European Commission

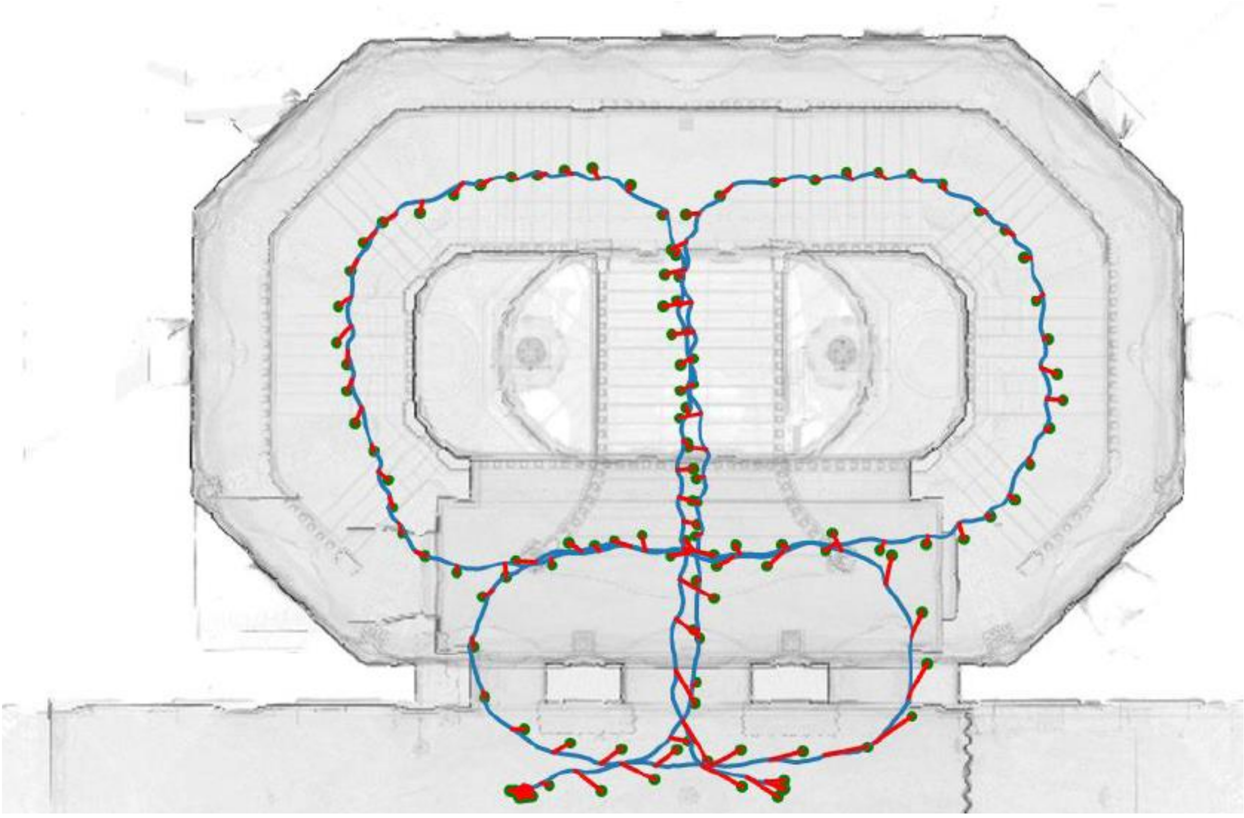
JRC TECHNICAL REPORTS

Evaluating the Accuracy of Indoor Localization Devices

Support to the Microsoft Indoor Localization Competition 2018

SANCHEZ BELENGUER C, TADDEI P, PUIG ALCORIZA D, WOLFART E, SEQUEIRA V

2018



Joint Research Centre

EUR 29627 EN

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Abstract

Indoor localisation in GPS-denied areas is a subject that currently receives a lot of attention in research and industry. There are many potential applications for indoor localization based on small and affordable consumer devices. However, it is often difficult to evaluate the localization accuracy due to the unavailability of accurate ground-truth information.

Over the last years, JRC has developed the Mobile Laser Scanning Platform (MLSP) for 3D mapping and indoor localization, which has been demonstrated to be significantly more accurate than what can be achieved with other (consumer) technologies.

Since 2014, Microsoft has organized an Indoor Localization Competition to evaluate the current state of the art in indoor localization. JRC participated in the 2015 edition and won the first prize using the MLSP. In the following years, JRC co-organised the event and was responsible for evaluating the accuracy of the competing devices. In 2018, the evaluation was based on the average distance between the positions reported by the devices and the ground-truth trajectory generated by MLSP.

This report describes the evaluation process and the activities that JRC carried out in preparation and during the event.

1 Introduction

Indoor localisation in GPS-denied areas, for example inside large buildings or underground sites, is still an unsolved problem. Potential applications include support to emergency responders inside buildings; facility management; (nuclear) inspections in large facilities; localisation/navigation in shopping malls, airports and museums. Different approaches to indoor localisation have been proposed, using for example RF signals, visual information, distance information or inertial sensors.

Microsoft has organized the Indoor Localization Competition over the last years to test different indoor localization devices from industry and academia and evaluate the current state of the art in indoor localization [1].

JRC participated in the 2015 edition with its Mobile Laser Scanning Platform (MLSP) and won the first prize. MLSP is based on 3D SLAM (Simultaneous Localization and Mapping) technology: a laser scanner acquires several 3D scans per second; by aligning consecutive scans to each other, it is possible to build a 3D map as the sensor moves through the environment. In *Tracking* mode, the acquired data is aligned in real-time with a pre-loaded reference map, which allows reporting the current location with respect to the reference model with centimetre accuracy [2, 3]. In the case of the Microsoft Competition, the reference model was generated using static 3D laser scanners.

In subsequent competitions, JRC was co-organizer of the event and responsible for evaluating the accuracy of the competing localization devices. Evaluating indoor localization accuracy is not a trivial task, as ground truth information is not easily available: GPS can provide centimetre accuracy in outdoor environments, but is not available indoors. Optical tracking provides high-accuracy results on room-scale systems, but is difficult to implement in larger environments.

In the 2016 and 2017 Microsoft Competitions, the evaluation was based on a discrete number of known ground truth positions, which were obtained by scanning the competition area using static laser scanners and measuring the positions in the resulting 3D model. The competitors were asked to move to the positions and report the location given by their device. The final result was the average distance between ground truth and reported location. However, the approach had two limitations: i) the analysis is limited to a relatively small set of control points and does not consider the complete trajectory and ii) most localization devices were handheld and it was therefore difficult to place them exactly at the control points.

As the 2018 Competition focused on small consumer devices not using laser scanning [4], the accuracies are significantly lower than what can be achieved with MLSP. Therefore, MLSP measurements could be used as ground-truth measurements to address the two limitations mentioned above. The competing localization devices were mounted rigidly on MLSP. It was then possible to continuously measure the ground-truth location of the device and compare it to the location reported by the competing device itself. The final result was the average difference between ground-truth and reported location over the entire trajectory.

This report describes the MLSP customizations that were implemented to facilitate the evaluation and the activities carried out during the Competition.

2 Evaluation Procedure

The 2018 Microsoft Indoor Localization Competition took place in Portugal. The evaluation area covered two floors and the connecting staircase in a historical building (see Figure 1).

Figure 1: Evaluation area of the 2018 Indoor Localization Competition.

The evaluation of the 22 competing indoor localization devices was based on the average distance between the positions reported by the devices and the ground-truth trajectory generated by MLSP. The remainder of this section describes the developments that were made in preparation of the event and the activities carried out during the Competition.

2.1 Preparation

1. In order to mount the competing devices and produce the ground-truth trajectory, JRC extended the MLSP as follows (see annex 1 for details):
    a. A special mounting was designed and manufactured that allows fixing the competing localization device on the backpack. A calibration procedure ensures that the origin of the ground-truth position is at the mounting of the competing device.
    b. The MLSP client software generates a text file with the ground-truth trajectory containing 3D position (relative to the device mounting) and time stamp.
2. The competitors were asked to adapt their localization device in such a way that i) it can be fixed on the backpack mounting and ii) it reports the measured position and related timestamp with a frequency of 1Hz (see annex 2).
3. JRC wrote a script for evaluating the accuracy of the device, which is calculated as the average Euclidean distance between the positions reported by the competing device and the trajectory reported by MLSP.

2.2 Reference Mapping and Setup

In order to compare the measurements of the competing devices to the ground truth trajectory, it was necessary to define a common coordinate frame to which all devices can be aligned. To do so, the following activities were carried out in the evaluation area on the days before the competition:

1. A corner in the evaluation area was selected as origin, the floor and two orthogonal walls defined as coordinate system. Several reference markers (A3 print-outs of a target) were placed in the area.
2. JRC scanned the entire evaluation area using a high-precision static laser scanner. The resulting 3D point cloud was aligned with the physical coordinate frame defined in step 1. The exact position of the reference markers were measured in the point cloud using a custom-made utility.
3. On the day before the competition, the competitors could setup their systems and align them with the given coordinate frame using the known positions of the reference markers.
4. The point cloud was loaded to MLSP as reference map. It was then possible to use MLSP for ground-truth measurements with centimetre accuracy.

2.3 Evaluation Day

On the evaluation day each competing device was evaluated as follows:

1. Using the calibrated custom-mounting, the competing device was fixed on the backpack and carried along a pre-defined path (see Figure 2). MLSP recorded the ground-truth data and the competing device generated a file with one position measurement per second.

Figure 2: Using MLSP for the evaluation of a localization device: the laser scanner acquiring the ground truth data is mounted on the left. The competing device is mounted on the right.

2. Following the acquisition, the MLSP data was processed to refine the ground-truth trajectory. Then, the average distance between the positions measured by the competing device and the ground-truth trajectory was calculated. To illustrate the

result, a plot was generated that superimposes the ground-truth trajectory and the measured positions on a 2D map of the evaluation area (see Figure 3).

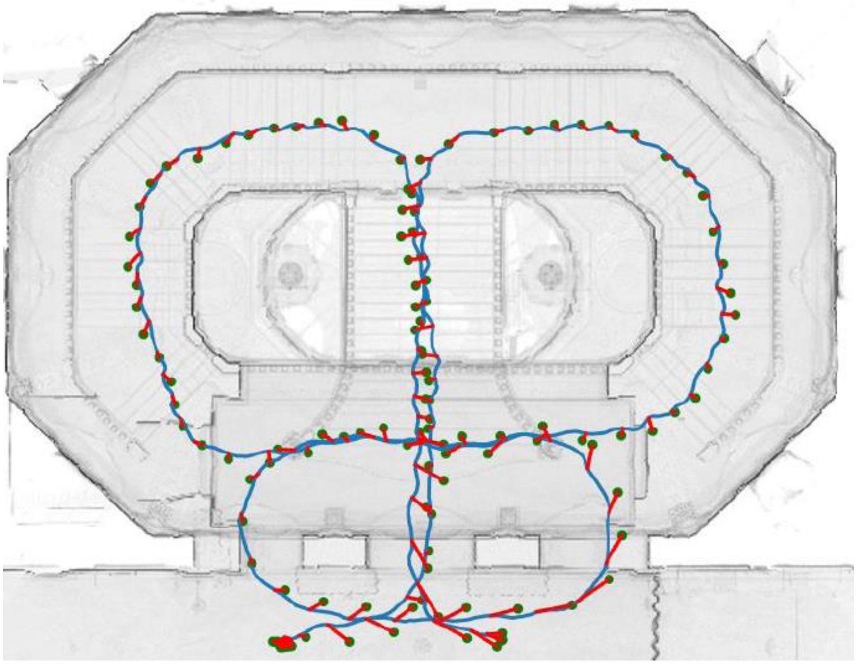


Figure 3: Example of a ground-truth trajectory (blue) and measured points plotted on the 2D map of the evaluation area. The red lines indicate the distance between the measured and the ground truth position.

The following day, Microsoft presented the final results that were based on the ranking and graphs produced by JRC (see annex 3).

2.4 Data Publication

Following the Competition, the 3D reference map and the ground truth trajectories for all competing devices were made publically available [5]. The data sets are valuable information for the competing teams as it is normally difficult for them to obtain accurate ground-truth information. Using the MLSP trajectory and the raw data that they recorded during the competition, they will be able to assess the impact of possible improvements they make to their localization algorithms. The 3D map of the evaluation environments can be useful to better understand the signals received from the respective sensors, e.g. the echo received from acoustic signals.

3 Conclusion

JRC's MLSP is a powerful tool for evaluating the accuracy of indoor localization devices. The custom-developments made for the 2018 Microsoft Indoor Localization Competition allowed to efficiently make an evaluation that is based on the entire 3D trajectory instead of using only a limited set of control points.

The ground-truth trajectories generated during the competition are value information that can be used by the competitors for assessing future improvements of their systems.

References

[1] D. Lymberopoulos, *The Microsoft Indoor Localization Competition: Experiences and Lessons Learned*, IEEE Signal Processing Magazine (Volume:34 , Issue:5 , Sept. 2017),

[2] SANCHEZ BELENGUER C, PUIG ALCORIZA D, WOLFART E, SEQUEIRA V, *Mobile Laser Scanning Platform (MLSP)*, European Commission, 2018, JRC114248

[3] SANCHEZ BELENGUER C, TADDEI P, WOLFART E, SEQUEIRA V, *Sensor Tracking and Mapping (STeAM)*, European Commission, 2018, JRC114245

[4] Microsoft Indoor Localization Competition – IPSN 2018, https://www.microsoft.com/en-us/research/event/microsoft-indoor-localization-competition-ipsn-2018/

[5] Sequeira, Vitor; Wolfart, Erik; Taddei, Pierluigi; Sanchez, Carlos; Puig, David (2019): Microsoft Indoor Localization Competition. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-10111-10001

Annexes

- Annex 1: Developments made in preparation of the competition
- Annex 2: Competition guidelines provided to competitors
- Annex 3: Results presented after the presentation

Annex 1: Developments made in preparation of the competition

MLSP Customization

In the standard MLSP configuration, the sensor head, which contains the laser scanner and the IMU, is mounted on a pole that is fixed on the backpack. All 3D positions are reported in the coordinate frame of the laser scanner.

For the 2018 Microsoft Indoor Localization Competition, a new mounting for the sensor head had been designed and constructed: a horizontal bar that is fixed on the backpack pole; it allows placing the MLSP sensor head at the primary side of the bar (left) and the competing device at the secondary end using a standard camera screw. Through a calibration procedure, the relative pose of the secondary side w.r.t. the sensor head can be calculated, so that MLSP is able to report the 3D positions of the competing device instead of the sensor head.

The following extensions to MLSP and the related STeAM processing software were implemented:

- Design and construction of the mounting, together with a calibration cylinder that can be screwed in the secondary side of the bar.

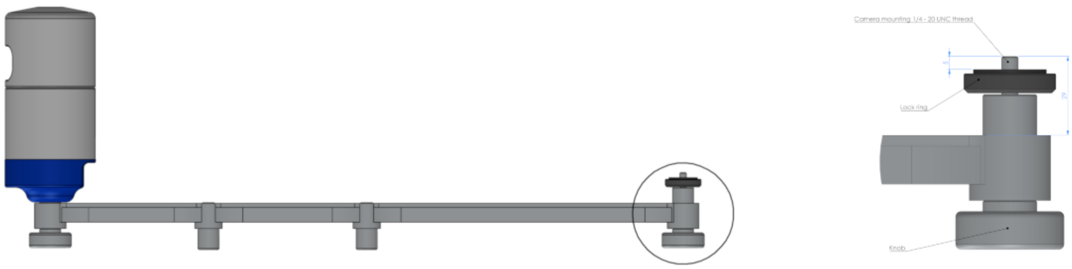


Fig. 1: (left) Design of the mounting and (right) detail of the mounting screw for the secondary sensor.

- Implementation of a calibration procedure: each time the sensor head is fixed on the mounting, the relative pose of the secondary mounting screw has to be re-calculated to ensure the highest accuracy. To do so, the calibration cylinder has to be mounted on the exposed screw on the secondary side. The calibration procedure automatically detects the cylinder shape in the laser scan data and calculates the central axis' pose w.r.t. the sensor head. Using nominal calibration values for the vertical component of the position of the screw tip, the system fully characterizes the rigid transformation that moves from the primary reference frame to the secondary one.
- Extended functionality added to the MLSP client application to report and store the poses of the competing device: given the result of the previous calibration step, the system is able to provide the tracking information in the coordinate system of the competing device.
- Extended functionality added to the post-processing software to improve the results produced by the client application: the tracking algorithm executed in the MLSP backpack is limited by the real-time constraint that a live system imposes. Being able to refine live results in an offline processing stage allows improving both, accuracy and robustness.

Data Analysis

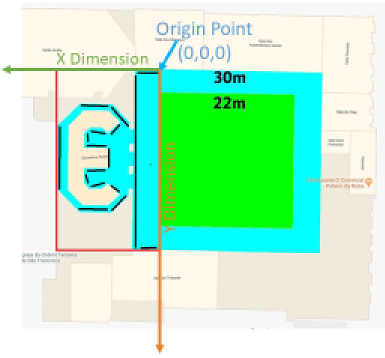
Development of offline scripts to perform a time-shift estimation between the MLSP and the competing device and to evaluate the accuracy of the measured positions:

- Time-shift estimation: given the poses reported by the competing device and the poses reported by the MLSP backpack, time calibration is performed using a grid search optimizer that minimizes the error between the two poses (being the error the Euclidean distance between the two reported positions).
- Accuracy evaluation of the competing devices: given the result of the time-shift estimation, poses reported by the MLSP backpack are compared with the ones reported by the competing devices. Since the trajectory generated by the main head is discrete in time, poses are interpolated in se3 algebra to fit the corrected timestamps reported by the competing device. The estimation error is defined as the Euclidean distance of the two reported positions, and the overall error is the average of all the estimations.

Annex 2: Competition guidelines provided to competitors

Source : https://www.microsoft.com/en-us/research/uploads/prod/2017/12/competitionlogistics_2018.pptx

Evaluation area (red box)



- Covering two floors
  - Ground floor corridor
  - Stairs connecting ground floor and first floor
  - First floor corridor

- Origin point is indicated on the lower left corner of the 3rd floor
- All systems in the 2D category should report an (X,Y) location with respect to this origin point
- All systems in the 3D category should report an (X,Y,Z) location with respect to this origin point
- Reported locations should be in meters.

Evaluation area pictures

Ground Floor Corridor

Stairs Areas

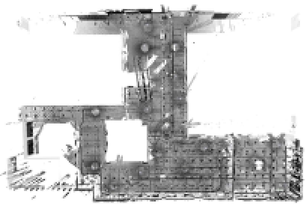
Ground Truth Measurements

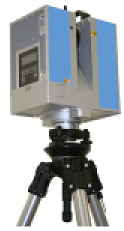
- JRC (https://ec.europa.eu/jrc), the winner of the 2015 competition, has volunteered to provide its expertise for ground truth measurements
- The JRC creates tools for Euratom (European Atomic Energy Community) inspectors and the International Atomic Energy Agency (IAEA), which inspects some 700 facilities worldwide each year. For more than a decade, the JRC has deployed 3D laser scanning technology, to verify design information within nuclear facilities.
- Before the competition we will acquire the ground truth positions of the markers employing two independent systems both based on time-of-flight laser measurements.

Ground Truth Measurements – System 1

High Resolution 3D Acquisition and Registration

- The ground truth environment and the markers location will be acquired using multiple high definition 3D scans using a tripod mounted laser scanner (e.g. ZF 5006).
- The single acquisitions will be aligned and the marker positions accurately identified using a proprietary software (JRC 3DLVS).



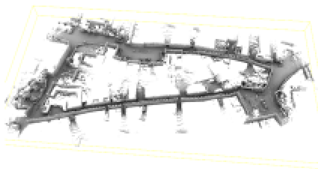


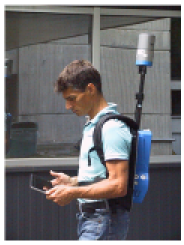
Robust surface registration using N-points approximate congruent sets
J Yao, MR Ruggeri, P Taddei, V Sequeira
EURASIP Journal on Advances in Signal Processing 2011
DOI:10.1186/ 1687-6180-2011-72

Ground Truth Measurements – System 2

On-the-fly Tracking and Mapping Using a Spinning Laser

- A second independent measurement will be done using a backpack mounted spinning laser scanner (e.g. Velodyne VLP-16) while walking in the competition area using a proprietary software (JRC STEAM) and moving on each marker position.





Localization and tracking in known large environments using portable real-time 3Dsensors
C.Sánchez, P. Taddei, S. Ceriani, E. Wolfart, V. Sequeira
Computer Vision and Image Understanding (2015)
DOI: 10.1016/j.cviu.2015.11.012 to be published

Pose interpolation SLAM for large maps using moving 3D sensors
S. Ceriani, C. Sanchez, P. Taddei, E. Wolfart, V. Sequeira
Intelligent Robots and Systems (IROS)
DOI: 10.1109/IROS.2015.7353456

Hardware Deployment

- You will be able to attach your equipment on:
  - Floors and walls
  - Ceiling is very tall. If you were planning to deploy hardware on the ceiling, come up with an alternative plan.
- When attaching equipment
  - Use paint-safe tape than can be removed without causing damage to the walls
  - Don't even think about drilling holes to attach equipment! I mean it…
  - This is a historic building. We need to be respectful of it.
- Maximum number of deployed anchor points: 10
  - Absolutely no teams will be allowed to deploy more than 10 anchor points!

Hardware Deployment

- If your team has been classified into the 2D category, you will not be allowed to deploy your own hardware (i.e., WiFi APs)
- In special cases, the organizers will consider exceptions. To request an exception for your team:
  - Send an email to dlymper@microsoft.com explaining in detail why you need to deploy your own hardware
  - You will receive a reply from the organizers with one of the following outcomes:
    - You are granted the right to deploy your own APs/hardware, and you are still classified as a 2D solution.
    - You are not granted the right to deploy your own APs/hardware, and you are still classified as an infrastructure-free submission
    - You are granted the right to deploy your own APs/hardware, but you are now classified as a 3D submission

WiFi APs

- All teams that leverage WiFi will have to use the WiFi APs that are already deployed in the conference venue for internet connectivity
- All teams that need to deploy their own WiFi APs (assuming they have been granted by the organizers to do so), will be allowed to deploy the same number of APs that are already deployed in the conference venue. This number will become available to the organizers in late March. If a team wants to deploy more APs, then it will be classified in the infrastructure-based teams.

Come prepared!

- Make sure you bring everything you need
  - Paint-safe tape
  - Ropes
  - Attachment mechanisms
  - Laser range finders for ground truth measurements
  - Tripods
  - Cables
  - Power adaptors for your equipment (The competition is in Europe!)
- Power outlets will be available throughout the evaluation area
- The organizers will not provide any other equipment! It is up to the teams to bring what they need…

Competition Logistics – Setup Day

- After the end of the first day (setup):
  - Your deployed hardware will remain at the evaluation area
    - The deployed hardware must be turned off!
    - Laptops/phones can be removed from the evaluation area. However, everything else must remain within the evaluation area.
    - The conference venue is not open to the public after hours, so your hardware will be safe
    - No other calibration/modification of the deployed system will be allowed after the setup day! Teams that do that will be automatically disqualified!
  - All contestants will have to leave the evaluation area
  - The organizers will assume control of the evaluation area to mark the path that will be used for evaluation.

Competition Logistics – Evaluation Day

- At the beginning of the evaluation day, the evaluation path will be revealed to all teams
- If any team attempts to reverse engineer or manually measure locations of the evaluation path, it will be automatically disqualified!
- Each team will be assigned a 15min time window (communicated well in advance)
  - During this time window, only the system from this team will be active.
  - The hardware to be localized will be carried/worn by the organizers.
  - The organizers will also wear the ground truth measurement device that will continuously compute location with sub-cm accuracy

Competition Logistics – Evaluation Day

- At the beginning of the evaluation of each system
  - Organizers will indicate that evaluation begins by simultaneously pressing a button/key on the system under test and on the ground truth measurement system.
    - This will allow time synchronization between the system under test and the ground truth measurement system.
    - It is fine if the system under test reports location on a server/laptop further away.
  - After the initial key press, the system under test is expected to continuously log its location into a file
    - If your system cannot report location updates at the rate of 1 location update per second or faster, please let the organizers know by emailing: dlymper@microsoft.com. This is not a problem, but we need this information to make sure that enough locations are recorded for every team.
  - At the end of the evaluation, the team will hand out the file with the estimated locations to the organizers.

Example Output Location File

First line: UTC timestamp in ms of the time when the button/key was pressed at the start of the evaluation

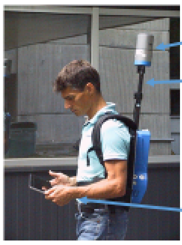
```
1519673851000
1,1,0,1519673852000
3,2,1,1519673853000
1.55,1.55,,3.1,1519673854000
```

Location Updates. Each line is comma separated with the following format:
<X in meters>,<Y in meters>,<Z in meters>,<UTC Timestamp in ms>
For 2D systems the Z value will be ignored.

Evaluation Metric

- The Euclidean distance between the ground truth coordinates and the estimated by the system under test coordinates in the output file will be computed.
- The average Euclidean distance across all evaluation points will be the overall score of each team
- The team with the lowest score wins!
  - In case of a tie, the team with the lowest hardware deployment requirements wins

Mounting your location sensor during evaluation



Ground-truth LiDAR sensor

Mount your sensor on the black pole through a standard camera connector clamp

Alternatively, let the organizer carry your location sensor

LiDAR-based ground truth system

No matter how your team wants the organizers to carry your location sensor, the location offset between the ground-truth LiDAR sensor and the location sensor will be recorded to allow us to adjust the recorded locations and ensure best accuracy.

Competition Logistics – What to expect

- Expect people and furniture/objects in the evaluation area during both setup time and evaluation!
- Multiple people will be in the evaluation area and they will be moving
- Placement of furniture/objects can change at any given time during, or after setup day, as well as during the evaluation day.
- Given the large number of submissions, there will be interference! Plan ahead!

Annex 3: Results presented after the presentation

Source: https://www.microsoft.com/en-us/research/uploads/prod/2017/12/RELEASED_2018-Microsoft-Indoor-Localization-Competition.pptx

Microsoft Research

BOSCH

2018 Microsoft Indoor Localization Competition

Organizers

Dimitrios Lymberopoulos (Microsoft Research)
Jie Liu (Microsoft Research)
Vitor Sequeira (European Commission – Joint Research Center)
Vivek Jain (Bosch)
Niki Trigoni (University of Oxford)
Anthony Rowe (CMU)
Nader Moayeri (NIST)

Competition Goals

- Evaluate and compare technologies from academia and industry in the same, unfamiliar space.
- Bring teams working in this area together in a more effective way.

2014: Berlin

2015: Seattle

2016: Vienna

2017: Pittsburgh

2018: Porto

34 teams submitted abstracts

26 systems officially registered

25 systems showed up in Porto

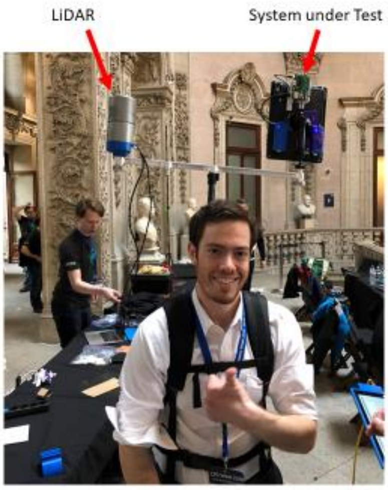
22 systems were evaluated

Two Categories

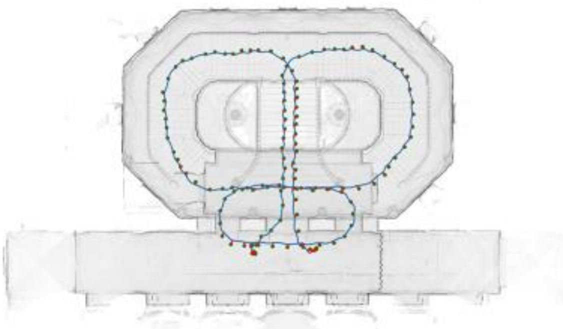
- 2D Category
  - Report **(X,Y)** locations
  - Do not require the deployment of any infrastructure (WiFi and/or IMU based)
- 3D Category
  - Report **(X,Y,Z)** locations
  - Require custom hardware deployment (UWB, Ultrasound etc.)
  - Each team can deploy up to 10 anchor devices in the evaluation space

Evaluation Process

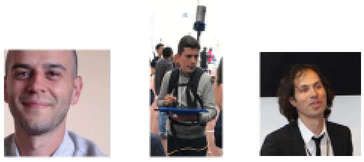
- Day 1: Tuesday
  - Teams were given 8 hours to setup and calibrate their systems.
- Day 2: Wednesday
  - Each team mounted their systems on our evaluation backpack and continuously logged locations over a predetermined path.
- Evaluation Metric
  - Average localization error across all recorded points along the path.
  - The lower the error the better.



Evaluation Area - Two Floors



Ground Truth Measurements & Evaluation

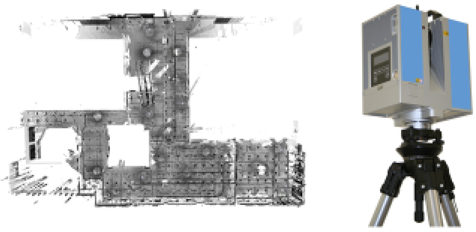


Pierluigi Taddei **Carlos Sanchez** **Vitor Sequeira**

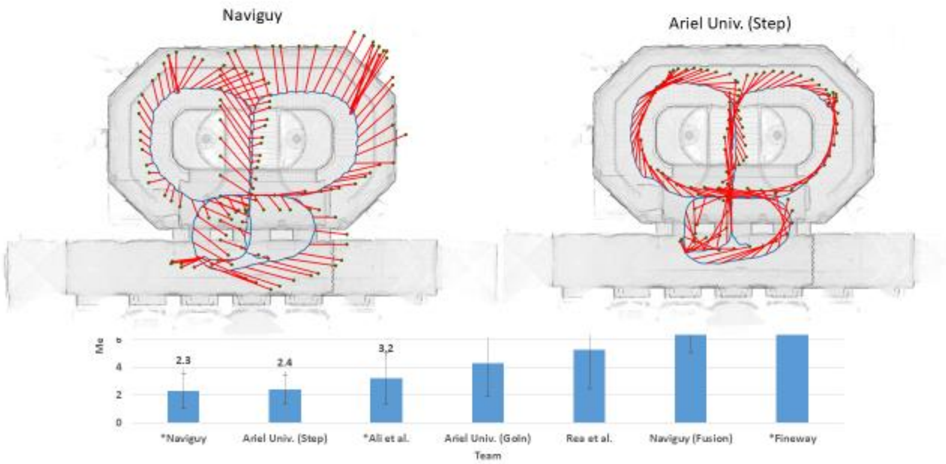
JRC (https://ec.europa.eu/jrc), the winner of the 2015 competition, volunteered to provide its expertise for ground truth measurements.

JRC has been deploying 3D laser scanning technology to verify design information within nuclear facilities for more than 10 years.

High Resolution 3D Acquisition and Registration

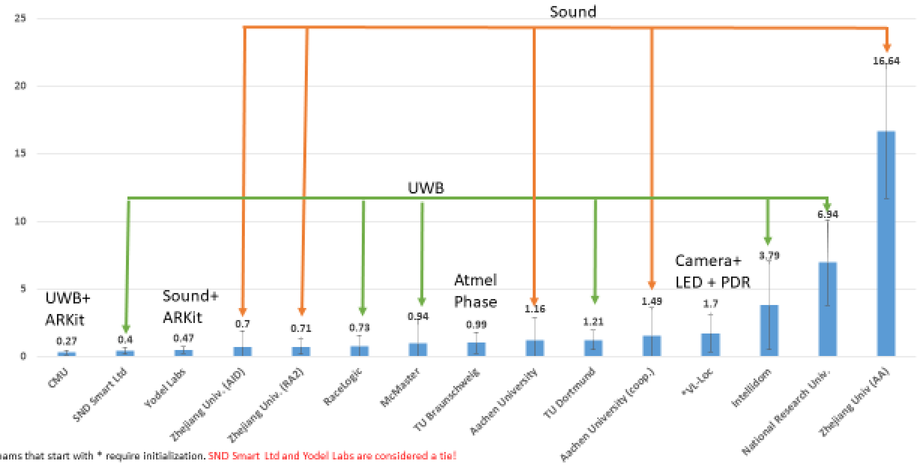


The ground truth environment and the test points were acquired using multiple high definition 3D scans using a tripod mounted laser scanner (e.g. ZF 5006) and proprietary software

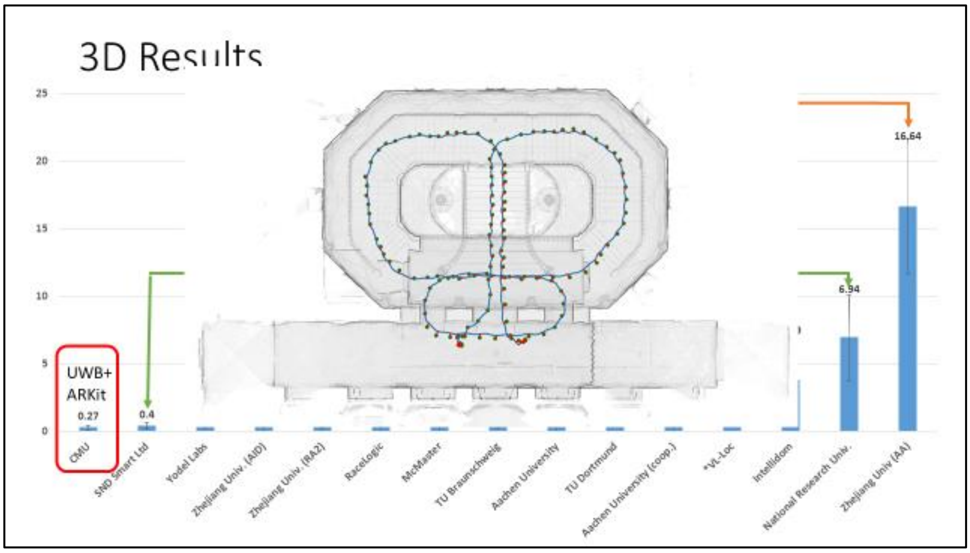


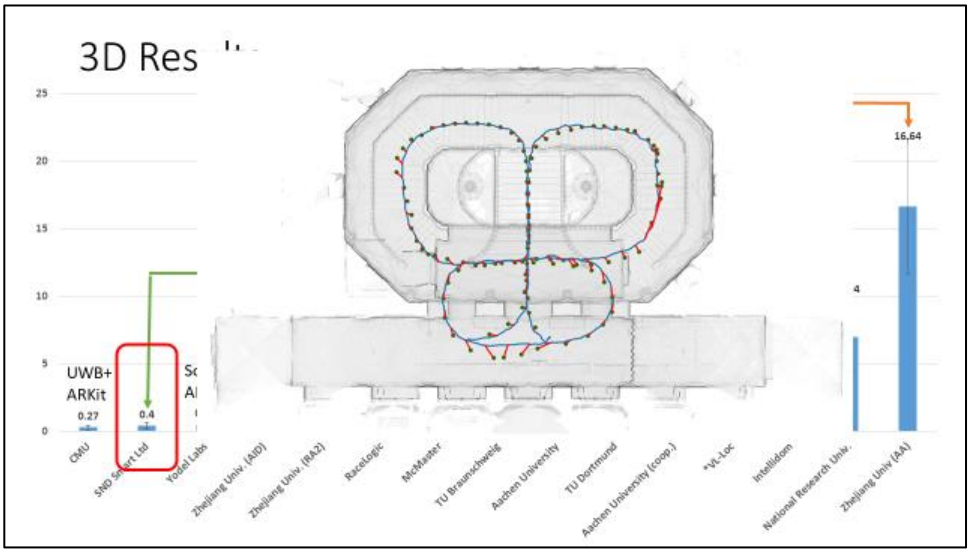
Teams that start with * require initialization.
Naviguy and Ariel Univ. were considered a tie! Ariel University is the winner as Naviguy required initialization while Ariel University did not.

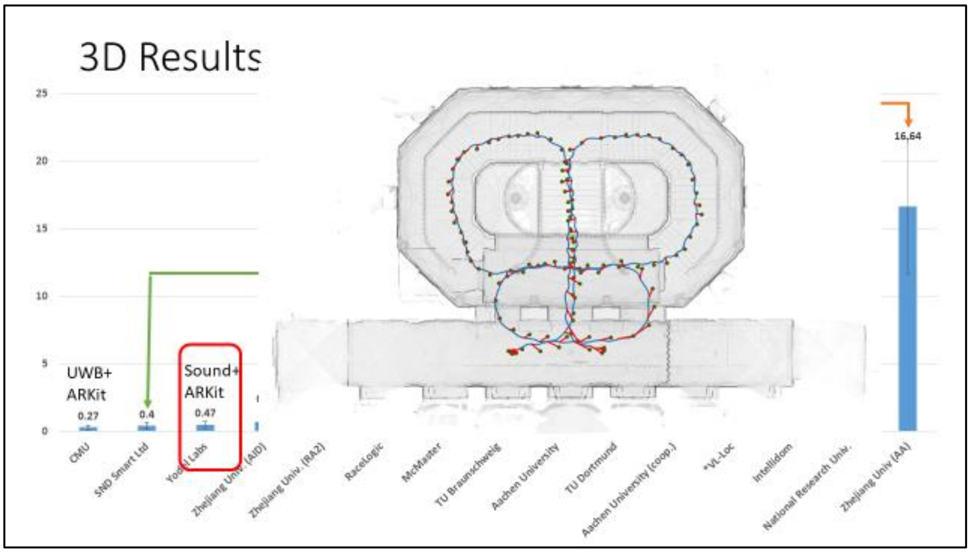
3D Results



Teams that start with * require initialization. SND Smart Ltd and Yodel Labs are considered a tie!


3D Results
25
20
15
10
5
0
UWB+
ARKit
0.27
0.4
6.94
16,64
CMU
SND Smart Ltd
Yodel Labs
Zhejiang Univ. (AID)
Zhejiang Univ. (RA2)
RaceLogic
McMaster
TU Braunschweig
Aachen University
TU Dortmund
Aachen University (coop.)
*VL-Loc
Intellidom
National Research Univ.
Zhejiang Univ (AA)


3D Res
25
20
15
10
5
0
UWB+
ARKit
0.27
0.4
16,64
CMU
SND Smart Ltd
Yodel Labs
Zhejiang Univ. (AID)
Zhejiang Univ. (RA2)
RaceLogic
McMaster
TU Braunschweig
Aachen University
TU Dortmund
Aachen University (coop.)
*VL-Loc
Intellidom
National Research Univ.
Zhejiang Univ (AA)


3D Results
25
20
15
10
5
0
UWB+
ARKit
Sound+
ARKit
0.27
0.4
0.47
16,64
CMU
SND Smart Ltd
Yodel Labs
Zhejiang Univ. (AID)
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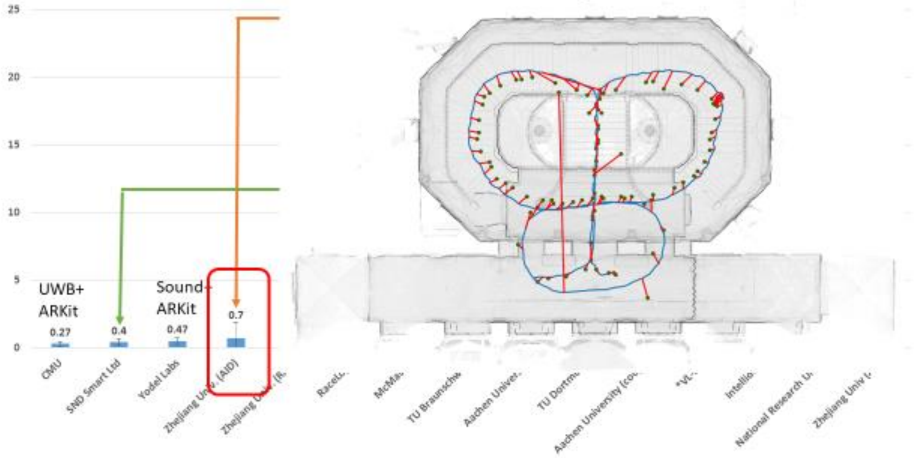
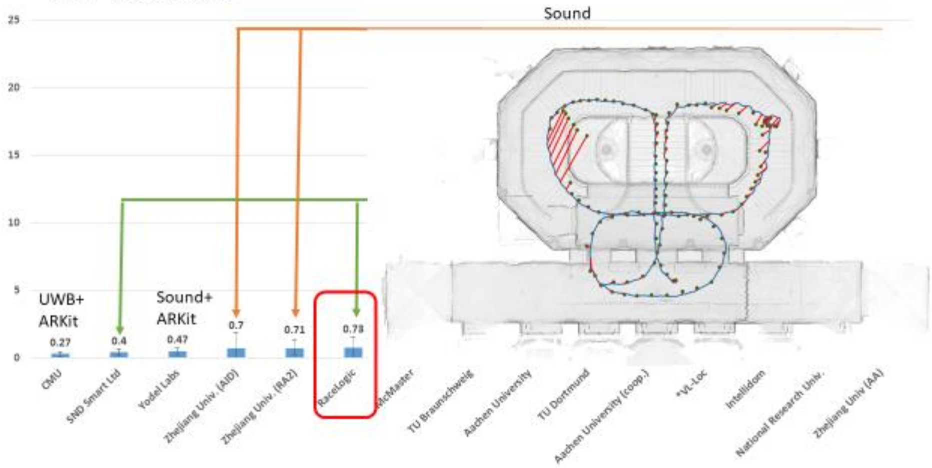
3D Results



3D Results



	2D Category	3D Category
1st $1000	Steps – An Accurate Relative Positioning Method for First-Responders **Landau et al.** **(Ariel University)** 2.4m error	Realty and Reality: Where Location Matters **Miller et al.** **(CMU)** 0.27m error
2nd $600	Inertial Sensing Approach for Indoor Localization **Qu et al.** **(Naviguy/Tongji University)** 2.3m error	NavInThings – An Indoor Localization and Navigation UWB System **Gao et al.** **(SND Smart Ltd/ATE Electronics** 0.40m error
2nd $600		ALPS: The Acoustic Location Processing System **Lazik et al.** **(Yodel Labs)** 0.47m error

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