50 at**
1	$s(G)$	1200	300
2	$c(G)_1$	$0.25 \cdot$ screenwidth	$0.75 \cdot$ screenwidth
3	$o(G)$	$-\frac{\pi}{2}$	$\frac{\pi}{2}$

Arm Control

- *CartesianArmManager*
- Accepts target positions for the C5 hand palm
- Requests IK solution for position endlessly
- When solution received: Set at *AxisManager*
- 3-Pointer-Gestures are used for arm positioning

Axis	**min**	**max**	**Prop.**	**min at**	**max at**
X	-0.2	0.4	$c(G)_1$	$0.25 \cdot$ screenwidth	$0.75 \cdot$ screenwidth
Z	1.10	1.35	$c(G)_2$	$0.75 \cdot$ screenheight	$0.25 \cdot$ screenheight

Arm Coordinate System



RelativeSynergyProxy

- Very similar to absolute mapping
- Mapping from property to Amplitude/Axis same
- Rate of change stored for every mapping
- Current value is altered

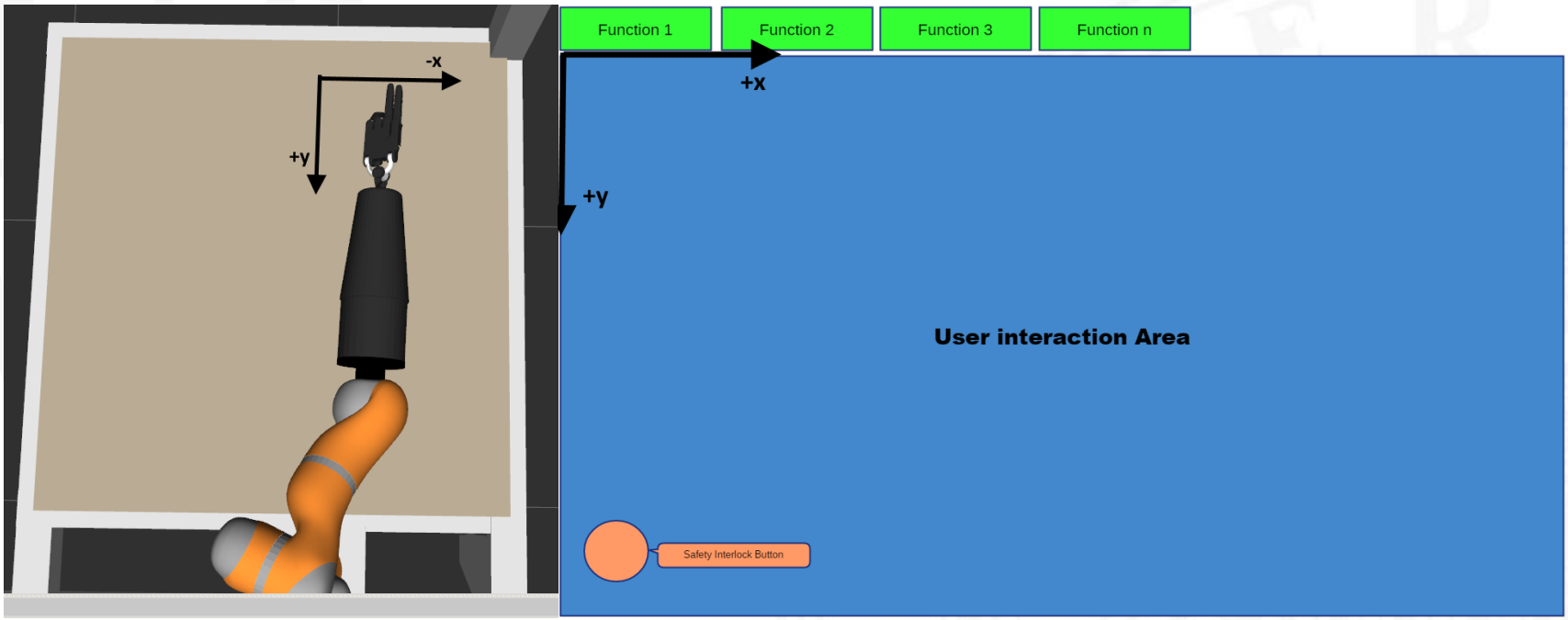
Direct Fingertip Mapping

- *DFTM*
- Mapping fingertips from touch screen to a plane in 3D space
- Relative positions of fingertips equal
- Plane in 3D space:

$$E : \vec{p} = \vec{b} + x \cdot \vec{e_1} + y \cdot \vec{e_2} \tag{6}$$

- $|\vec{e_1}| = |\vec{e_2}| = 1$ (1m)

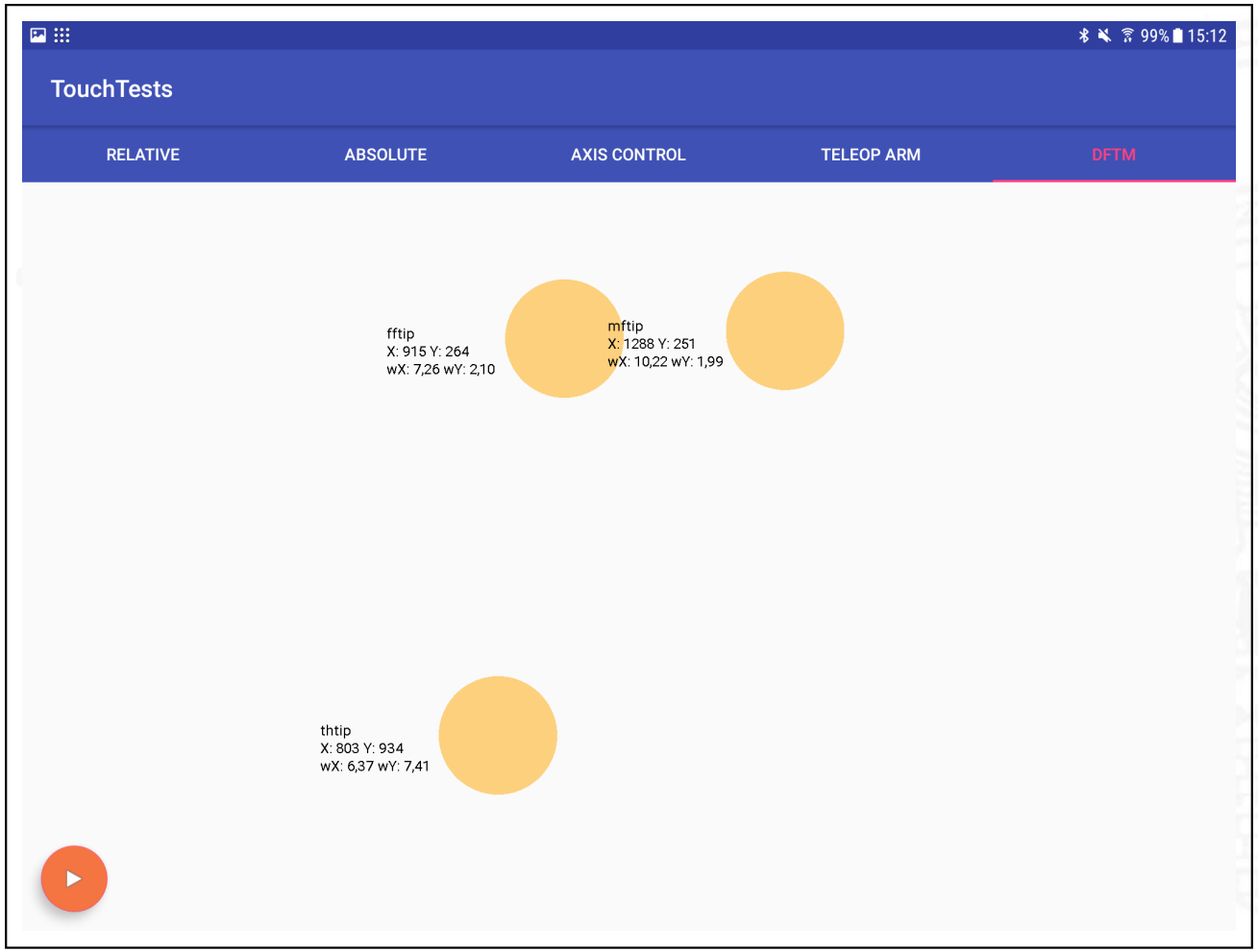
Direct Fingertip Mapping



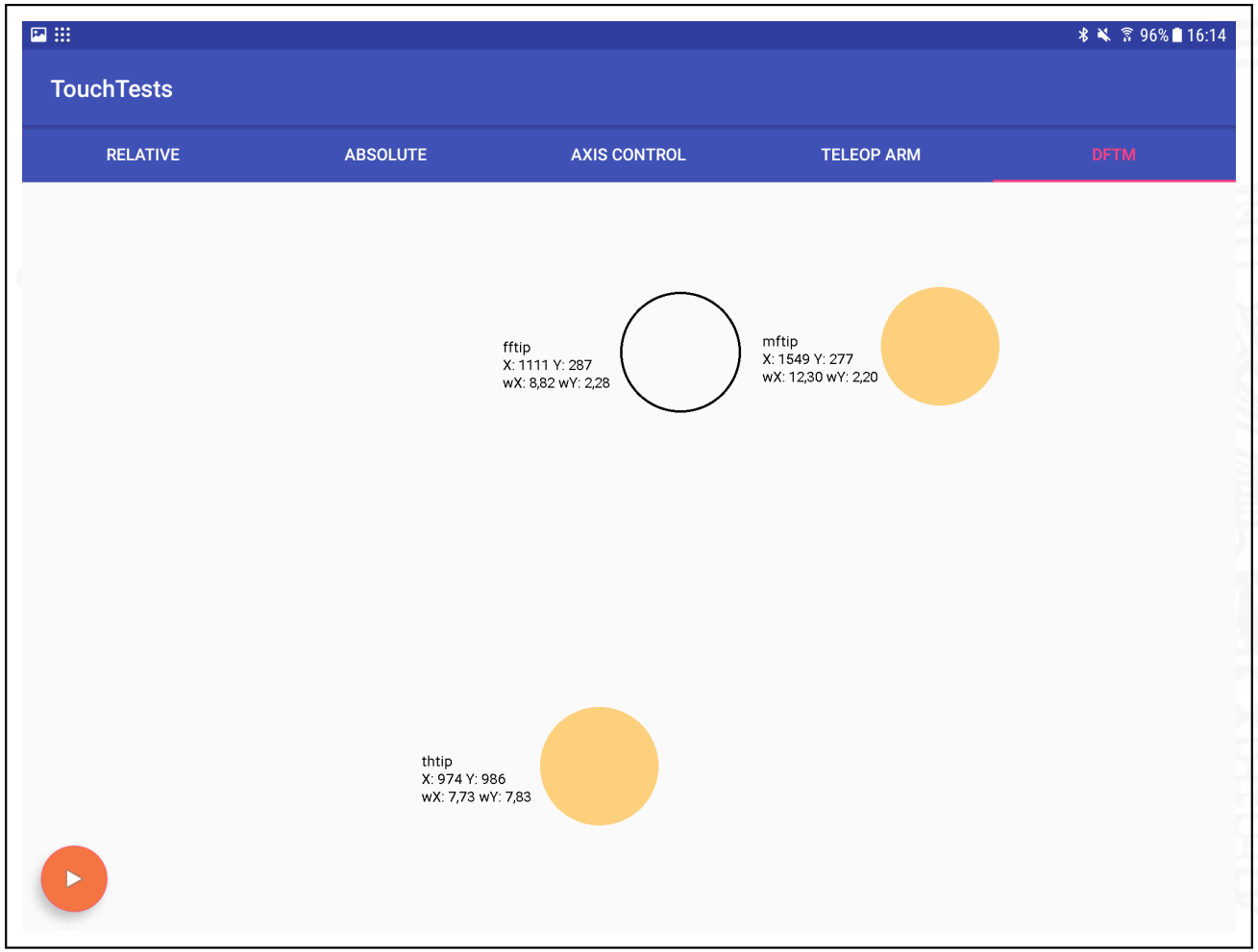
DFTM Parameters

- $\vec{b} = \begin{pmatrix} 0 \\ -1.25 \\ 1.2 \end{pmatrix}$
- $\vec{e_1} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}$
- $\vec{e_2} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$

DFTM Screen


99% 15:12
TouchTests
RELATIVE
ABSOLUTE
AXIS CONTROL
TELEOP ARM
DFTM
fftip
X: 915 Y: 264
wX: 7,26 wY: 2,10
mftip
X: 1288 Y: 251
wX: 10,22 wY: 1,99
thtip
X: 803 Y: 934
wX: 6,37 wY: 7,41

DFTM Screen


96% 16:14
TouchTests
RELATIVE
ABSOLUTE
AXIS CONTROL
TELEOP ARM
DFTM
fftip
X: 1111 Y: 287
wX: 8,82 wY: 2,28
mftip
X: 1549 Y: 277
wX: 12,30 wY: 2,20
thtip
X: 974 Y: 986
wX: 7,73 wY: 7,83

Summary

- Kuka LWR Arm + Shadow C5 Hand
- Relative Synergy Control
- Absolute Synergy Control
- Direct Fingertip Mapping Control
- on a 10” Android Tablet

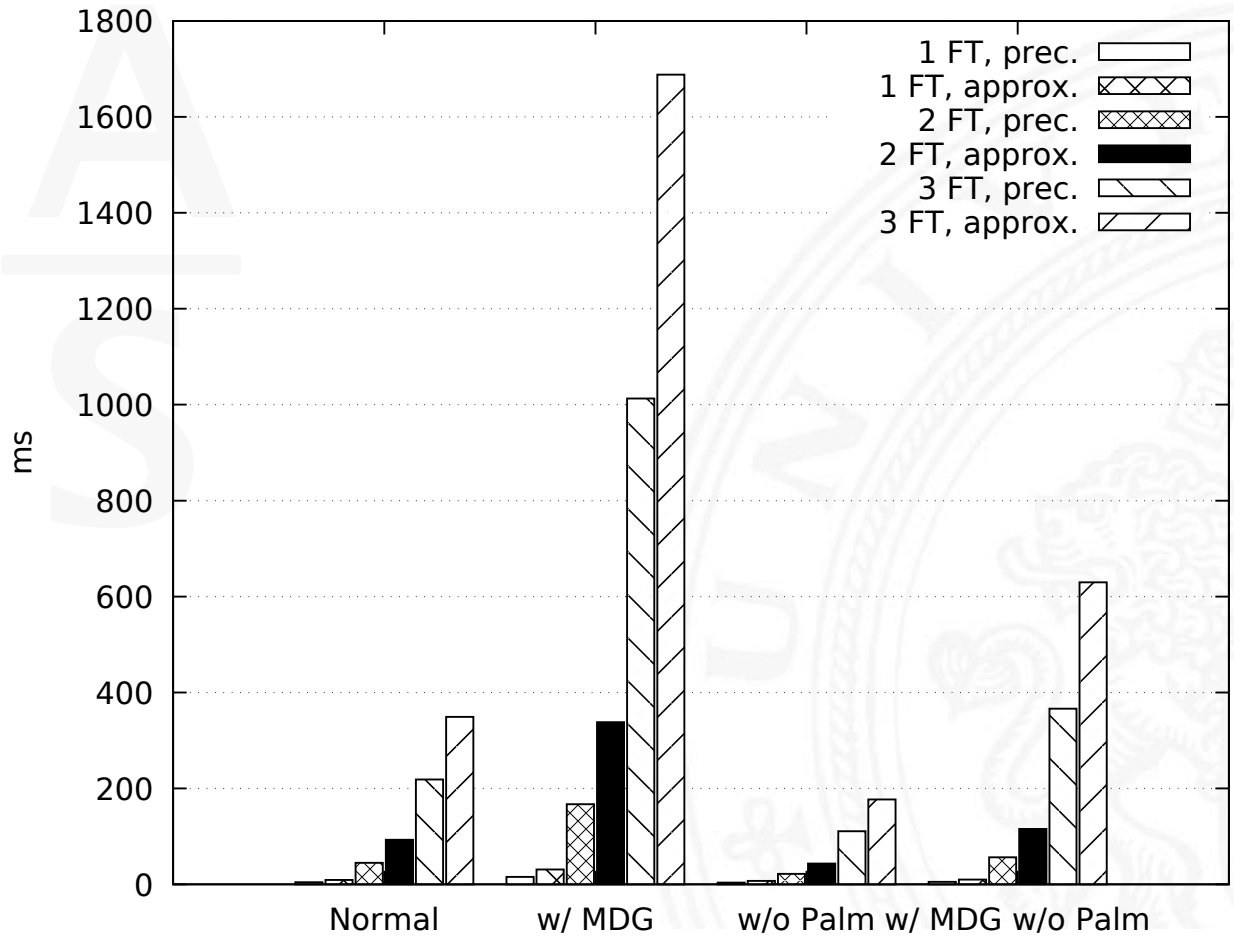
Evaluation

- Works as expected, in principle
- Synergy control is fine
- Unwanted arm movements when gesture is stationary
- BioIK seems to return a different / new solution for the same position
- Jittering even more disturbing in DFTM mode
- $\Rightarrow$ *MinimumDisplacementGoal* helps, slows down IK

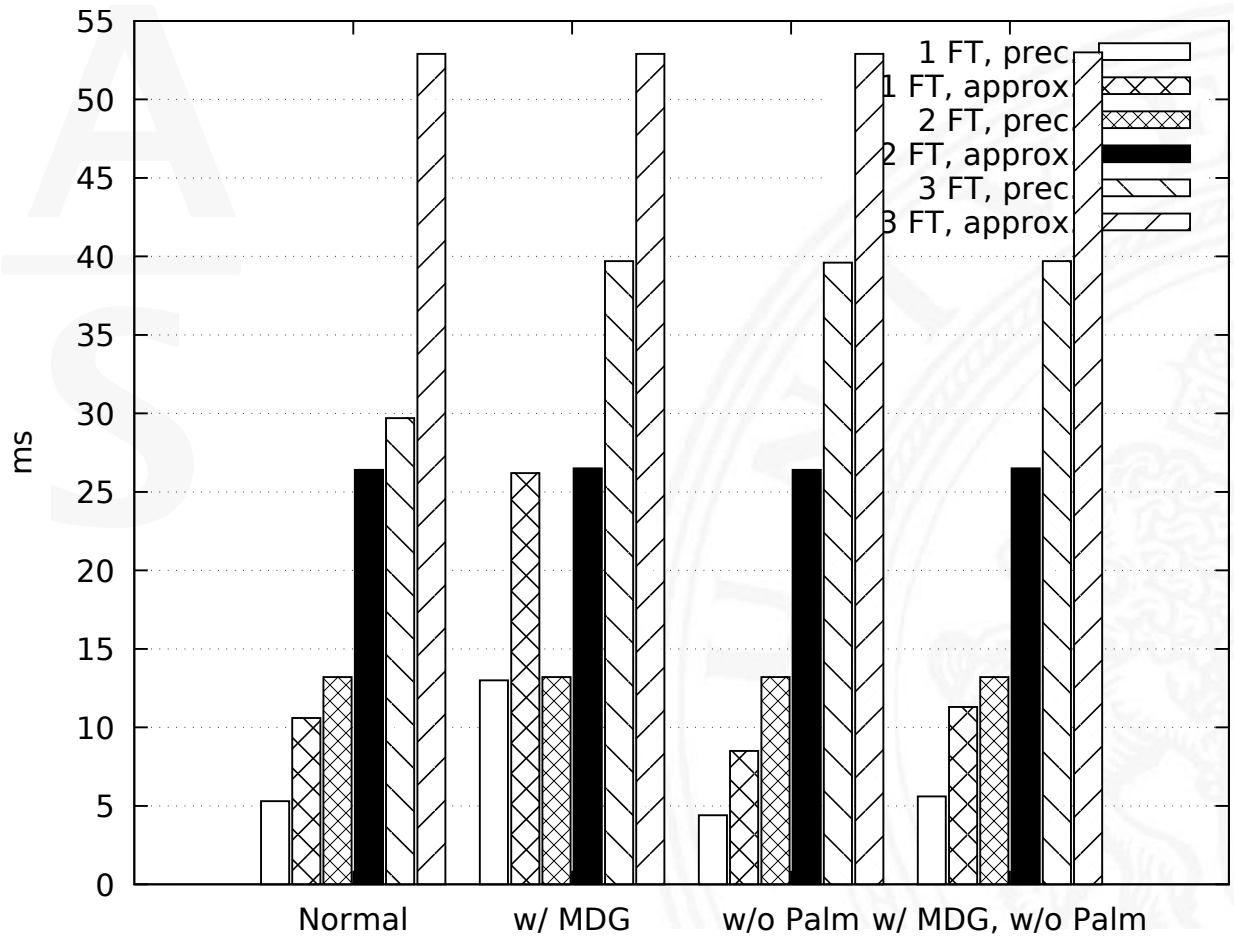
Performance

- Application overall performance is good
- Device gets warm $\Rightarrow$ constant network flow with small packages
- Service calls in *rosjava* / *rosandroid* designed to be asynchronous, but UI blocked during service calls
- Service calls to the BioIK service take long

BioIK Service Performance (1000ms timeout)



BioIK Service Performance (10ms timeout)



Conclusions

- BioIK uses the time it is given [9]
- IK frequency doesn't rise significantly in application
- The BioIK service doesn't seem to be the problem
- Implementation of *rosjava* / *rosandroid* buggy?

Future Work

- Look into performance issues
- Look into arm position jitter
- Implement user feedback (sound, visual, vibration)
- User Studies

- Implement more approaches

Thank you.

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[1] Charan Ram Akupati. "Control of ROS Compatible Mobile Robot with Android Platform using ROSJAVA". Diploma. Universität Siegen, 2017. URL: https://www.eti.uni-siegen.de/ezls/lehre/studiendiplomarbeiten/controlofmobilerobotwithandroidplatform/control_of_mobile_robot_with_android_platform.pdf (visited on 2018-04-01).

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[11] Sebastian Starke, Norman Hendrich, and Jianwei Zhang. "A memetic evolutionary algorithm for real-time articulated kinematic motion". In: *2017 IEEE Congress on Evolutionary Computation (CEC)*. IEEE, 2017. DOI: 10.1109/cec.2017.7969605.

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