Diploma Thesis – Final Report:
"*A Wall-sized Focus and Context Display*"

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Agenda

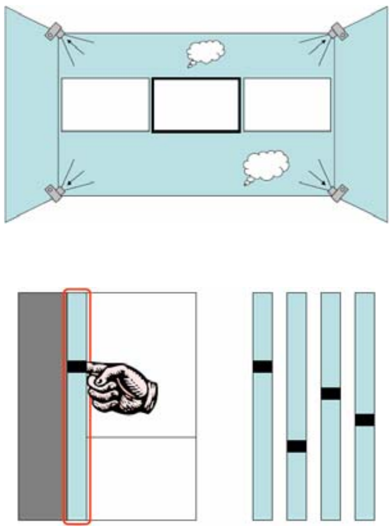
- Introduction
- Problem Statement
- Related Work
- Design Decisions
- Finger Recognition
- System Setup
- Implementation
- Conclusions & Future Work

Introduction

» Instrumented Environments / Ubiquitous Computing

- Used to simulate ubiquitous computing in specific settings
- Equipped with sensors and other tracking devices
- Questions:
  - How can information be displayed in such environments?
  - How does interaction need to be implemented to support users?

Problem Statement



Drawings by Andreas Butz

- Large display wall (three back-projected displays + steerable projector)
- Interaction without augmentation of users
- Requirements:
  - Tracking of multiple fingers
  - Low-cost system (Webcams)
  - Complete wall as one display

Related Work

» Instrumented Environments (I)

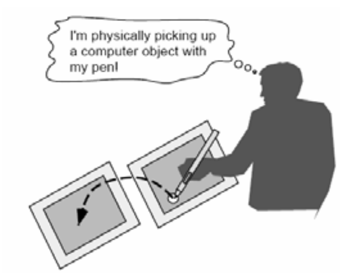
iWork [7]

- Interactive Workspaces Project (*iWork*) [7]:
  - Meeting and office room
  - *iROS* for communication
  - No interactivity on the whole wall
- *Roomware* [12]:
  - DynaWall ®, InteracTable ®, ConnecTable ® and CommChair ®
  - Limited to pen-based gestures

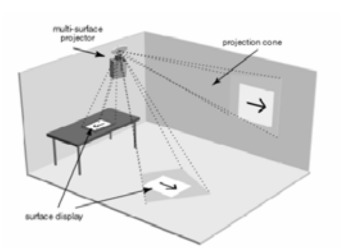
Related Work

» Instrumented Environments (II)

Augmented Surfaces [15]



Pick'n'Drop [14]

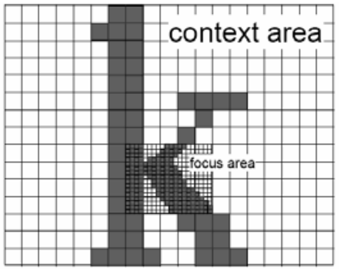


MSIDP [11]

- *Augmented Surfaces* [15]:
  - Computer augmented environment
  - Virtual extension of limited screen size (wall, tables, mobile displays)
  - Indirect interaction
- Interaction Techniques:
  - *Pick'n'Drop* [14] → Pen-based
  - *Multi-Surface Interactive Display Projector* (*MSIDP*) [11]
    → Camera-based tracking

Related Work

» Focus plus Context Displays

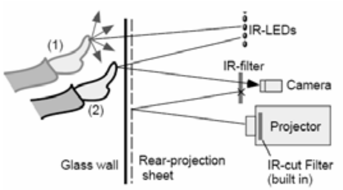


Focus plus Context Screens [1]

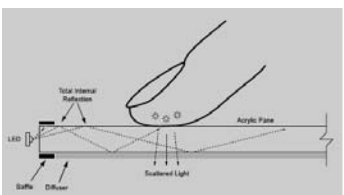
- Region of special interest (*focus*)
- Global view preserved (*context*)
- *Focus plus Context Screens* [1][2]:
  - Combination of display and visualization techniques
  - Fixed focus region
  - Interaction only possible in the focus region → context provides overview

Related Work

» Touch Sensitive Displays (I)



HoloWall [10]

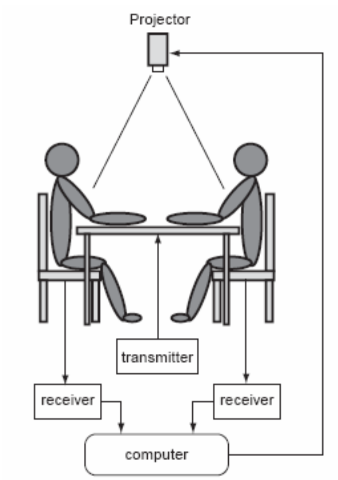


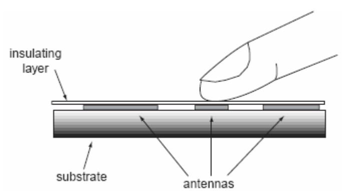
FTIR [5]

- *HoloWall* [10]:
  - Rear-projected glass wall
  - Tracking: IR-Camera
- *FTIR* [5]:
  - Basic idea of fiber optics
  - Acrylic surface with IR-LED arrays attached to it
  - Tracking done by rear-mounted IR-Camera

Related Work

» Touch Sensitive Displays (II)





DiamondTouch [4]

- SMART Technologies [18]:
  - IR-LEDs in the frame surrounding the screen
  - IR-Cameras mounted in the corners
  - Angulation as tracking method
- *DiamondTouch* [4]:
  - Capacitive sensing
  - Users are actively “connected” to the computer

Design Decisions

» Hardware Decisions




- The Display Wall:
  - Three displays (SmartBoard in the center, projection foil on the side)
  - Steerable projector (beamMover 40 by publitec [13])
- Tracking System:
  - SmartBoard for high resoultion
  - Webcams (Logitech QuickCam ® Fusion [9]) for low resolution

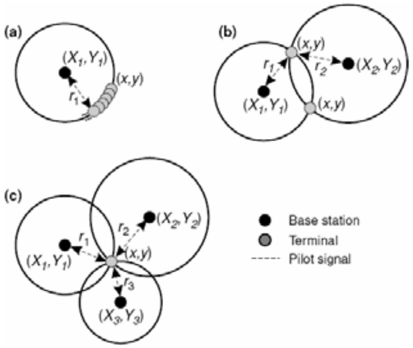
Design Decisions

» Software Decisions

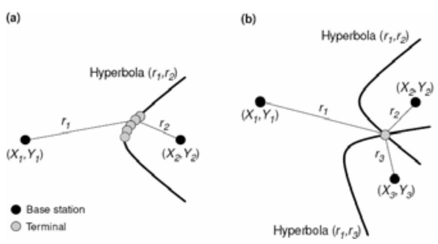
- C# vs. Java:
  - C# supports multiple cameras with DirectShow (Java/JMFonly supports one camera at a time
  - Java for communication (Event Heap [6]) and visualization (Swing)
- SmartBoard SDK for input events
- C/C++ DLL (with JNI) for the steerable projector

Finger Recognition

» The Tracking Method (I)

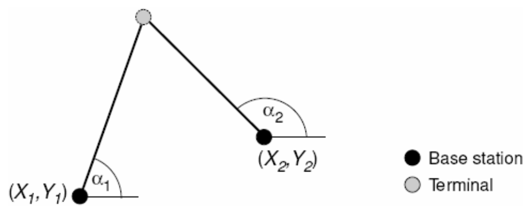


Circular lateration (2D) [8]



Hyperbolic lateration (2D) [8]

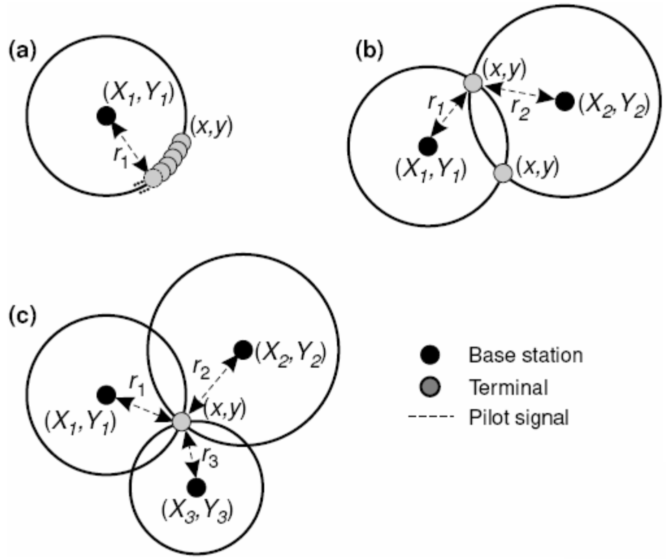
- Lateration:
  - Range (Difference): Traveling time (difference) of emitted signal
- Angulation:
  - Antenna arrays (sectorized)
  - Each pixel is an antenna



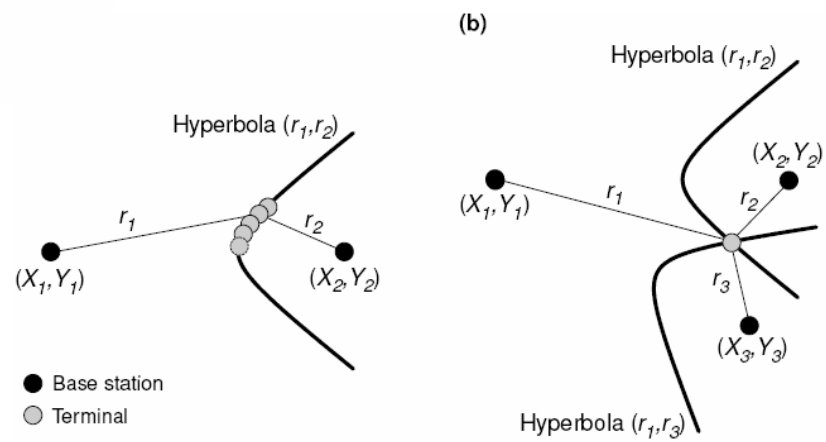
The basic principle of angulation (2D) with two receivers. The positions (*X*, *Y*) are known before the measurement of the angles [8]

Finger Recognition

» The Tracking Method (II)



Circular lateration (2D) [8]



Hyperbolic lateration (2D) [8]

Finger Recognition

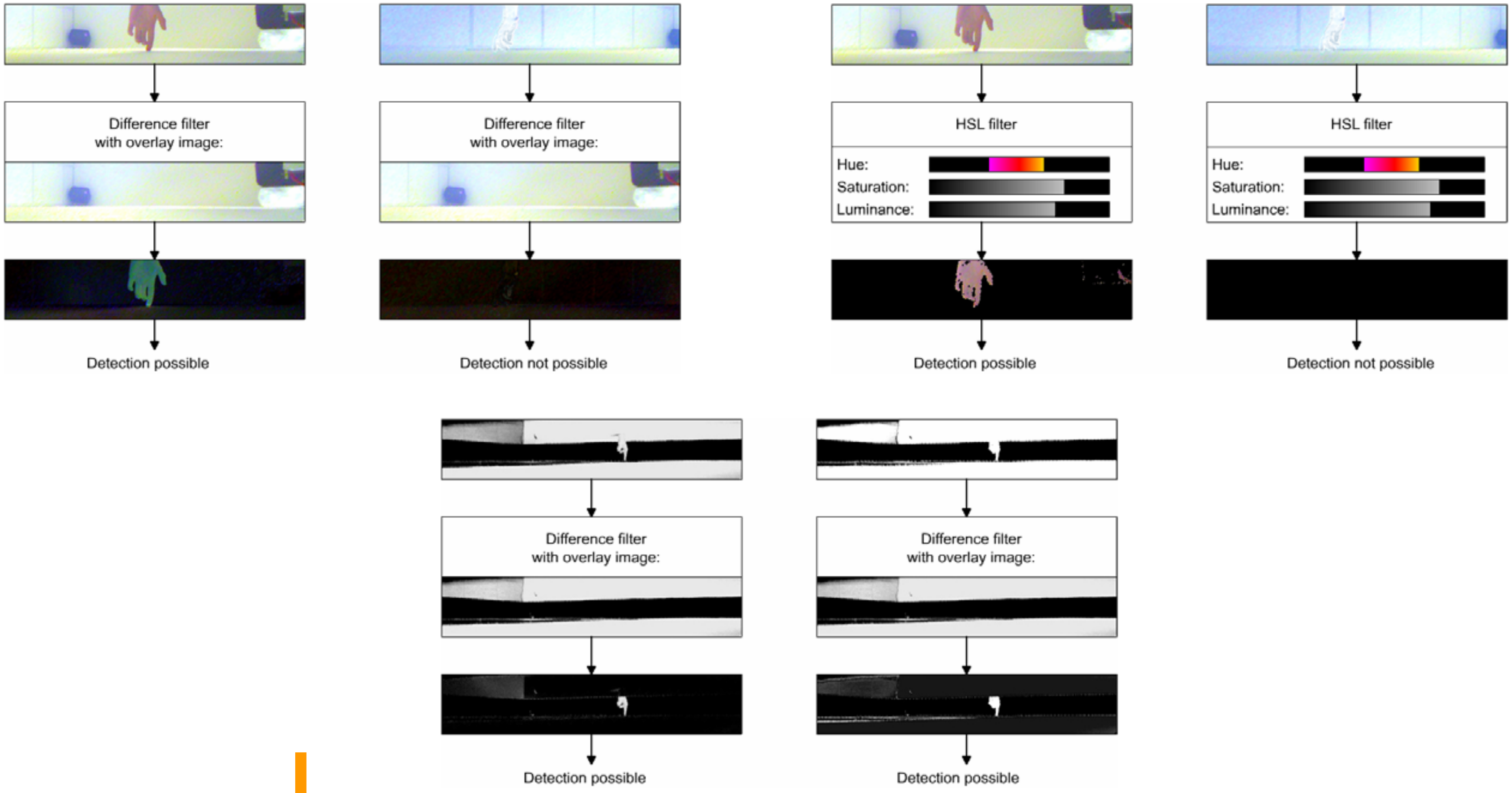
» Calculating Angles from Live-Captured Images (I)

- Frame Differencing:
  - Does not work if screens are turned on → Fingers will have the same color as the background
- HSL Filtering:
  - Does not work if screens are turned on → Fingers will have arbitrary colors
- Non-reflection surface needed

→ black velvet

Finger Recognition

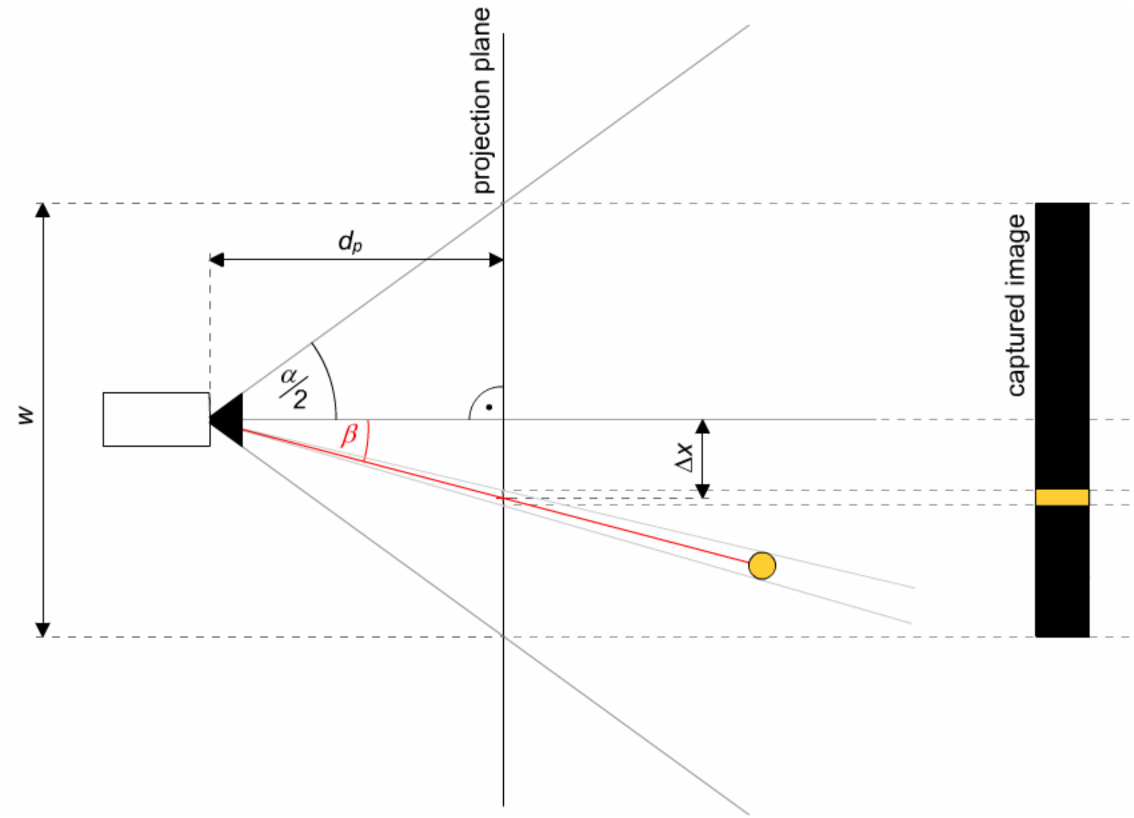
» Calculating Angles from Live-Captured Images (II)



Different filter techniques for object (e.g. finger) recognition. Top left shows differencing, top right shows HSL filtering. Bottom illustrates differencing with black velvet mounted onto the wall.

Finger Recognition

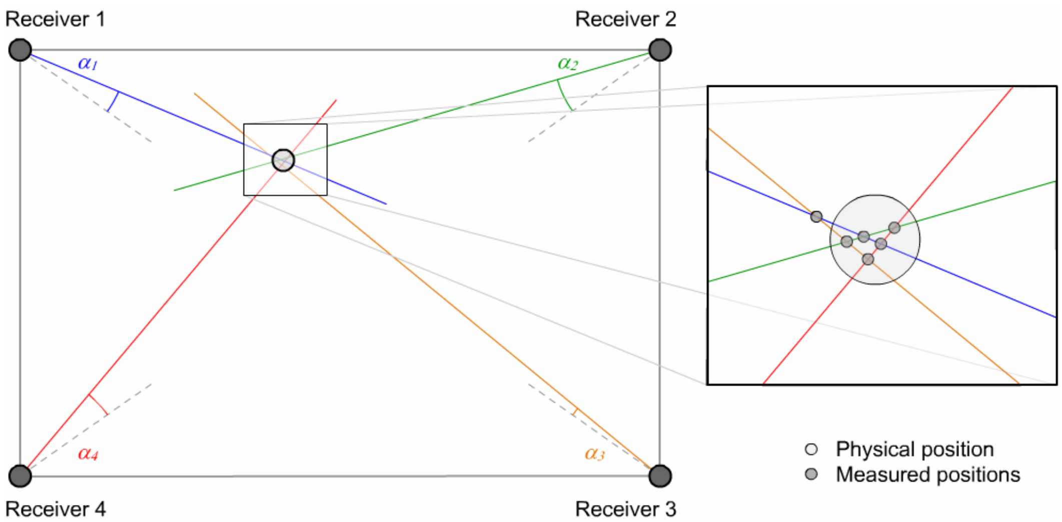
» Calculating Angles from Live-Captured Images (III)



Geometrical illustration of the calculation of images captured by a camera.

Finger Recognition

» Process of Triangulation (I)



The positioning using angulation with four receivers. The magnification illustrates the error potential for a single position. Small circles indicate intersections of a pair of lines from two receivers.

Finger Recognition

» Process of Triangulation (II)

- Multiple fingers require more than two receivers
- Calculate the line between each detected finger and every camera
- Take two cameras and intersect all detected lines
- Intersection is valid if it is close enough to the lines of the other two cameras

Finger Recognition

» Continuity of Finger Movement

- Recognized fingers need to be matched to previously detected fingers
- Dead Reckoning as simple method:
  - Store the orientation vector of the last movement
  - Make the assumption that the finger moves in the same direction
  - Old position + orientation vector = estimated position

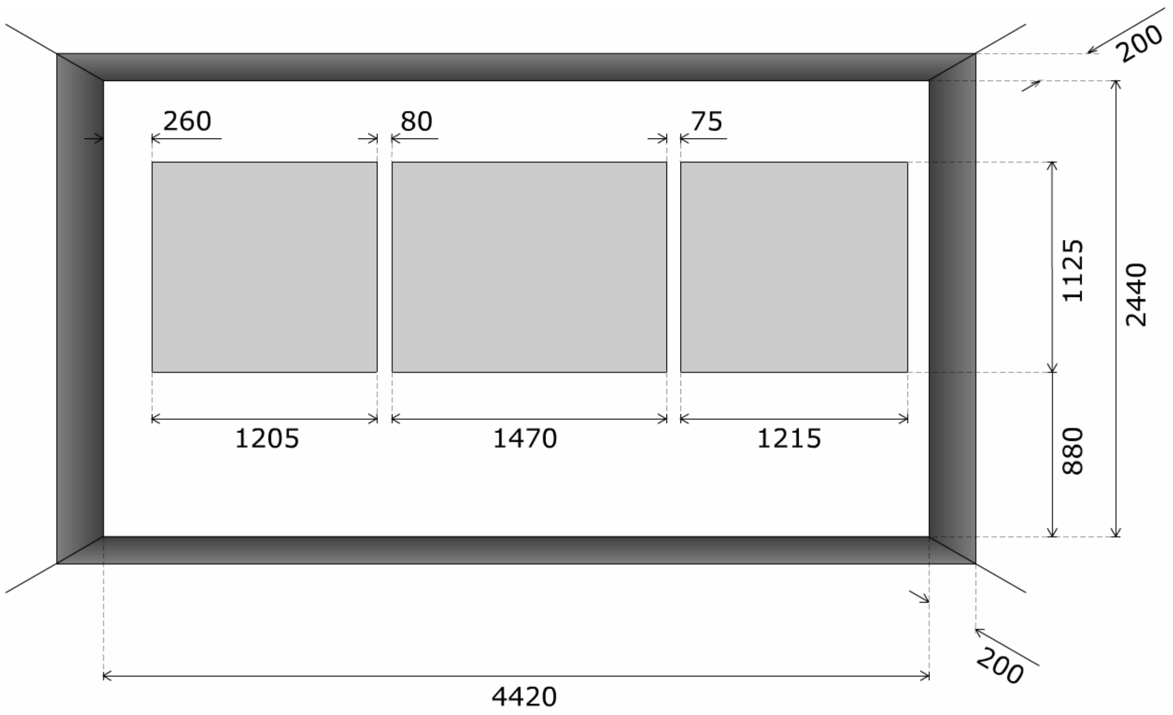
Finger Recognition

» Calibration Issues

- Camera Calibration:
  - Individual settings for each camera
  - Calibration image, camera's position and filter threshold as parameters
- System calibration:
  - Association between raw position data and screen coordinates
  - Interactive calibration procedure

System Setup

» The Display Wall

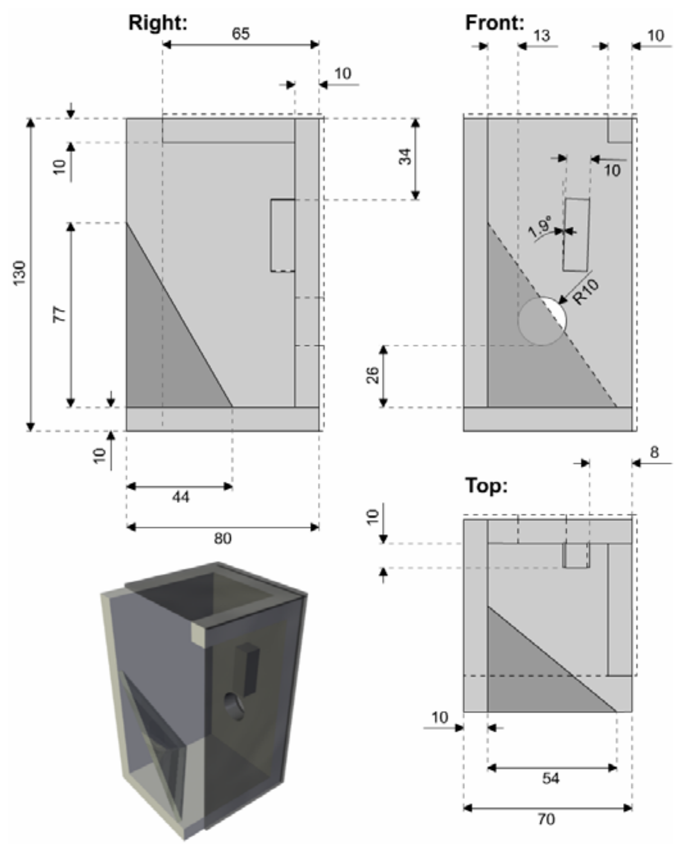


Wall setup and display arrangement. Unit of measurement is millimeter.

System Setup

» Camera-based Tracking System

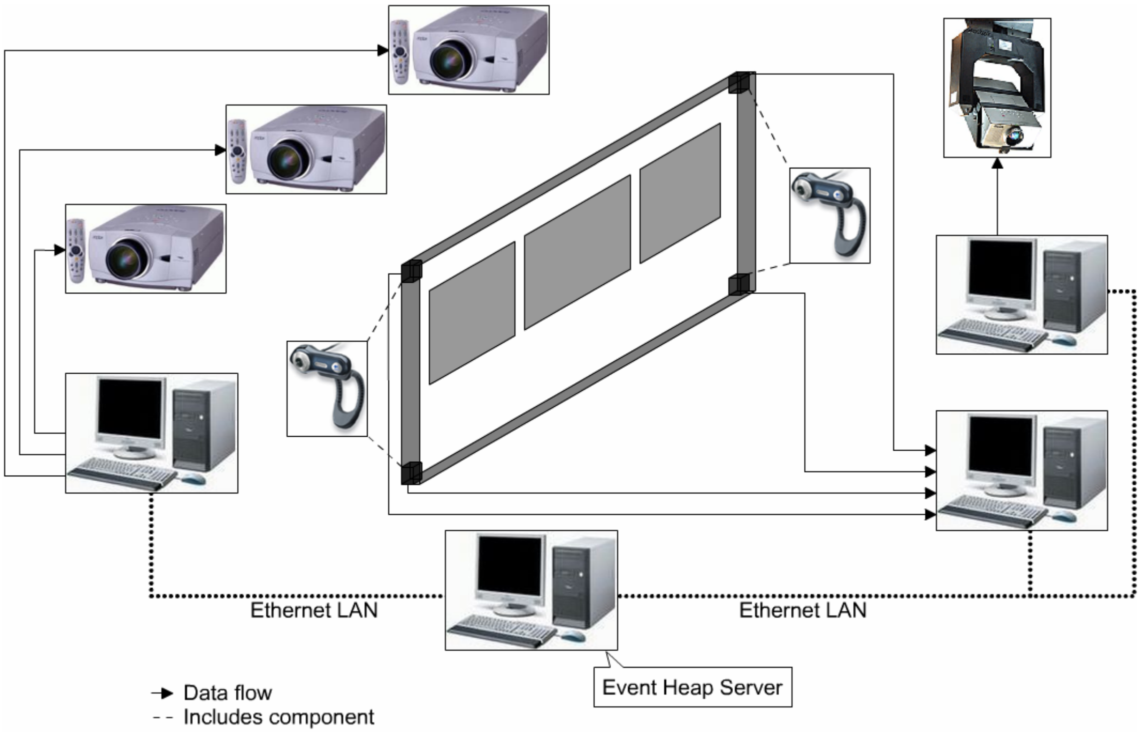
Different views of the fixation for one camera.



Design drawing of the fixation for one camera.
Unit of measurement is millimeter.

System Setup

» Complete System Overview

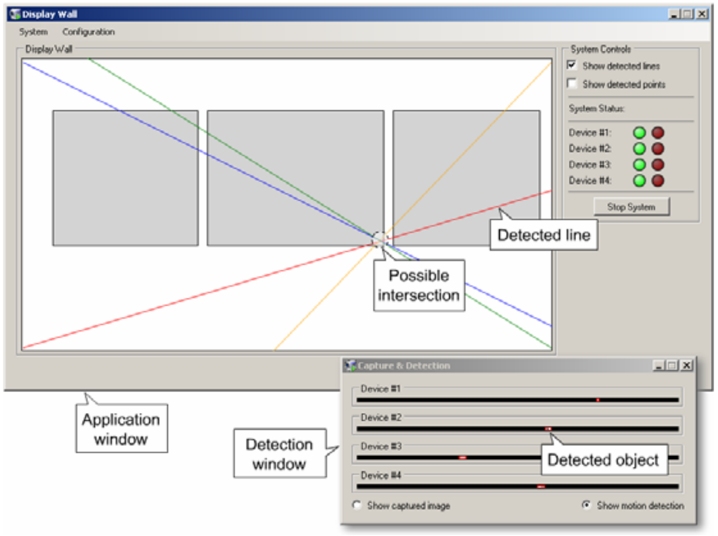


Basic setting of the system in the instrumented room. [3][9][16][17]

Implementation

» The Tracking Engine

- Implemented in C# + DirectShow
- Calculates raw positions and sends it to listening applications through the Event Heap

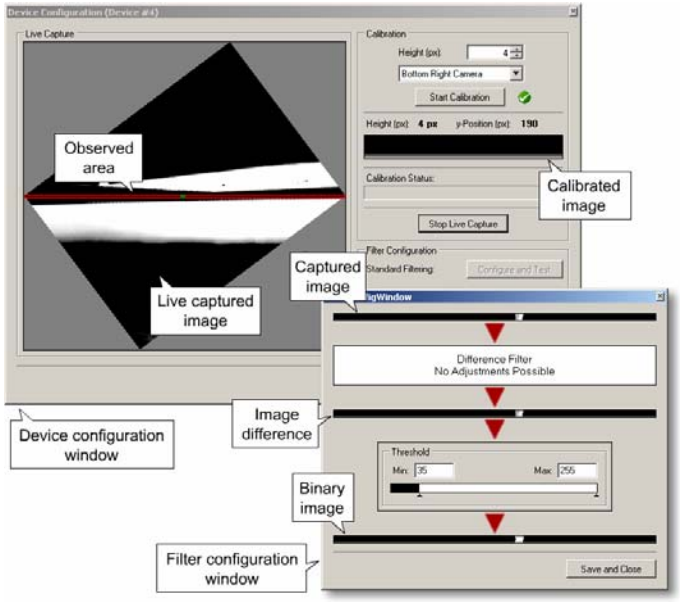


Screenshot of the main application window and the detection window. In the detection window, the user is able to see currently detected objects which will be drawn as lines in the main application window.

Implementation

» Camera Calibration

- Implemented in C# + DirectShow
- Stored calibration data in XML

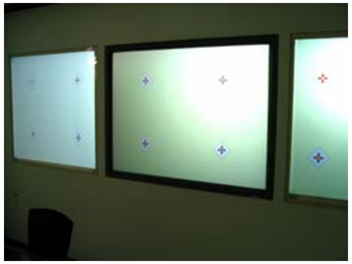


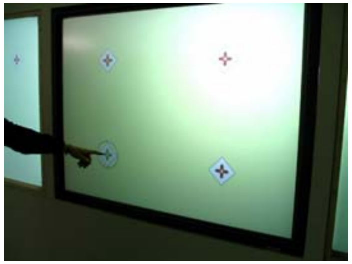
Screenshot of the device configuration window and the filter configuration window. Both give the user all necessary controls to calibrate and adjust device related data.

Implementation

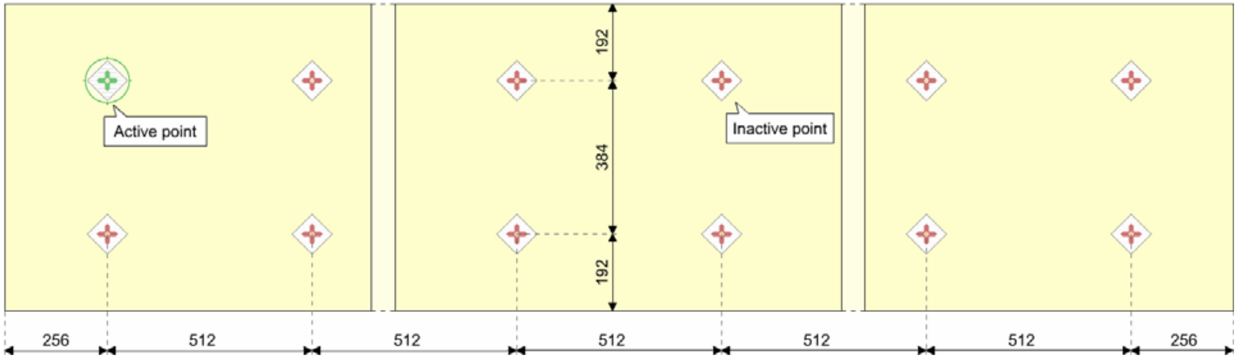
» Interactive System Calibration

- Runs on two different machines:
  - Tracking engine (C#)
  - Calibration display (Java)





The calibration screen projected onto the displays and bottom right demonstrates a user calibrating the system.



Sketch of the calibration screen (projected onto all three displays) with the first point as active point.

Implementation

» Connecting Fingers and Positions

- *Input Layer*:
  - Merges input from the wall and the SmartBoard
  - Associates recognized fingers with previously detected ones
  - Sends unified finger positions to listening applications

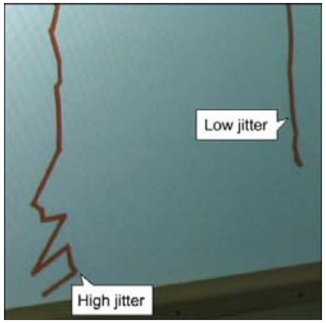
Implementation

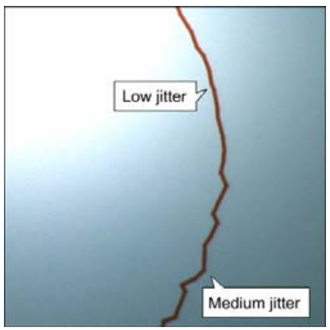
» Steerable Projector

- Runs on a third computer
- Provides an interface to the USB2DMX interface to control the projector
- Available DMX [19] values:
  - Pan/Tilt
  - Focus/Zoom
  - Trapeze adjustment (H/V)
  - Control channel

Conclusion & Future Work

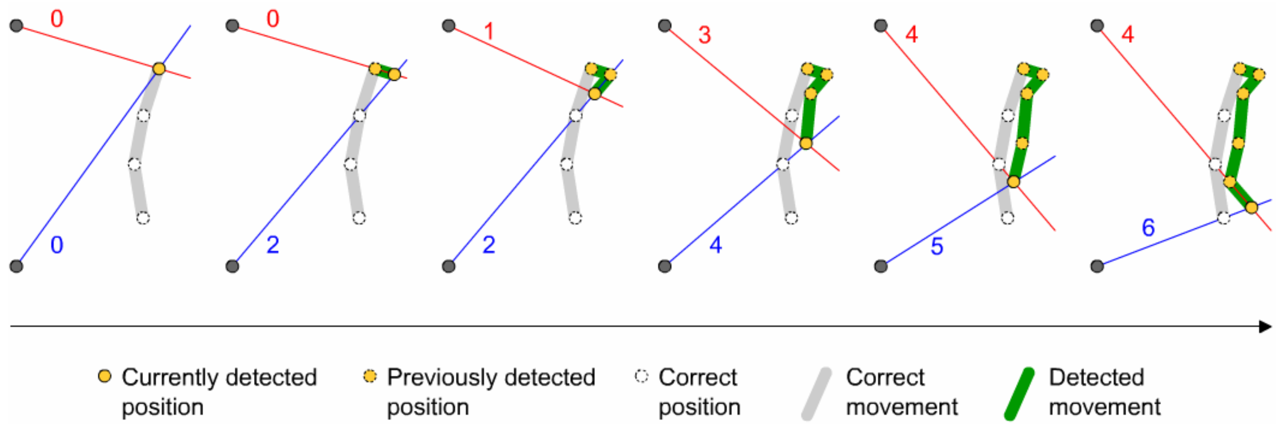
» Possible Improvements of the System (I)





Jitter occurring while running the *WallDraw* demo application

- Jitter as a major problem

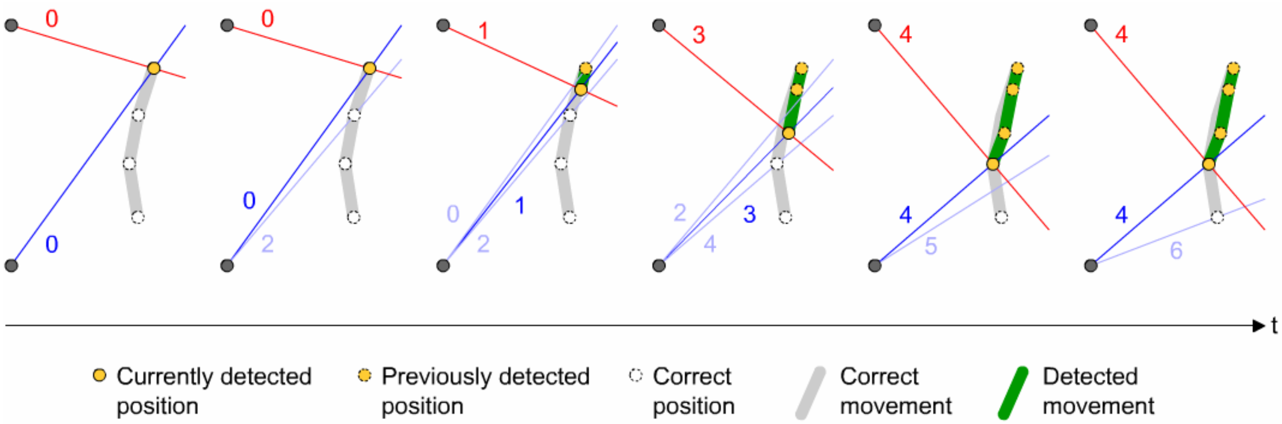


Example of a detection process with the currently used method. The numbers represent the time stamps of each line

Conclusion & Future Work

» Possible Improvements of the System (II)

- Possible solution to avoid jitter:



Example of a detection process with the interpolated method. The numbers represent the time stamps of each line

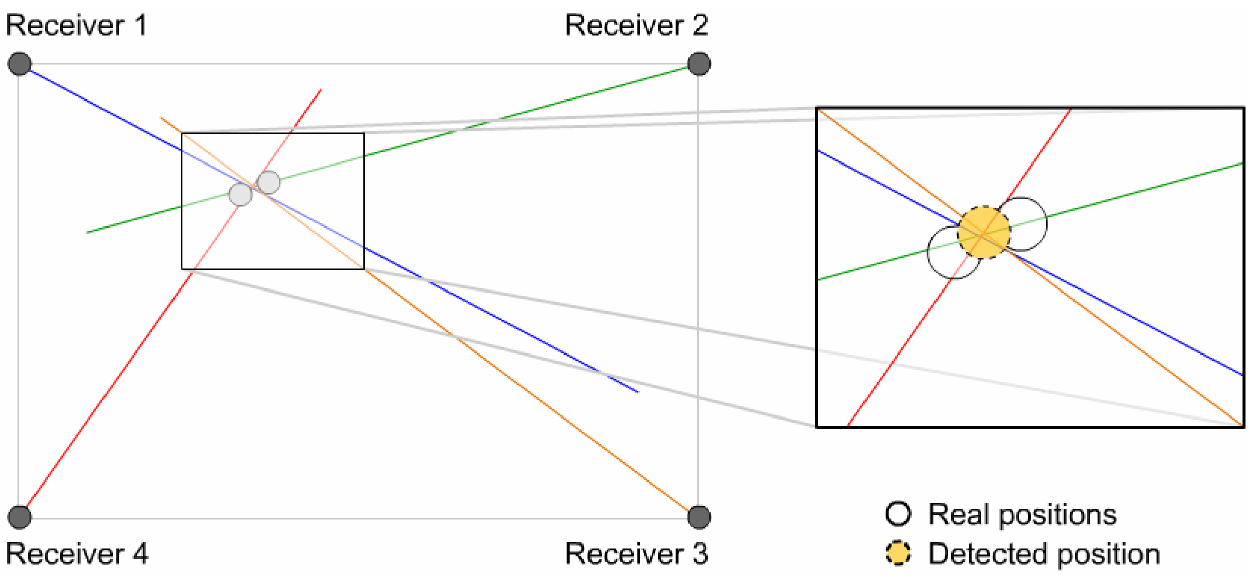
Conclusion & Future Work

» Possible Improvements of the System (III)

- Low resolution is not able to detect closely neighbored fingers:
  - Fingers might be undetected
  - Two positions might be merged into one (inaccurate)
- Traces of fingers can be incorrect with the current method of dead reckoning in special cases

Conclusion & Future Work

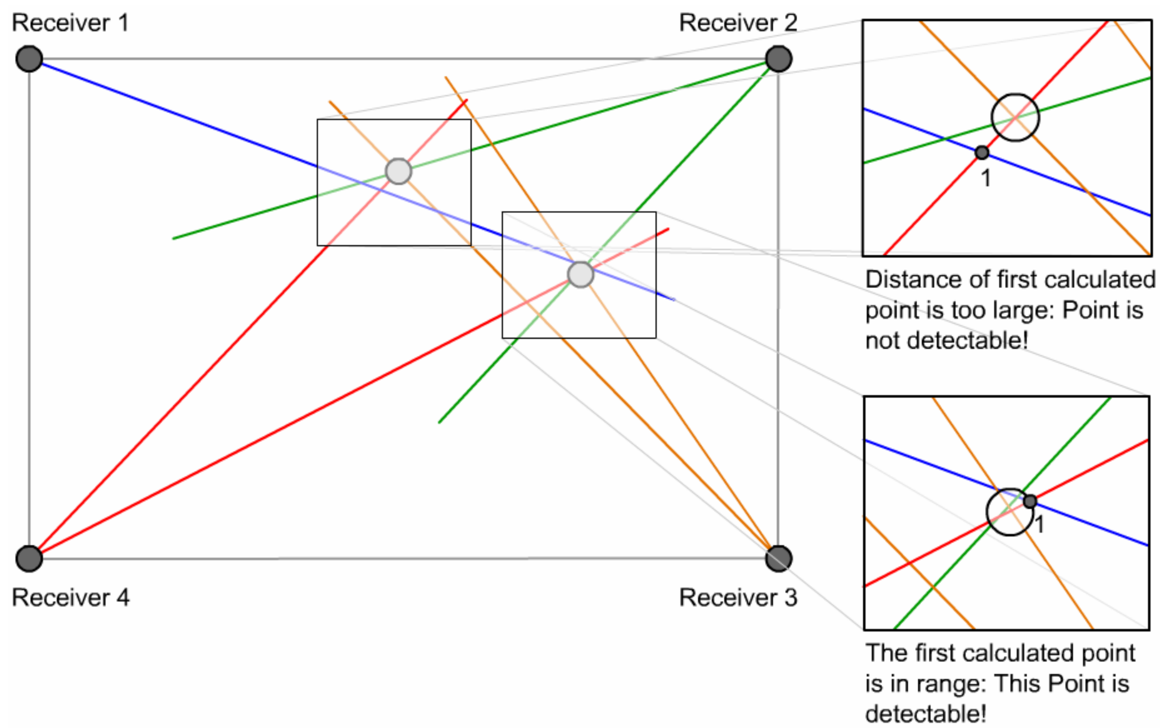
» Possible Improvements of the System (IV)



This shows two positions on the wall where only one will be detected. The upper magnification shows the detection error due to a too large distance of the calculated position from other lines. The lower one shows the correct detection of the second point on the wall.

Conclusion & Future Work

» Possible Improvements of the System (V)



This shows the inaccuracy as two intersections existing on the wall are merged into one detected intersection, causing jitter over a given time span.

Conclusion & Future Work

» Overall Impression

- Inexpensive wall-sized focus plus context display
- Execution speed <= 100 ms for each detection cycle
- Several input- and output technologies combined that form a large interactive display
- Not restricted to a single user

  → simultaneous detection of up to four fingers possible

Conclusion & Future Work

» Future Work

- Improvement of the tracking system in the near future
- Image equalization for the steerable projector to display rectangular images
- Implementation of a large demo to demonstrate the instrumented room

Thank you!

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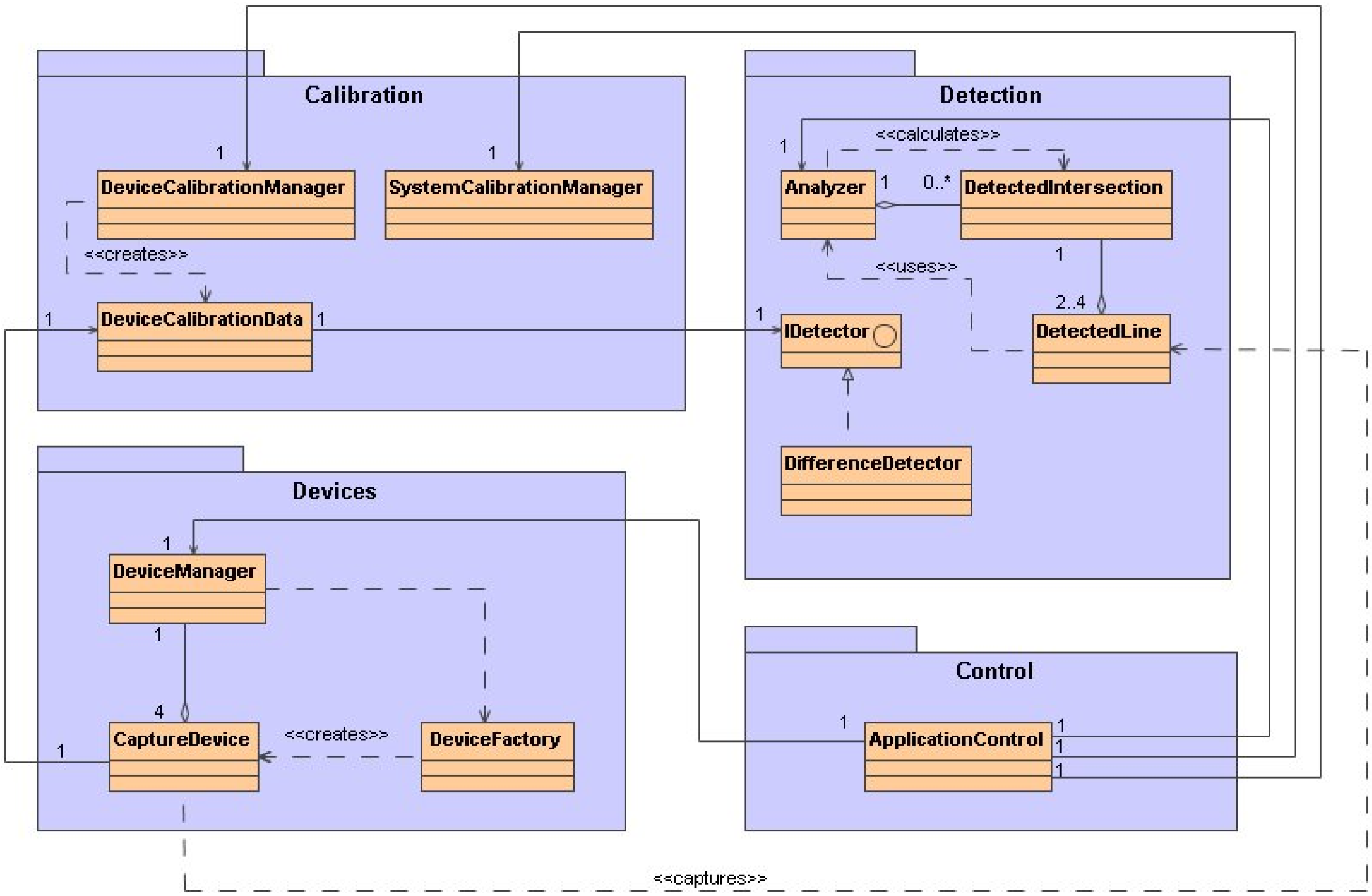
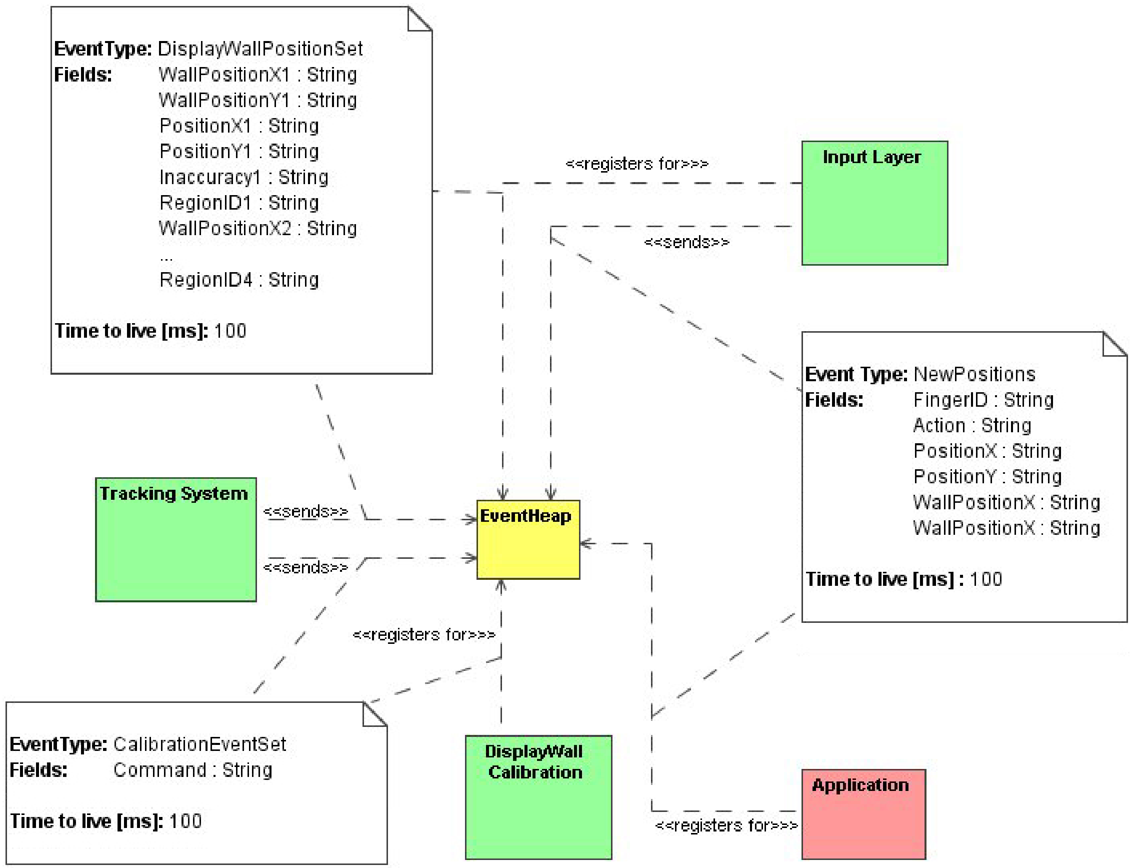
UML-Diagrams

» Device System



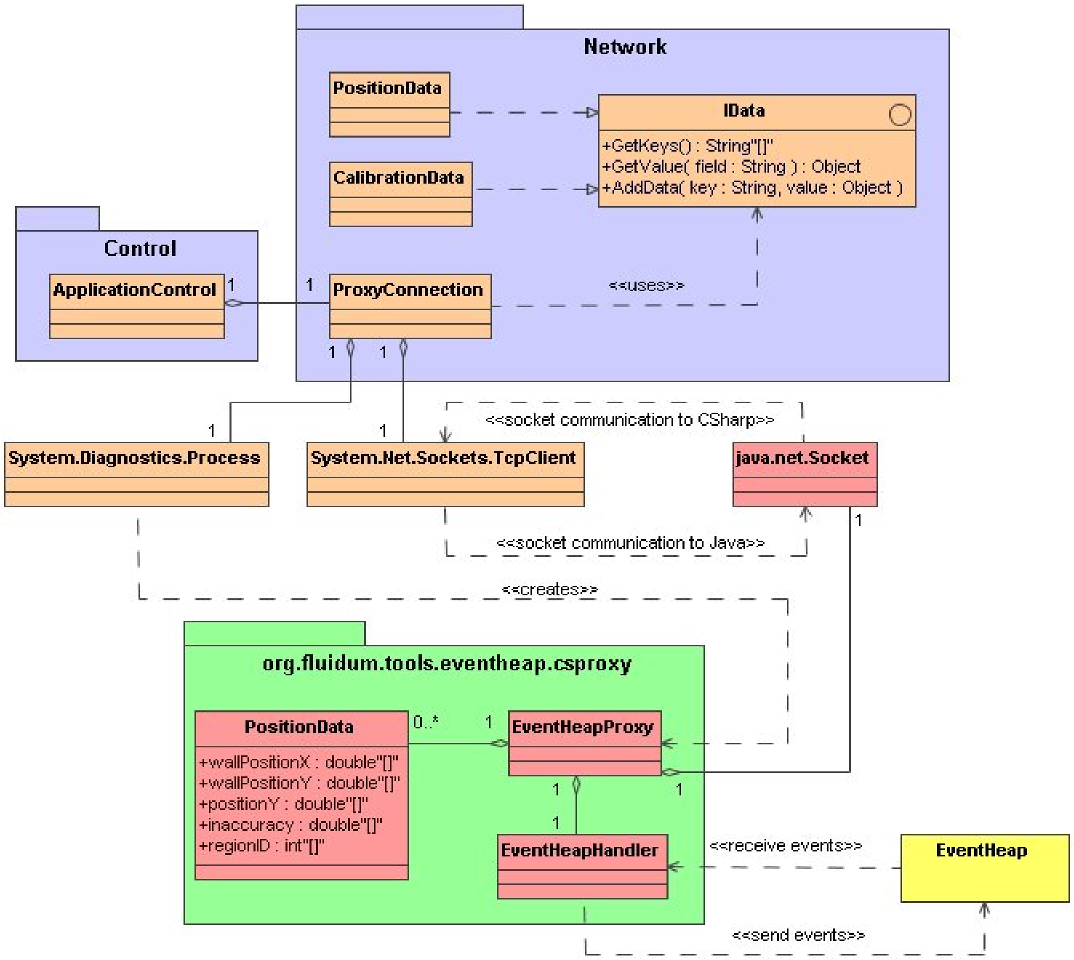
UML-Diagrams

» Event Heap Communication



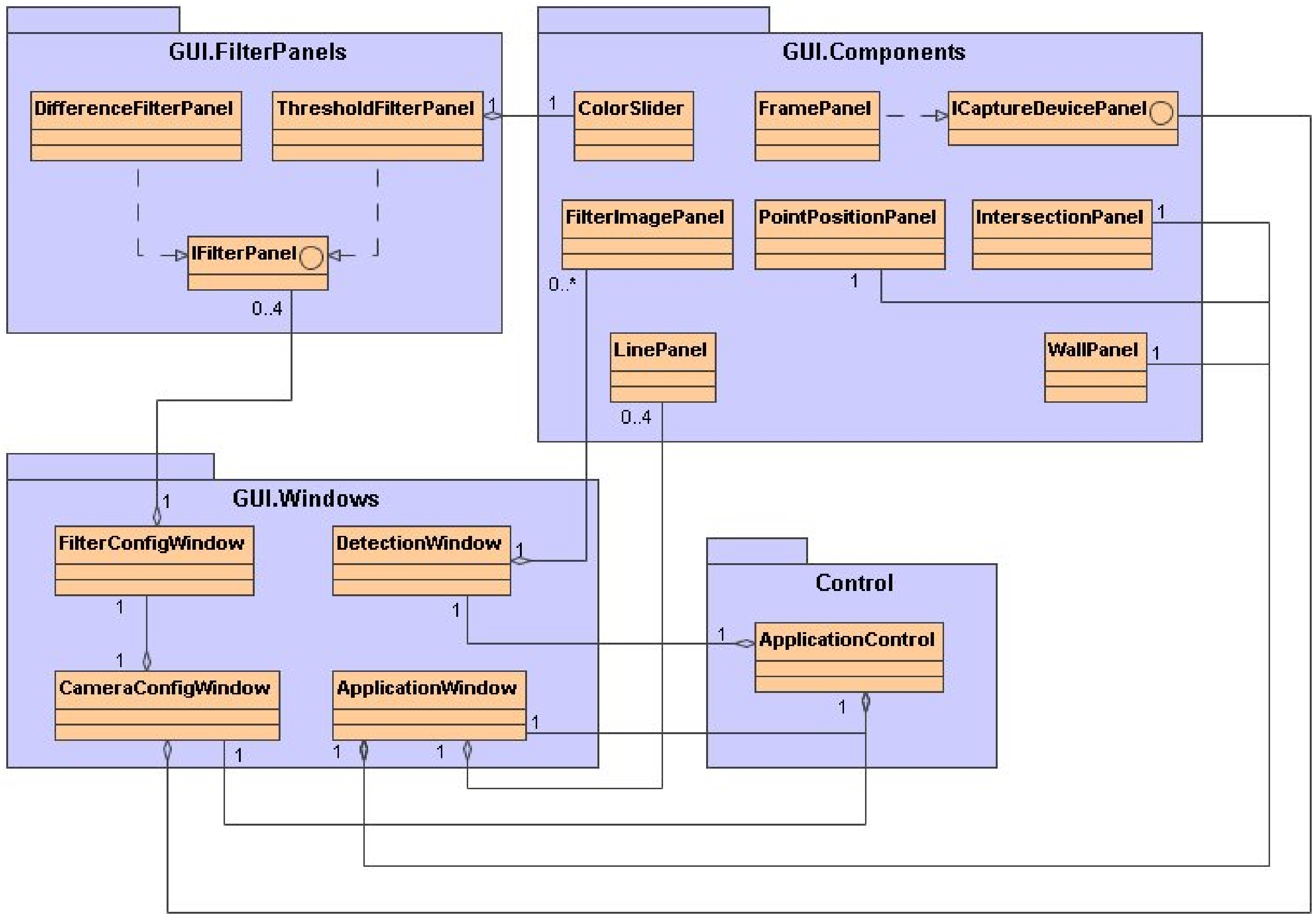
UML-Diagrams

» Event Heap Connection



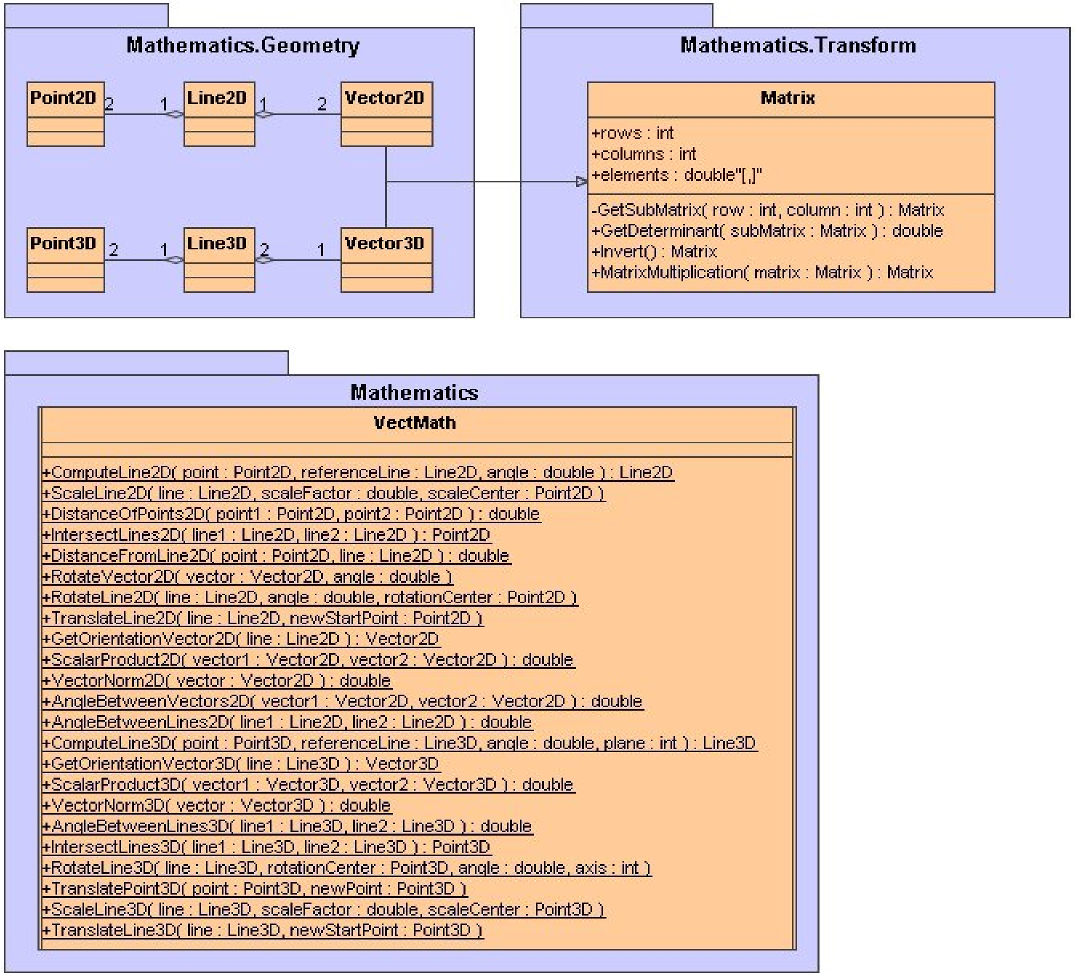
UML-Diagrams

» Graphical User Interface



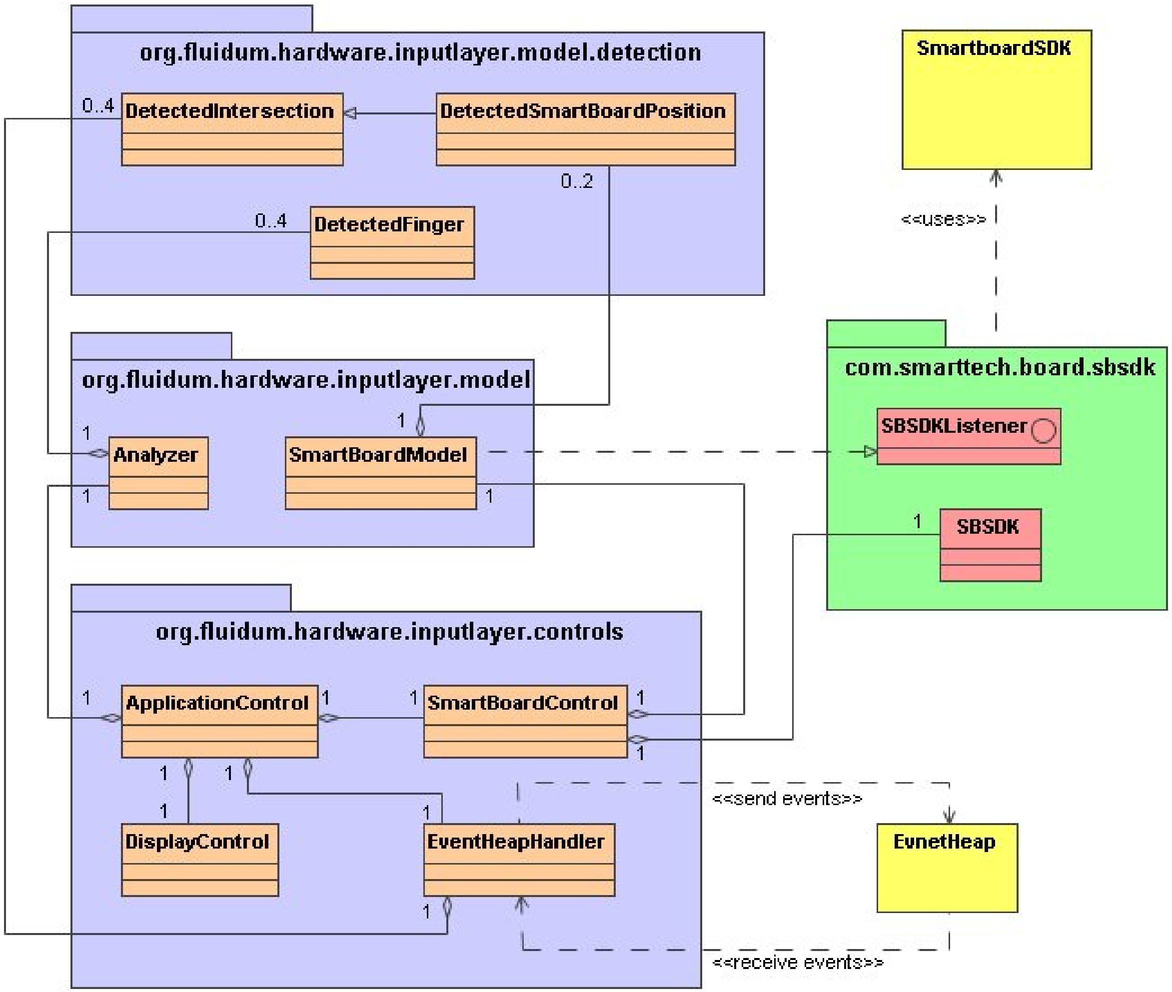
UML-Diagrams

» Mathematical Implementation



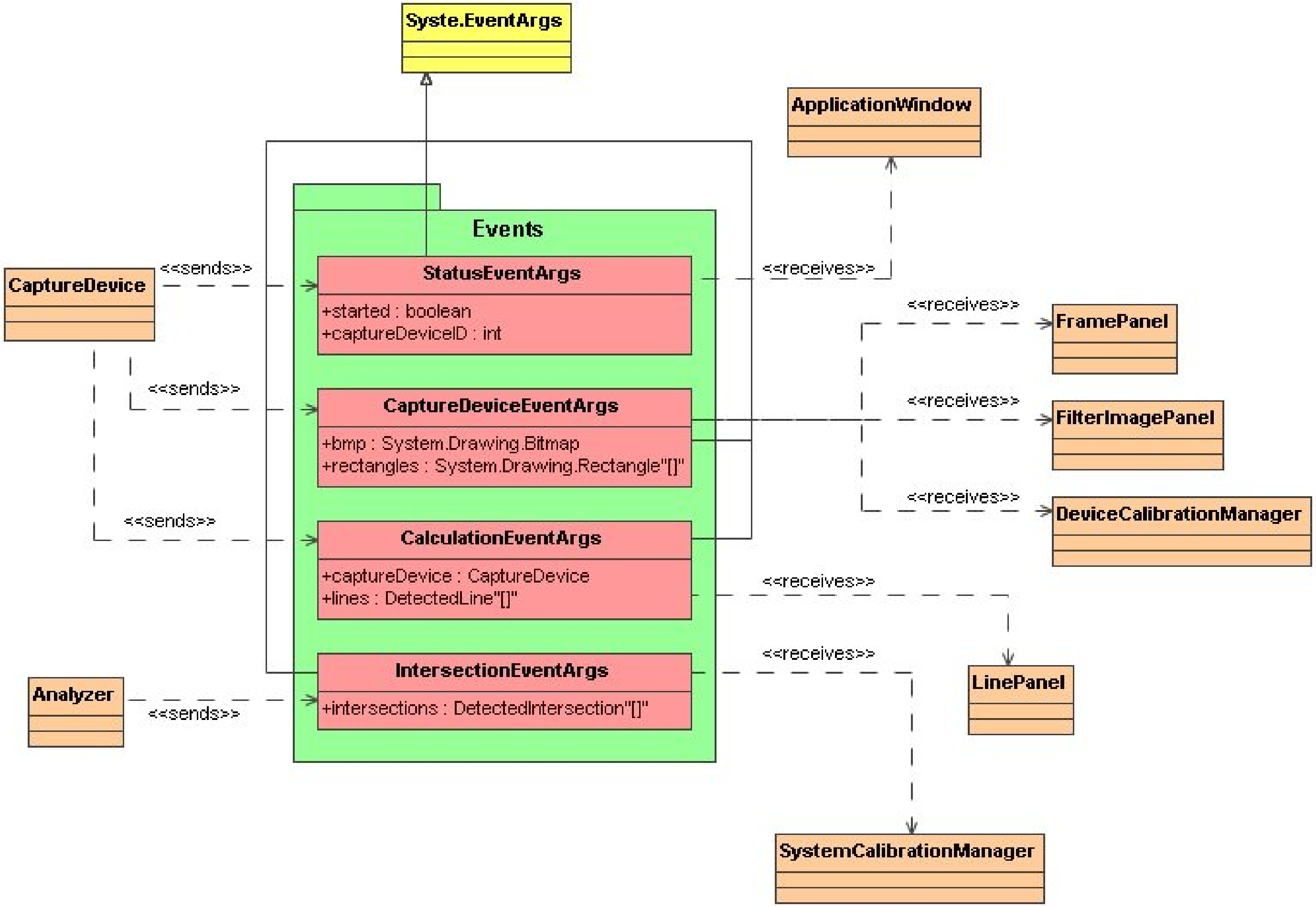
UML-Diagrams

» Input Layer



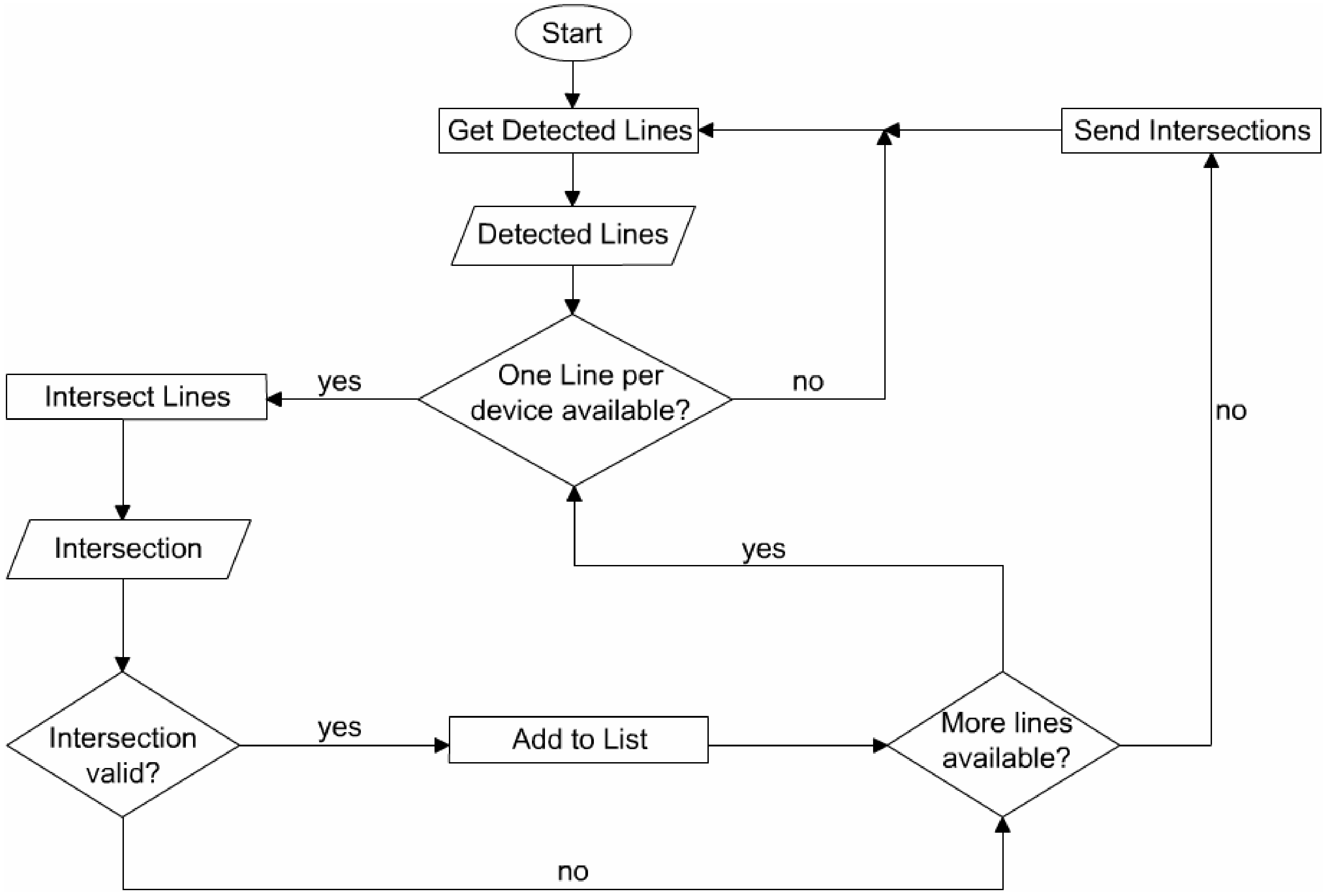
UML-Diagrams

» Internal System Events (C#)



Flow Charts

» Position Calculation



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Flow Charts

» Transformation Matrices