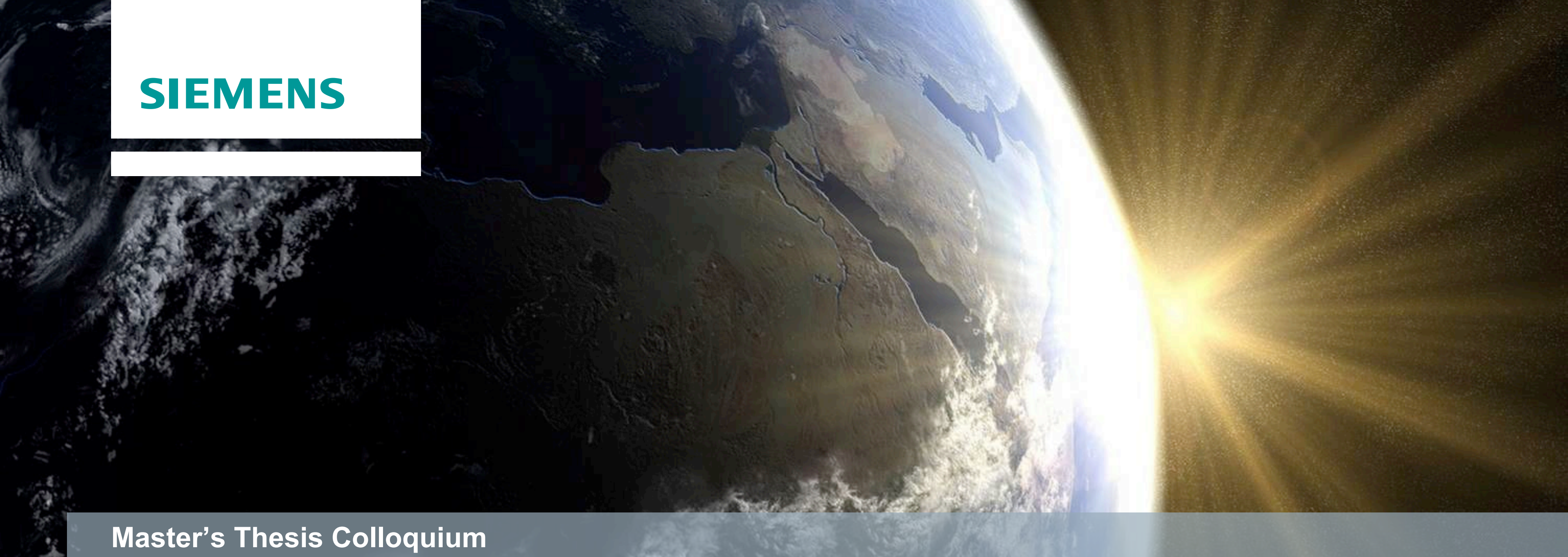


SIEMENS

Master's Thesis Colloquium

Portable Multisensory 3D Panorama Platform utilized for Remote Factory Planning

Technische Universität München

Ronny Bismark

Supervisor: Prof. Dr. Daniel Cremers
Advisors: Dr. Jürgen Sturm , Ph.D Yao-Jen Chang

SIEMENS

PRESENTATION OUTLINE

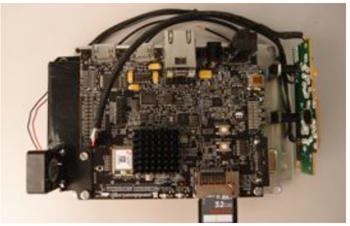
Topics Overview

Introduction

- Motivation
- Problem Statement
- Structure from Motion
- Siemens Bubble View
- Operating System

Hardware

- ARM & SoC
- Platform Selection
- Sensors
- Prototype

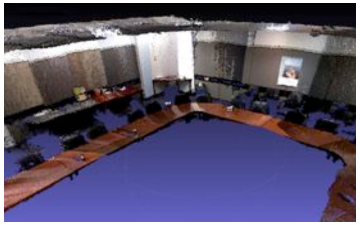


Software

- Sensor Interfaces
- Synchronizer
- Scene Reconstruction

Results & Conclusion

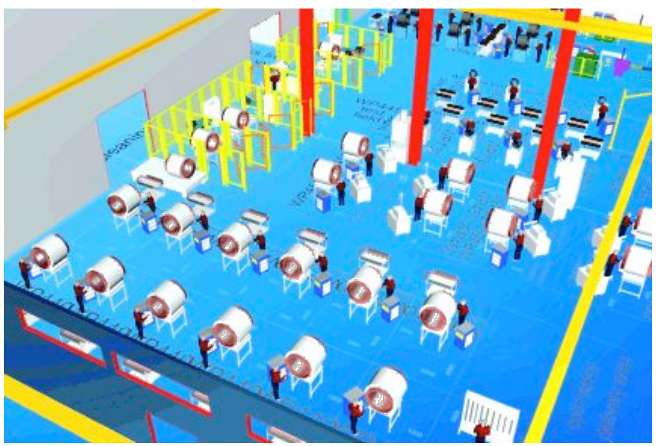
- Small Rooms
- Big Areas
- Factory Scenario
- Conclusion
- Future Work

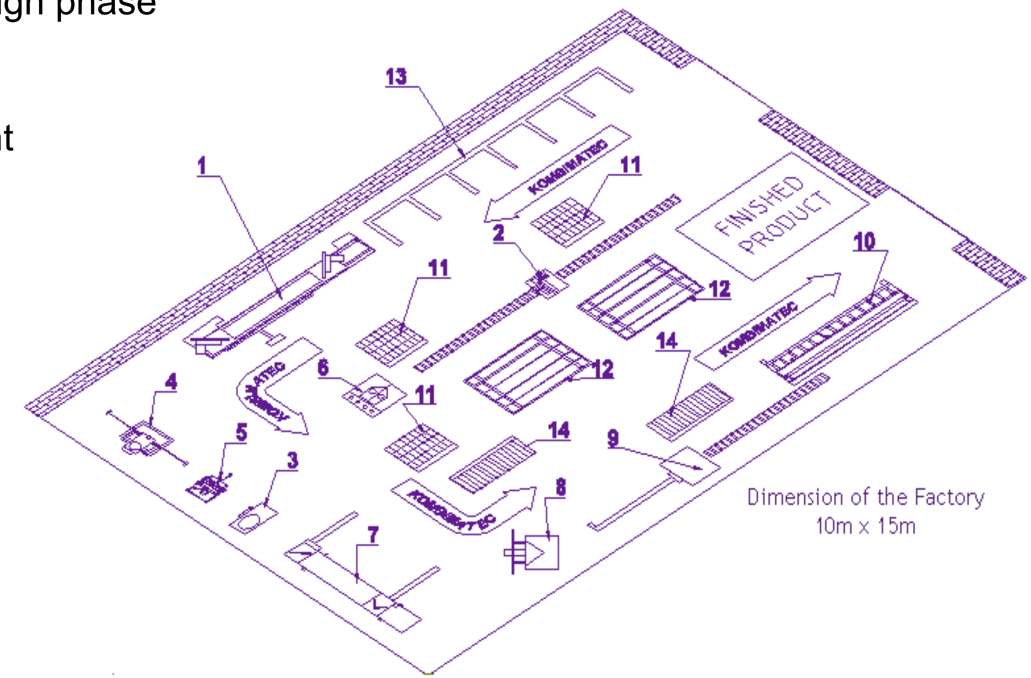


MOTIVATION

SIEMENS

- Common way to handle information for factory planning is to manually digitalize the factory site
- Remote Factory Planning needs as much information as possible
- Dense data with geometric information about objects
- Decrease time of factory planning and design phase
- Reduce traveling costs
- “Google street view” for indoor environment





PROBLEM STATEMENT

- Development of a portable 3D capture device
  - Selection of suitable hardware combination
  - Hardware adaptions and assembly
- Implementation of a reconstruction algorithm
  - Sensor interfaces compatible for the ARM processor
  - Integration of RGB-D data into an Structure from Motion algorithm

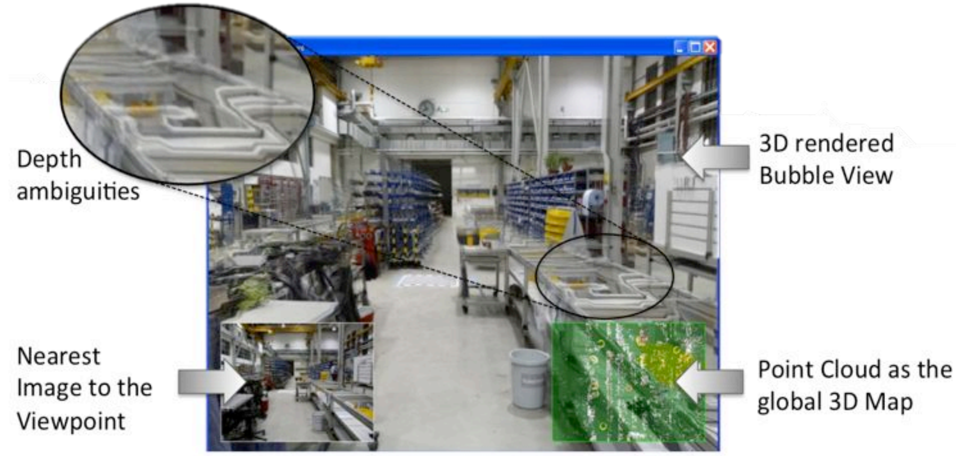
STRUCTURE FROM MOTION

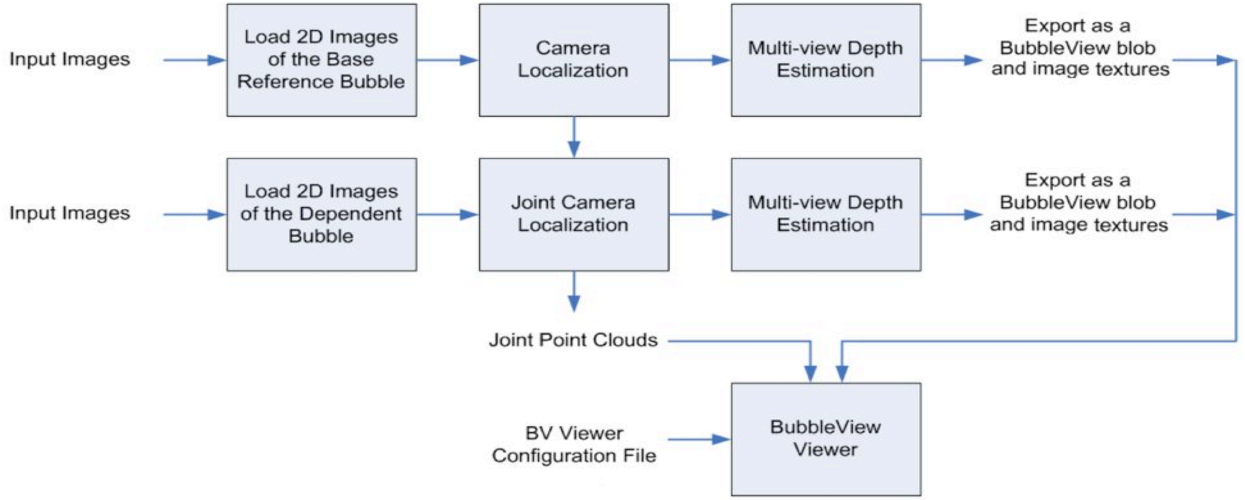
- To reconstruct the 3D geometry of a scene, the standard pipeline of Structure from Motion via Bundler is applied
- Based on epipolar geometry
- Bundler has been developed for large unordered image collections
- Includes several computer vision algorithms
  - F-matrix estimation
  - Calibrated 5-point relative pose
  - Triangulation of multiple rays
- Outputs a sparse point cloud, estimated camera poses, and SIFT keypoints

SIEMENS BUBBLE VIEW

SIEMENS

- Previous work on 3D factor visualization
- Image-based 3D panorama technique
- Image acquisition by a consumer point-and-shot camera
- Sparse 3D information
- Depth ambiguities for near by objects





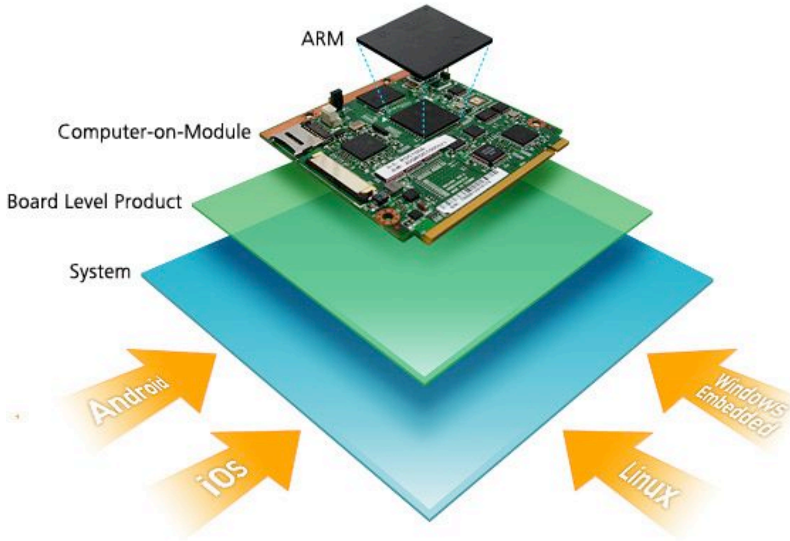
SOFTWARE BASE

- Operating system on the prototype is a standard headless Ubuntu distribution
- ROS (Robot Operating System) as middleware
- Invented by Willow Garage to solve common platform problems
- The platform is overseen by the nonprofit Open Source Robotics Foundation (OSRF)
- Provides hardware abstraction, device drivers, libraries, visualizers, message-passing, package management
- Integrated communication options makes ROS as middleware an easy to expand project base
- The presented software uses mainly the camera driver, the messaging and the synchronization capability

ARM & SoC

SIEMENS

- ARM processors are the main architecture for smart phones and tables
- ARM ensures high performance at low power
- All components of a computer on a single chip
- RISC instruction set
- $35 PC Raspberry Pi influenced project idea
- Various potential development board available



PLATFORM SELECTION

SIEMENS

- Cost-benefit analysis
  - Declaration of criterions and and their grading
  - Comparatively weighting
  - Categorize
  - Cost-benefit value estimation

- Result shows that the PandaBoard ES is the favorite platform choice for our needs

Criterion	Grading
acquisition cost	low
power consumption	medium
operating System	high
performance	medium
USB hosts	high
size	low
community	medium
availability	low

Criterion	1-2	3-4	5-6	7-8
acquisition cost	>$200	>$100	>$50	<$50
power cons.	>6 Watt	>5 Watt	>4 Watt	<4 Watt
operating system	custom OS	Linux based OS	Ubuntu	Ubuntu + ROS
performance	<1GHz core	1GHz core	1GHz dual-core	1GHz quad-core
USB hosts	1 port	2 ports	1 Host, 1 OTG	2 Hosts
size	>20 inch²	>15 inch²	>10 inch²	<10 inch²
community	<10.000	>10.000	>100.000	>1 million
availability	>1 month	2-4 Weeks	1-2 Weeks	in stock

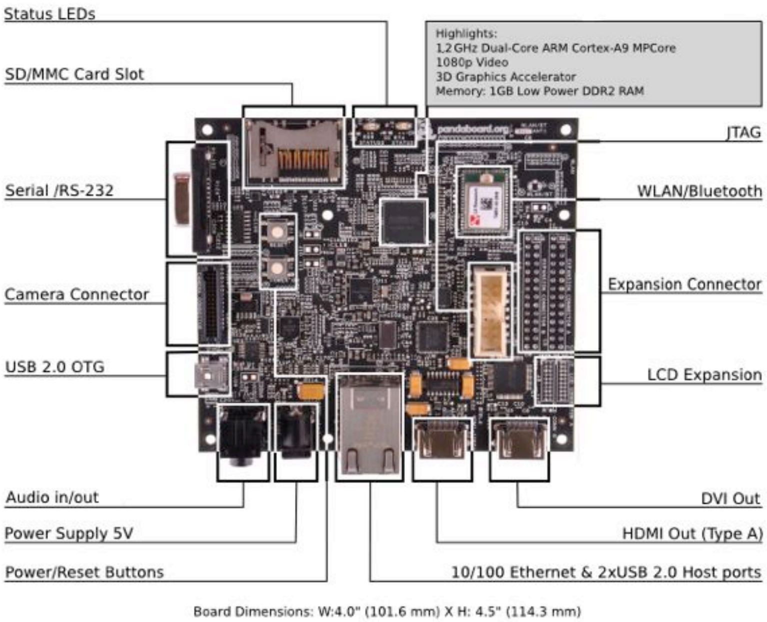
	1	2	3	4	5	6	7	8	value	factor
1. acquisition cost		0	0	0	0	1	1	1	3	0.054
2. power consumption	2		0	1	0	2	2	2	9	0.161
3. operating system	2	2		1	1	2	1	1	10	0.179
4. performance	2	1	1		0	2	2	2	9	0.179
5. USB hosts	2	2	1	2		2	2	2	13	0.232
6. size	1	0	0	0	0		1	1	3	0.054
7. community	1	0	1	0	0	1		1	4	0.0071
8. availability	1	0	1	0	0	1	1		4	0.0071
total									56	1

criterion	factor	BeagleBoard		PandaBoard		Odroid-X		Raspberry	
		TC	CBV	TC	CBV	TC	CBV	TC	CBV
acquisition cost	0.054	3	0.16	3	0.16	4	0.21	8	0.43
power cons	0.161	3	0.48	4	0.64	1	0.16	7	1.13
operating system	0.179	7	1.25	7	1.25	7	1.25	3	0.54
performance	0.179	4	0.71	6	1.07	7	1.25	1	0.18
USB hosts	0.232	4	0.93	6	1.39	1	0.23	1	0.23
size	0.054	4	0.17	3	0.16	4	0.21	8	0.43
community	0.071	3	0.21	5	0.36	3	0.21	7	0.50
availability	0.071	4	0.29	5	0.36	3	0.21	1	0.07
cost-benefit value			**4.28**		**5.39**		**3.75**		**3.50**

PANDABOARD ES

SIEMENS

- Fourth-generation TI OMAP4460 ARM Cortex-A9
- Dual-core 1.2GHz CPU
- 1GB RAM
- Two Cortex-M3 cores to increase power efficiency
- Processing power comparable to an Intel Atom netbook



SIEMENS

LOGITECH C920

- 1/3” sized 3.5 megapixel sensor
- 78° field of view
- Max. resolution 2304 × 1536 in YUYV
- Hardware enabled MJPEG decoding
- 10-20% bandwidth of a comparable RGB stream
- MJPEG is independent of the image motion
- 1920 x 1080 at 5 frames per second

ASUS XTION PRO LIVE

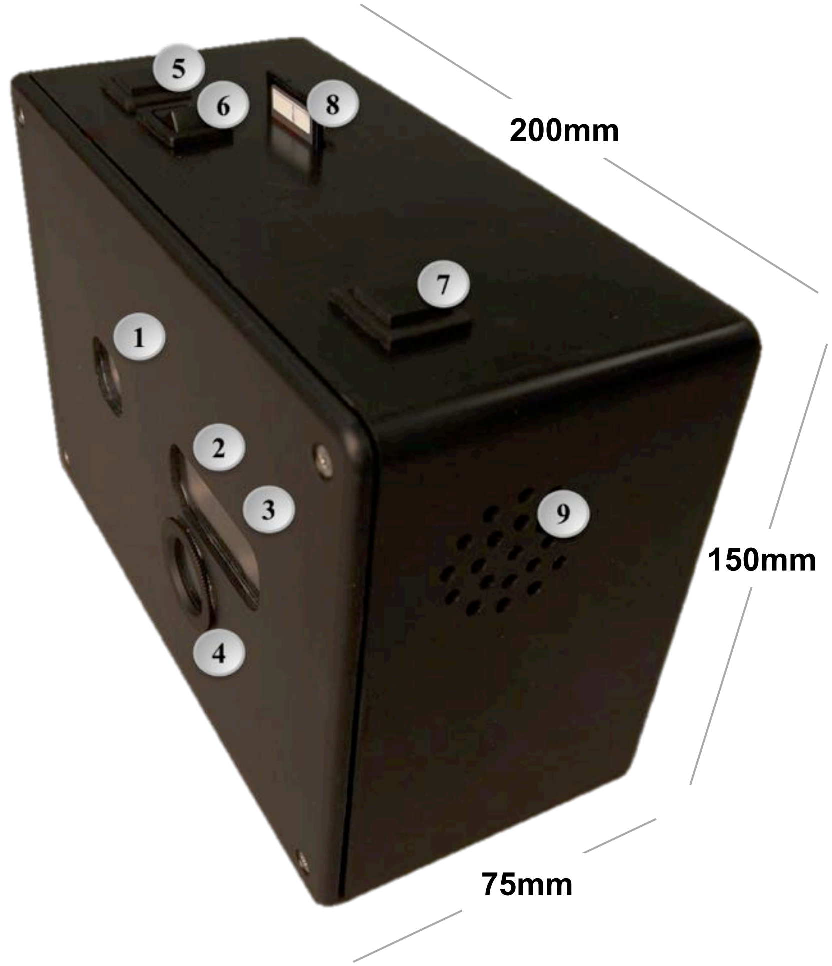
SIEMENS

- RGB-D cameras providing color (RGB) and depth (D) information for every pixel in the image
- Projective stereo technology
- Cheap, low powered, and light-weight compared to other stereo or Time of Flight cameras
- Only one USB connection as power supply

PROTOTYPE

SIEMENS

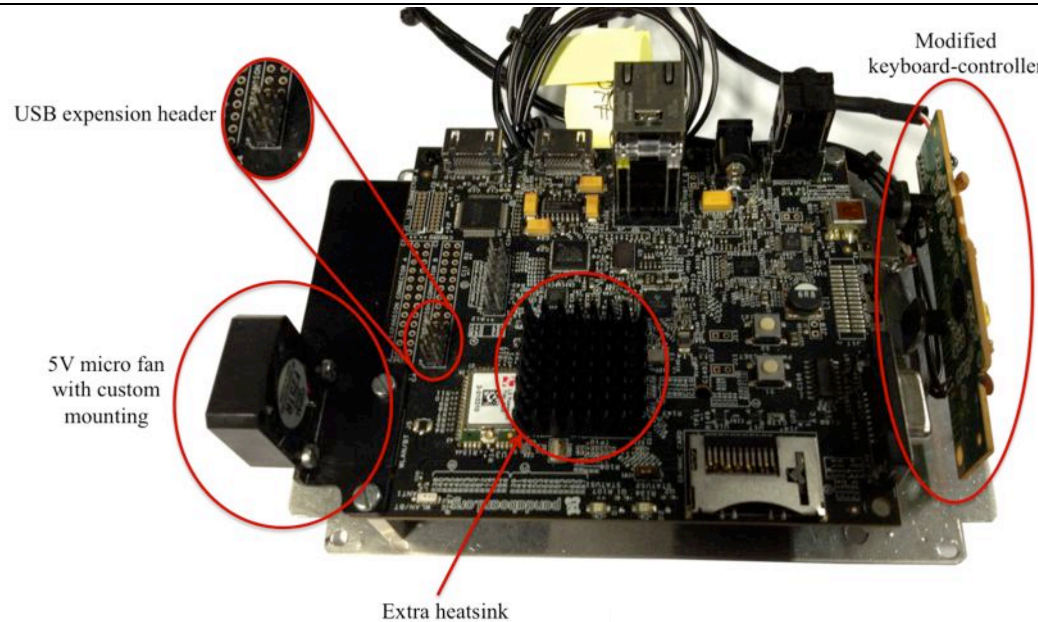
① IR projector
② RGB sensor Asus Xtion Pro Live
③ IR sensor
④ HD RGB camera Logitech c920
⑤ Trigger button
⑥ On/Off flip switch
⑦ Standby button
⑧ SD-card slot
⑨ Ventilation slot

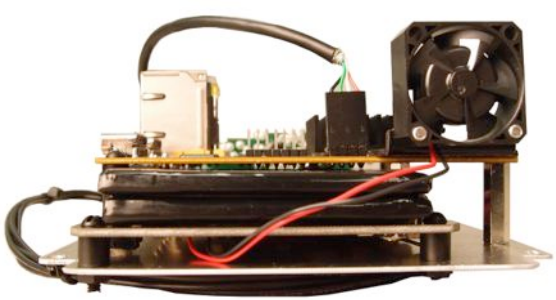


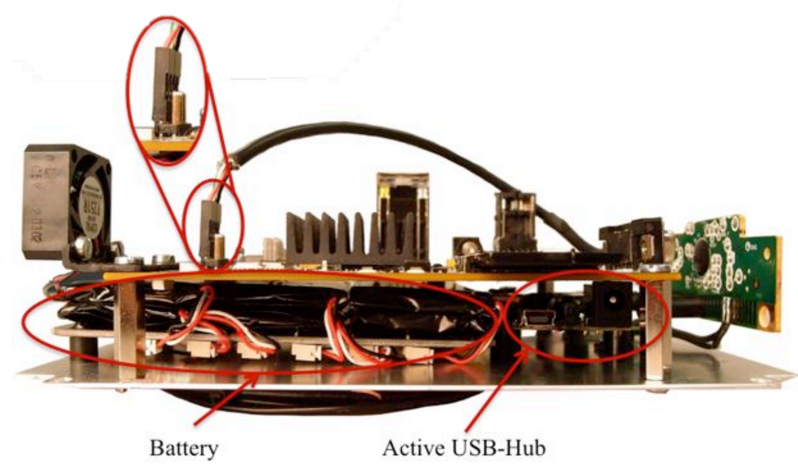
PROTOTYPE

SIEMENS

- PandaBoard ES
- Battery BeagleJuice 2 with 4200mAh
- Active powered USB-hub
- Custom USB A-type cable for OTG port
- Modified keyboard controller as input
- 30 x 30mm heat-sink
- 5V micro fan (20mm)



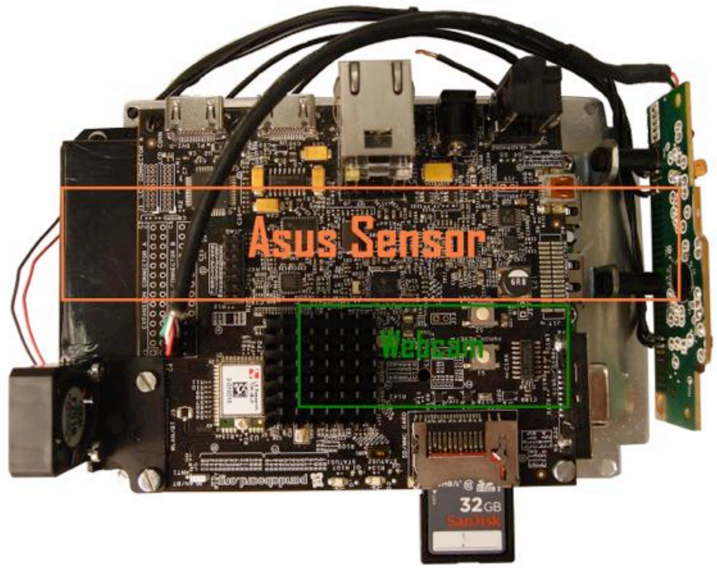




PROTOTYPE

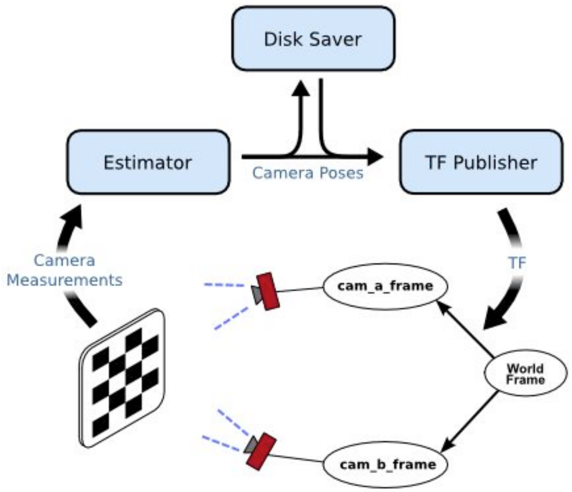
SIEMENS

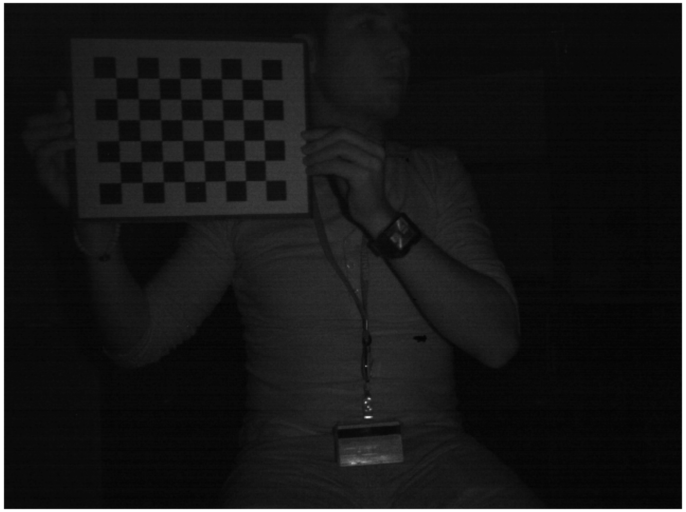
- PandaBoard ES
- Battery BeagleJuice 2 with 4200mAh
- Active powered USB-hub
- Custom USB A-type cable for OTG port
- Modified keyboard controller as input
- 30 x 30mm heat-sink
- 5V micro fan (20mm)

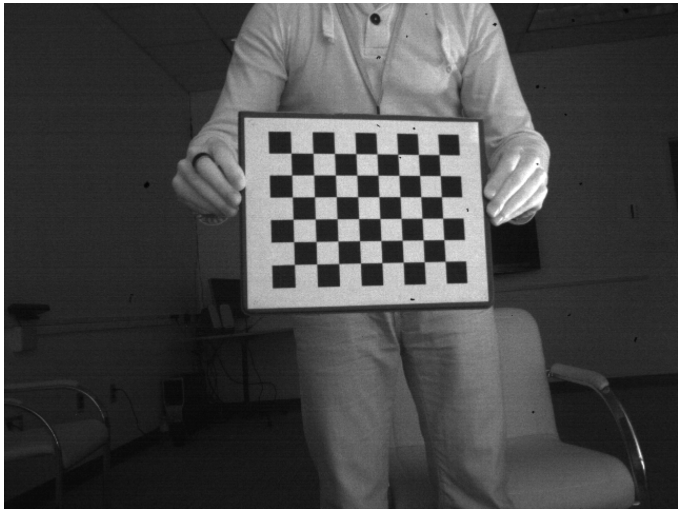


CALIBRATION

- Calibration algorithms provided by ROS
- Checkerboard as target
- Calibration result is used directly on Pandaboard ES
- Both sensors are calibrated the same way
- External IR lighting source and a covered projector are essential
- Mandatory for a reliable camera pose estimation



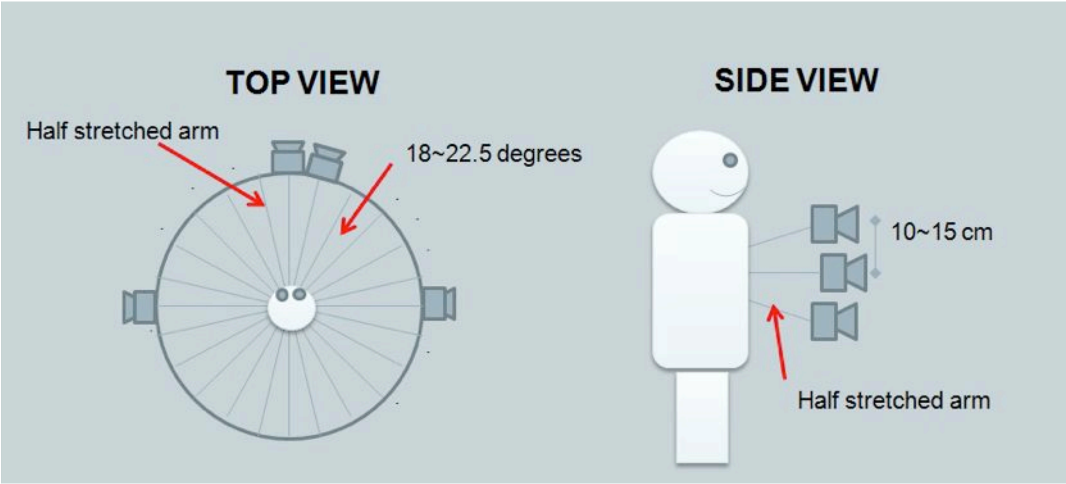




DATA ACQUISITION

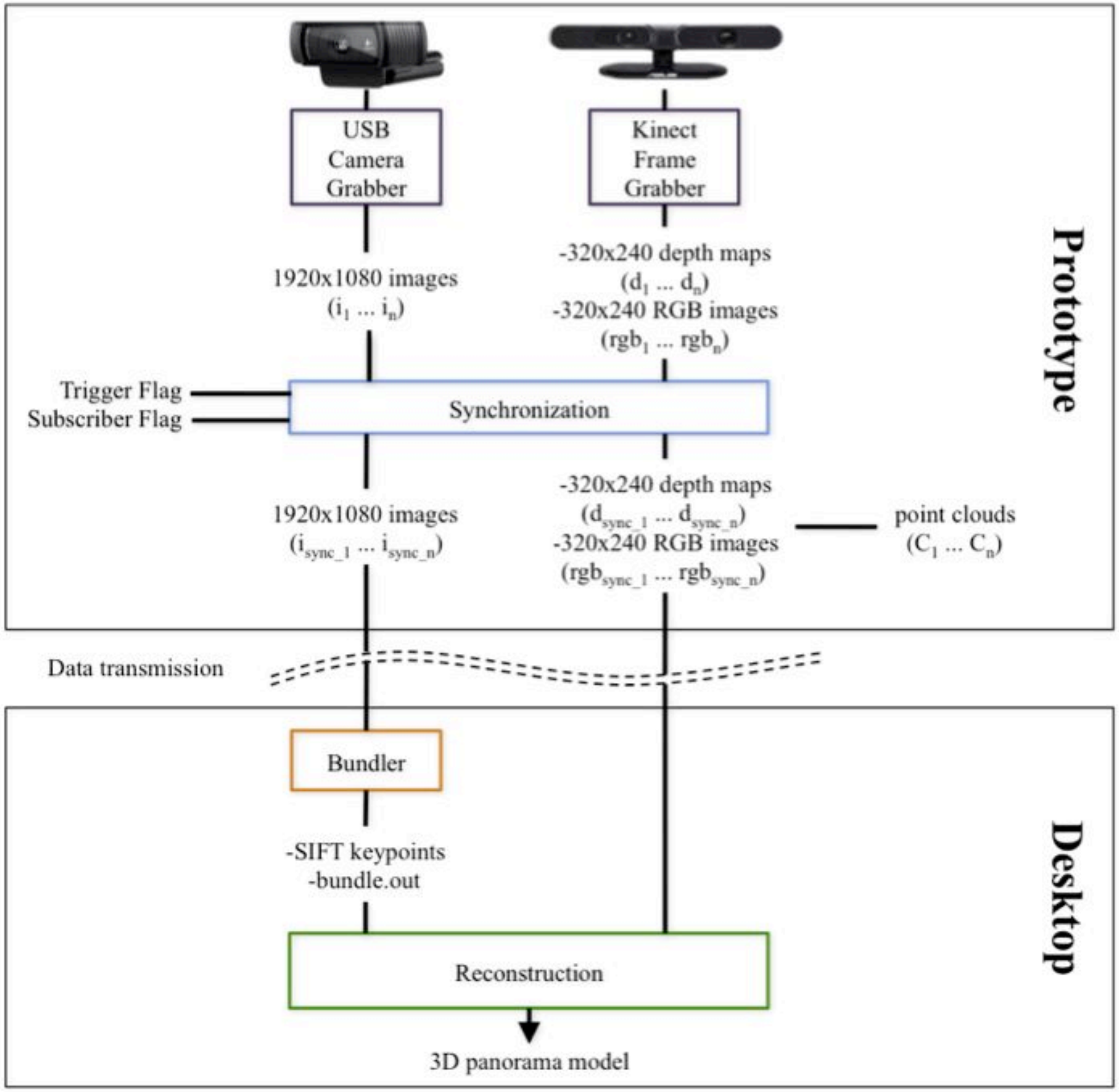
SIEMENS

- Circular path with a radius about 40 cm: about half length of the stretched arm
- Small angle separation: 15-18 images per circular path
- Multiple heights: 3 images at each angle position
- Each 360° 3D reconstruction will have 45-55 images
- Multiple views: Small distance separation: 5-10 m between centers



SOFTWARE OVERVIEW

SIEMENS



CAMERA GRABBER

SIEMENS

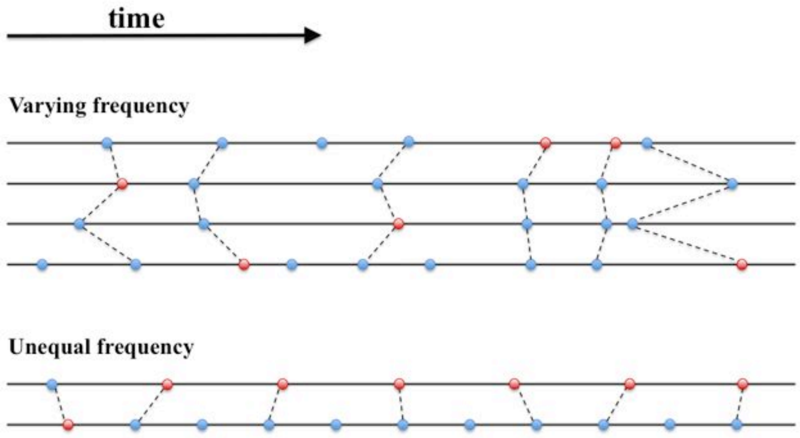
- Webcam Grabber
  - Based on usb_cam package
  - 1920x1080 resolution
  - Hardware MJPEG compression of webcam is used
  - 5 fps standalone
  - 3 fps together with RGB-D Sensor

- Kinect Grabber
  - Based on OpenNI library
  - 320x240 resolution of RGB & depth image
  - Transforms depth image to RGB frame for easy registration
  - 30 fps standalone
  - 15 fps together with webcam
  - 30% less CPU load compared to existing solution

SYNCHRONIZER

SIEMENS

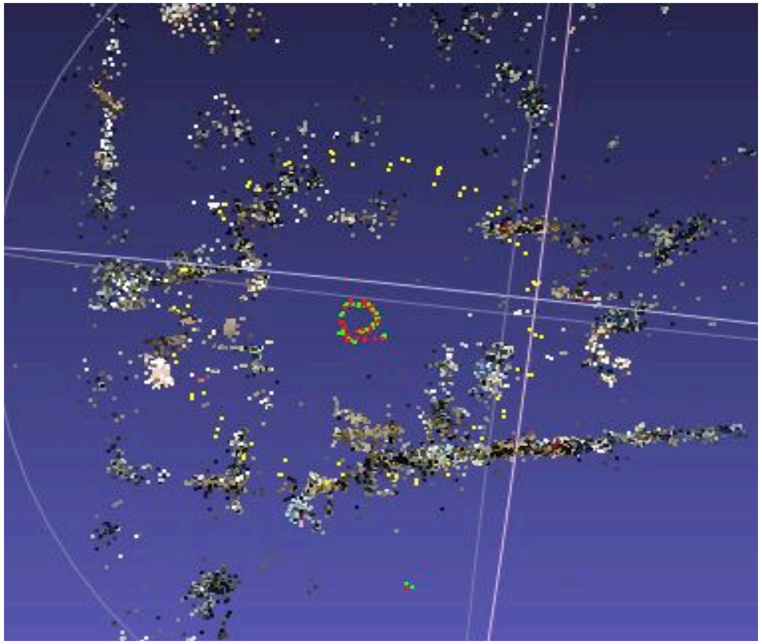
- Unequal frame rates are not consistent
- Adaptive message synchronization
- Approximate time policy of the ROS message_filter algorithm
    - Messages are used only once. Two sets cannot share the same message
    - Sets do not cross
    - Sets are contiguous -> no dropped message of one topic between the two sets
    - Output only depends on time stamps, not on the arrival time of messages



SCENE RECONSTRUCTION

SIEMENS

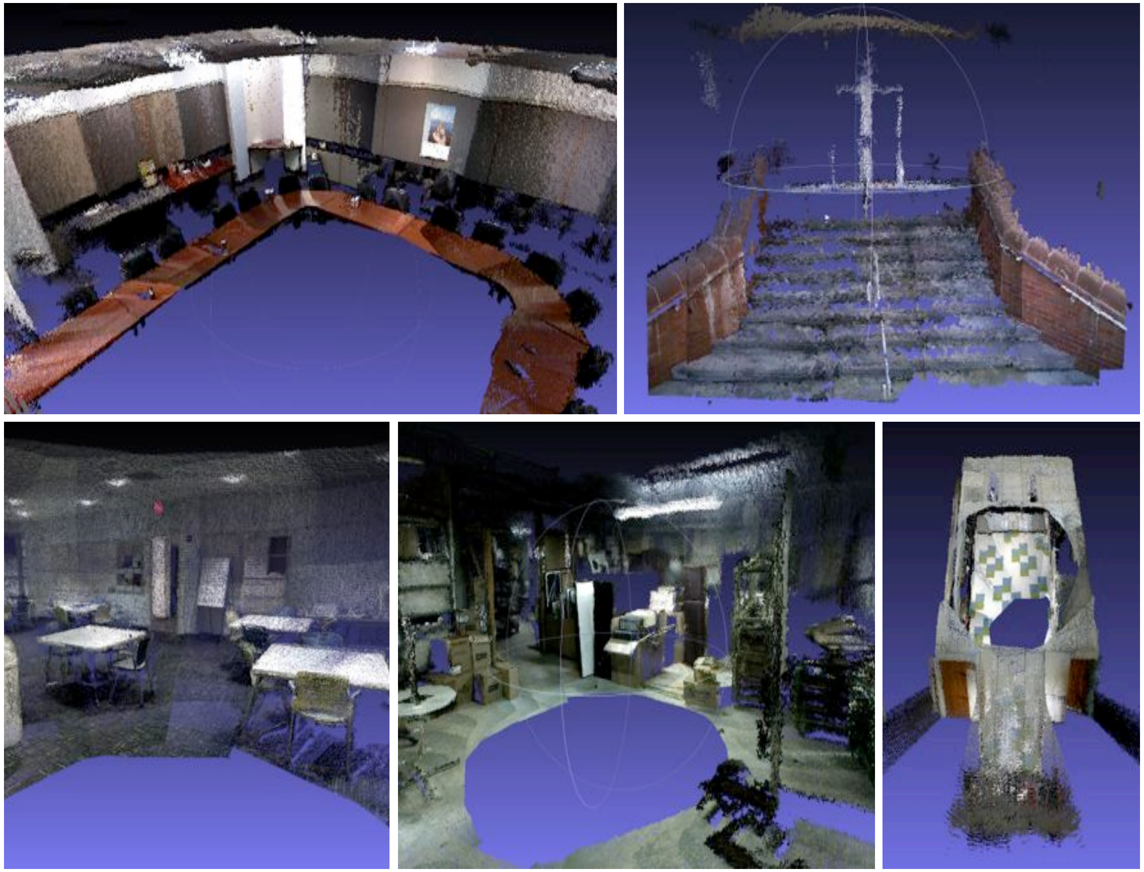
- Normalizing Bundler cloud
- Subset of 100 most stable 3D points
- Points are transformed into every individual viewpoint
- Matching SIFT key-points and compare depth value
- ROI check due to different view frusta of sensors
- Estimation of scaling difference
- 100 points results in more than 1000 depth values
- Histogram to determine scaling factor
- Scale bundler camera poses to real world coordinates
- Concatenation of RGB-D data with obtained poses
- Optional ICP to improve matching



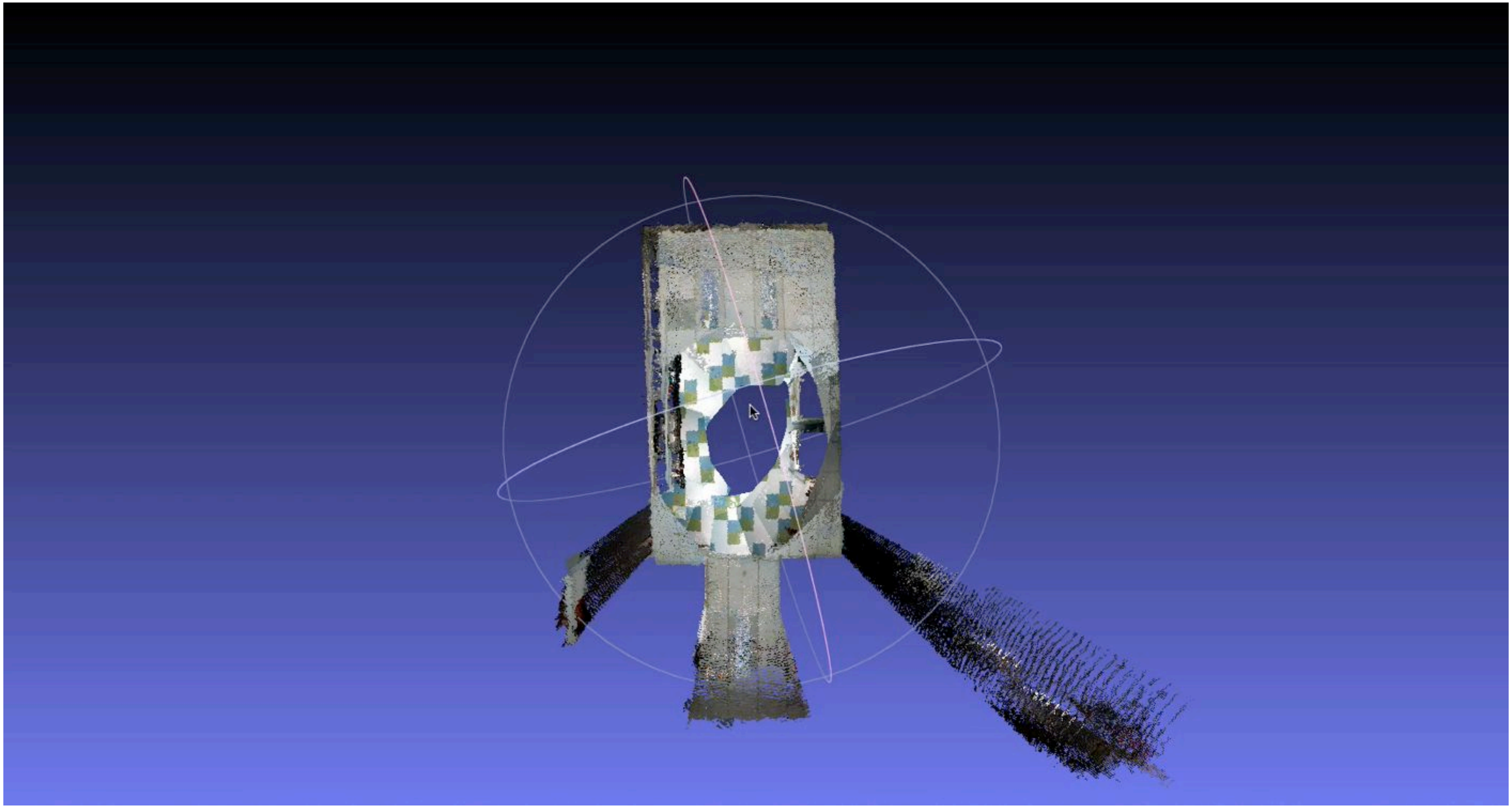
RESULTS

5 different environments:

- Conference room
- Outdoor scene
- Kitchen: Narrow scene
- Cafeteria: High average number of SIFT features
- Basement: Factory like setting



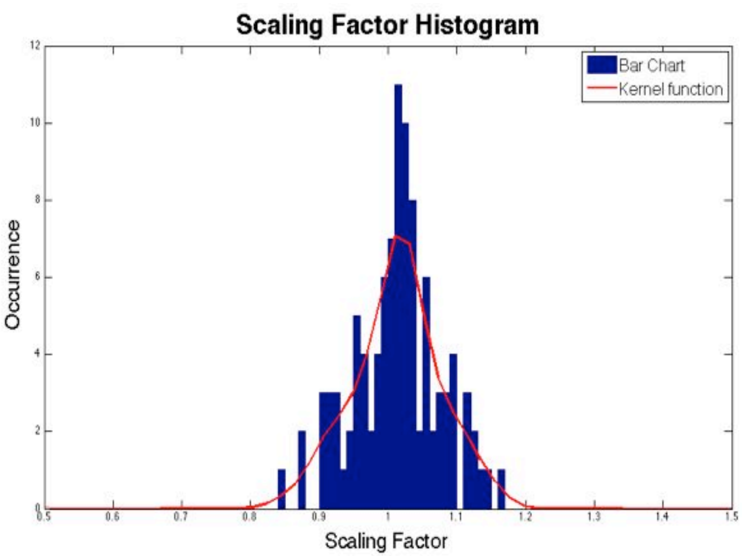
KITCHEN DATASET

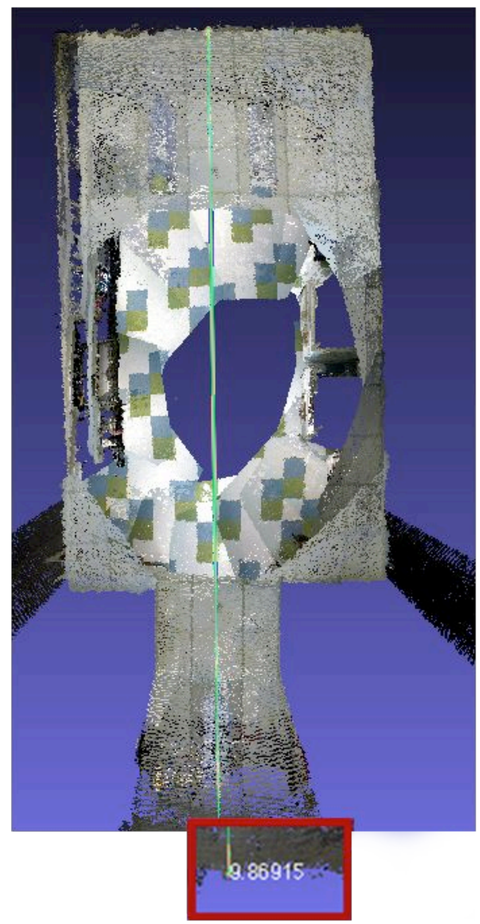


KITCHEN DATASET

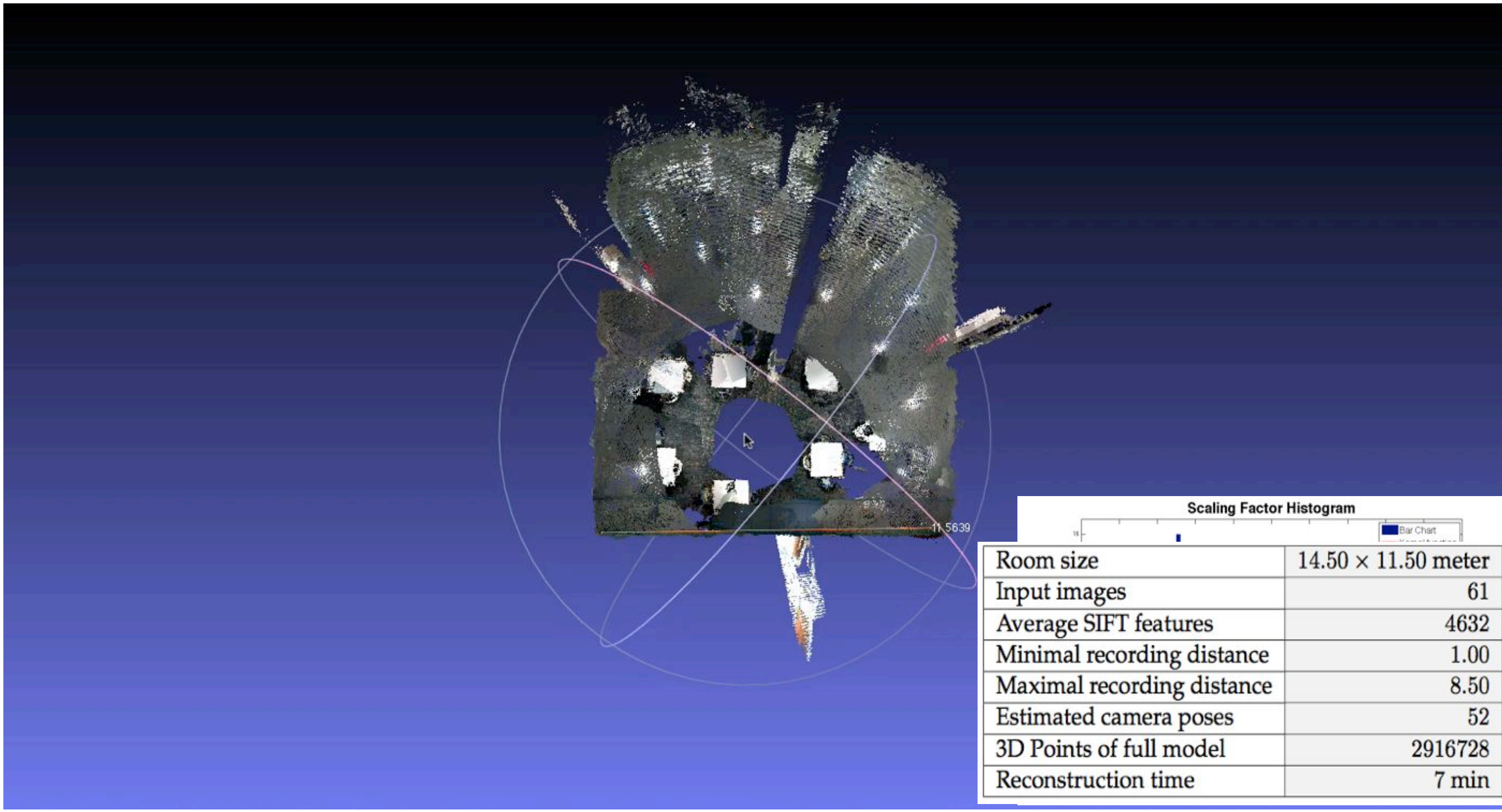
SIEMENS

- Room size 10 x 4 meter
- 59 input images
- Minimal recording distance was 0.6 meter
- Maximal recording distance was 3.70 meter
- Full model consists of 3447510 points
- Total time for reconstruction = 8 min





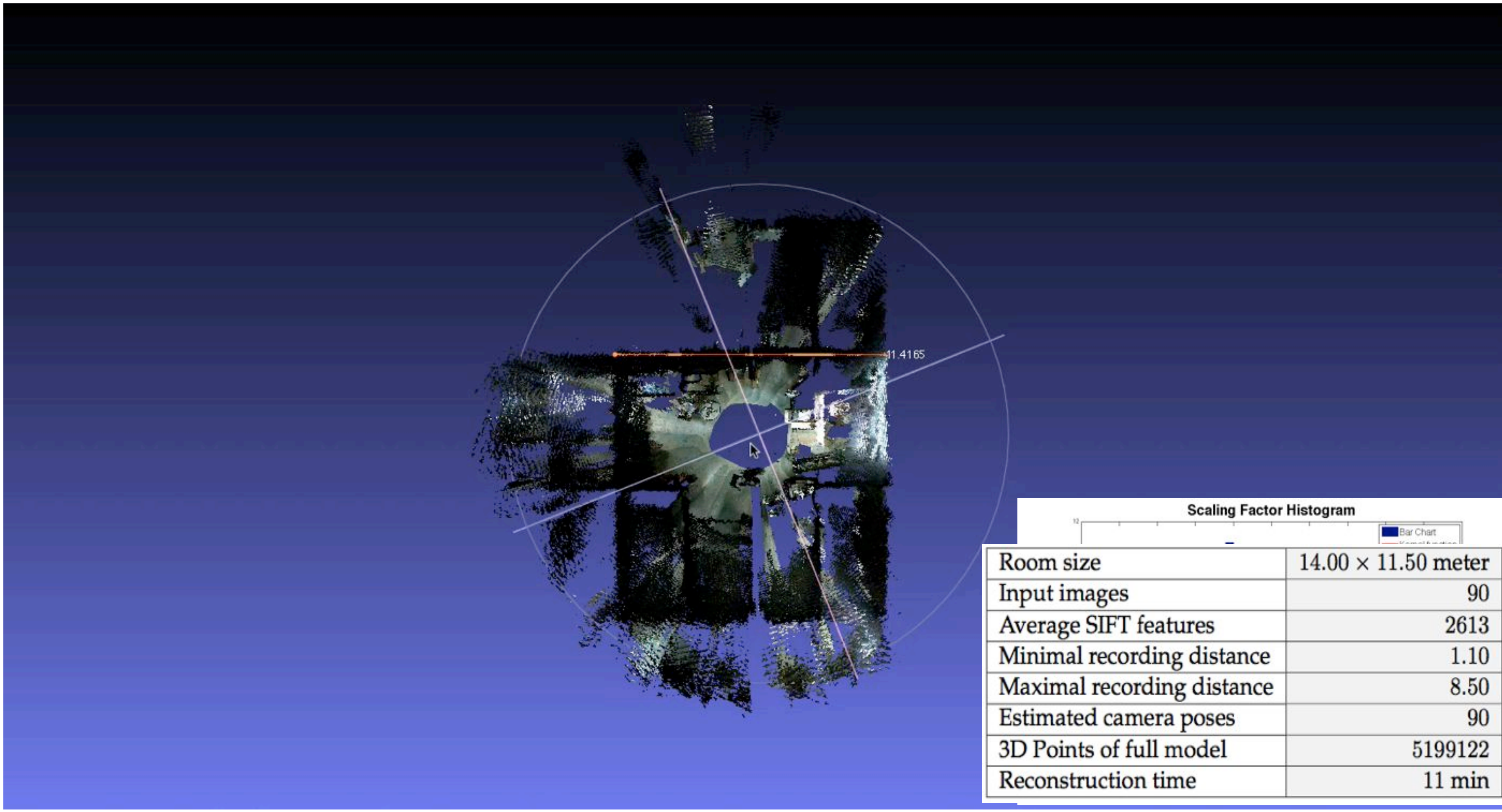
CAFETERIA DATASET



Room size	14.50 × 11.50 meter
Input images	61
Average SIFT features	4632
Minimal recording distance	1.00
Maximal recording distance	8.50
Estimated camera poses	52
3D Points of full model	2916728
Reconstruction time	7 min

BASEMENT DATASET

SIEMENS



Room size	14.00 × 11.50 meter
Input images	90
Average SIFT features	2613
Minimal recording distance	1.10
Maximal recording distance	8.50
Estimated camera poses	90
3D Points of full model	5199122
Reconstruction time	11 min

CONCLUSION

SIEMENS

- Development of extensible project platform
- Hardware
  - Portable 3D data acquisition device
  - Interfacing of 2 high bandwidth sensors
- Software
  - Interface for high definition MJPEG camera
  - Interface for RGB-D sensor on ARM platform
  - Synchronizing of messages
  - Scale estimation
  - Concatenation of RGB-D data
- Tested in 5 different environments
- Patent pending

FUTURE WORK

SIEMENS

- Mesh visualization
- Build up overview map and enable natural navigation
- Automated CAD model matching
- Combine with quadrocopter mapping
- Port to consumer platform like tablets
- PrimeSense Capri sensor or Kinect 2

Thank you for your attention.
Questions are welcome