Progress on Benchmarking framework of vision-based spatial registration and tracking methods for mixed and augmented reality (MAR) (ISO/IEC 18520)

Takeshi Kurata
AIST, Japan
(80%: Sumitomo Electric Industries, Ltd. (SEI), 20%: AIST from April, 2018 to March, 2020)
Indoor Positioning Technologies

- **Stationary nodes only (Infrastructure)**
  - IMES (iPNT)
  - Millimeter-wave Radar
    - Surveillance camera (RGB, RGB-D)
  - Light communication
  - Optical marker
  - LRF/LiDAR

- **Combo of stationary and mobile nodes**
  - Wi-Fi, BLE, Active RFID (ZigBee)
  - UWB (TDoA & AoA)
  - AR marker

- **Mobile nodes only (Wearable)**
  - Magnetic fingerprinting
  - xDR: PDR
  - SHS
  - INS (ZUPT)
  - Ultra Sound
  - Relative position and posture available
  - IMU-based motion capturing (Action recognition)
  - Scene recognition
  - Mobile camera (RGB, RGB-D)
    - vSLAM
    - vSRT

---

### Error (m)
- **Macro Positioning**: 3
- **Meso Positioning**: 1
- **Micro Positioning**: 0.3

### Coverage/$
- **Large**
- **Middle**
- **Small**

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vSRT (vision-based Spatial Registration and Tracking) methods for MAR

iOS

https://www.youtube.com/watch?v=ttdPqly4OF8

https://medium.com/ipg-media-lab/apples-arkit-vs-google-s-arcore-e00ff42b0547

Android

iOS

Web

## FDIS ballot result

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Contents

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  – Terms and Definitions
  – Benchmarking processes
  – Benchmark indicators
  – Trial set for benchmarking
  – Conformance

• Annex A: Benchmarking activities
• Annex B: Usage examples of conformation checklists
• Annex C: Conceptual relationship between this document and other standards
Benchmarking Process Flow

vSRT: Vision-based spatial registration and tracking
Example of stakeholders and their roles
Benchmark indicators

vSRT: Vision-based spatial registration and tracking
## Benchmark indicators

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**3DEVO**: 3D error of a virtual object  
**PEVO**: Projection error of a virtual object
## Benchmark indicators

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**3DEVO**: 3D error of a virtual object  
**PEVO**: Projection error of a virtual object

ISMAR 2015 Tracking competition (A.6)
Trial set for benchmarking

vSRT: Vision-based spatial registration and tracking
## Trial set for benchmarking

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### TrakMark (A.1)

- Film
- Studio
- Package
- NAIST
- Campus
- Package
- Conference
- Venue
- Package
# Trial set for benchmarking

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## Trial set for benchmarking

### The City of Sights (A.4): An Augmented Reality Stage Set

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### DIGITAL 3D MODELS AND PAPER MODELS

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## Trial set for benchmarking

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<td></td>
<td>• Depth image sequences</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Self-contained sensor data</td>
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</table>

<table>
<thead>
<tr>
<th>Physical object instances</th>
<th>Contents</th>
<th>Metadata</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Physical objects</td>
<td>Information on how to find the physical objects</td>
</tr>
</tbody>
</table>
# Trial set for benchmarking

## ISMAR 2014 Tracking competition (A.5)

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Off-site</th>
<th>On-site</th>
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<tbody>
<tr>
<td>Physical object instances</td>
<td><strong>Contents</strong></td>
<td>Physical objects</td>
</tr>
<tr>
<td>Metadata</td>
<td><strong>Image sequences</strong></td>
<td><strong>Challenge points</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Intrinsic/extrinsic camera parameters</strong></td>
<td><strong>3D models for the target objects and for virtual objects</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Camera configuration</strong></td>
<td><strong>Scenario</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Image quality</strong></td>
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</tr>
</tbody>
</table>
Trial set for benchmarking

<table>
<thead>
<tr>
<th>Dataset</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• Challenge points</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 3D models for the target objects and for virtual objects</td>
</tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• Information on how to find the physical objects</td>
</tr>
</tbody>
</table>
## Conformance checklist

<table>
<thead>
<tr>
<th>Process flow</th>
<th>Check</th>
<th>Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>[ ]</td>
<td>Develop vSRT methods and/or MAR systems:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Gather vSRT methods and/or MAR systems:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Prepare and conduct benchmarking:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Provide and maintain benchmarking instruments:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Provide and maintain benchmarking repositories:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Share benchmarking results:</td>
<td></td>
</tr>
<tr>
<td>Target/</td>
<td>[ ]</td>
<td>vSRT method:</td>
<td></td>
</tr>
<tr>
<td>Input/</td>
<td>[ ]</td>
<td>MAR system:</td>
<td></td>
</tr>
<tr>
<td>Output/</td>
<td>[ ]</td>
<td>Trial sets and physical objects:</td>
<td></td>
</tr>
<tr>
<td>Organized</td>
<td>[ ]</td>
<td>Benchmarking instruments:</td>
<td></td>
</tr>
<tr>
<td>storage</td>
<td>[ ]</td>
<td>Benchmarking results:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Benchmarking surveys:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Benchmarking repository:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>External repositories:</td>
<td></td>
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</table>

## Indicator

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Check</th>
<th>Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[ ]</td>
<td>3DEVO:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>PEVO:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Reprojection error of image features:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Position and posture errors of a camera:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Completeness of a trial:</td>
<td></td>
</tr>
<tr>
<td>Temporality</td>
<td>[ ]</td>
<td>Throughput:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Latency:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Time for trial completion:</td>
<td></td>
</tr>
<tr>
<td>Variety</td>
<td>[ ]</td>
<td>Number of datasets/trials:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Variety on properties of datasets/trials:</td>
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</tr>
</tbody>
</table>

## Dataset

<table>
<thead>
<tr>
<th>Trial set</th>
<th>Check</th>
<th>Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contents</td>
<td>[ ]</td>
<td>Image sequences:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Intrinsic/extrinsic camera parameters:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Challenge points:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Optional contents:</td>
<td></td>
</tr>
<tr>
<td>Metadata</td>
<td>[ ]</td>
<td>Scenario:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Camera motion type:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Camera configuration:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>Image quality:</td>
<td></td>
</tr>
<tr>
<td>Physical</td>
<td>[ ]</td>
<td>Physical objects:</td>
<td></td>
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<tr>
<td>object</td>
<td>[ ]</td>
<td>How to find the physical objects:</td>
<td></td>
</tr>
<tr>
<td>instances</td>
<td>[ ]</td>
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<td>Metadata</td>
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</table>
## Conformance checklist examples

<table>
<thead>
<tr>
<th>Process flow</th>
<th>Check Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>vSRT method</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>MAR system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial sets and physical objects</td>
<td>✔</td>
<td>See &quot;Trial set&quot; table.</td>
</tr>
<tr>
<td>Benchmarking instruments</td>
<td>✔</td>
<td>TU Graz, TUM, and UCSB</td>
</tr>
<tr>
<td>Benchmarking results</td>
<td>✔</td>
<td>TU Graz, TUM, and UCSB</td>
</tr>
<tr>
<td>Benchmarking surveys</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Benchmarking repository</td>
<td>✔</td>
<td>3D model data for paper craft buildings, paper folding plans, video sequences, etc. are distributed on TU Graz website.</td>
</tr>
<tr>
<td>External repositories</td>
<td>✔</td>
<td></td>
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<table>
<thead>
<tr>
<th>Reliability</th>
<th>Check Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3DEVO</td>
<td>✔</td>
<td>3D error between the estimated position of element and the ground truth</td>
</tr>
<tr>
<td>PEVO</td>
<td>✔</td>
<td>Reprojection error of image features</td>
</tr>
<tr>
<td>Reprojection error of image features</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Position and posture errors of a camera</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Completeness of a trial</td>
<td>✔</td>
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<table>
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<tr>
<th>Temporality</th>
<th>Check Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Latency</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Time for trial completion</td>
<td>✔</td>
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<table>
<thead>
<tr>
<th>Variety</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Number of datasets/trials</td>
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</tr>
<tr>
<td>Variety on properties of datasets/trials</td>
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<table>
<thead>
<tr>
<th>Dataset</th>
<th>Check Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contents</td>
<td>✔</td>
<td>Physical objects: The following paper craft buildings used as physical objects are as follows:</td>
</tr>
<tr>
<td></td>
<td>✔</td>
<td>Physical objects: 1) 1:10 vehicle model and other toy-like objects</td>
</tr>
<tr>
<td></td>
<td>✔</td>
<td>Optional contents: Reference points used only for calibrating (not available)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial set</th>
<th>Check Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contents</td>
<td>✔</td>
<td>Physical objects: 1) 1:10 vehicle model and other toy-like objects</td>
</tr>
<tr>
<td>Metadata</td>
<td>✔</td>
<td>Camera configuration: Tracking with high accuracy by placing competitors' own markers and features into a specified area</td>
</tr>
<tr>
<td></td>
<td>✔</td>
<td>Camera motion type: 3D error between the estimated position of element and the ground truth</td>
</tr>
<tr>
<td></td>
<td>✔</td>
<td>Image quality: 1600x1200 or 640x480 Several lighting conditions</td>
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</table>

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Check Item</th>
<th>Remarks</th>
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<td>3DEVO: 3D error between the estimated position of element and the ground truth</td>
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<tr>
<td>Completeness of a trial</td>
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<th>Remarks</th>
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</tr>
<tr>
<td>Variety on properties of datasets/trials</td>
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<table>
<thead>
<tr>
<th>Observed Objects</th>
<th>Check Item</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contents</td>
<td>✔</td>
<td>Physical objects: 1) 1:10 vehicle model and other toy-like objects</td>
</tr>
<tr>
<td>Metadata</td>
<td>✔</td>
<td>How to find the physical objects: Paper folding plans</td>
</tr>
</tbody>
</table>

**Benchmarking activities in A.4**

**On-site competition in A.6**
xDR (PDR & VDR) Challenge: Survey on indoor localization competitions and benchmarking activities

Takeshi Kurata
AIST, Japan
(80%: Sumitomo Electric Industries, Ltd. (SEI),
20%: AIST
from April, 2018 to March, 2020)
Indoor Positioning Technologies

- **Stationary nodes only (Infrastructure)**
  - IMES (iPNT)
  - Millimeter-wave Radar
  - Surveillance camera (RGB, RGB-D)
  - LRF/LiDAR
  - No ID

- **Combo of stationary and mobile nodes**
  - Wi-Fi, BLE, Active RFID (ZigBee)
  - Trilateration
  - Fingerprinting (RSSI, TDoA, ToF)
  - Proximity
  - AoA
  - Light communication
  - Optical marker
  - AR marker
  - UWB (TDoA & AoA)
  - Ultrasound
  - Intolerant of occlusion
  - IC tag (Proximity)

- **Mobile nodes only (Wearable)**
  - Magnetic fingerprinting
  - xDR: PDR
  - SHS
  - INS (ZUPT)
  - Relative position and posture available
  - IMU-based motion capturing (Action recognition)
  - Mobile camera (RGB, RGB-D)
  - Scene recognition
  - vSLAM
  - vSRT
  - Intolerant of occlusion

<table>
<thead>
<tr>
<th>Error (m)</th>
<th>Macro Positioning</th>
<th>Meso Positioning</th>
<th>Micro Positioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage/$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>3</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Middle</td>
<td>Middle</td>
<td>Micro</td>
<td>Small</td>
</tr>
</tbody>
</table>

Pedestrian Dead Reckoning

User →

First-person view

Station →
Red: PDR (Pedestrian Dead-Reckoning) with a smartphone on his chest
Green: Perception Neuron (Motion capture system)
Yellow: Google Tango on his waist (Wide-field of view RGB and depth)
Blue: HoloLens on his head (Wide-field of view RGB and depth)
Vibration-based Vehicle Dead Reckoning
(movie provided by Sugihara SEI)
Vibration-based Vehicle Dead Reckoning
xDR (PDR & VDR) Challenge for Warehouse Operations 2018
**Evaluation Metric**

Metrics related to accuracy
- Metric related to integrated positioning error (Ed)
- Metric related to PDR error based on EAG (Es)

Metrics related to the trajectory naturalness
- Metric related to the naturalness of travel speed (Ev)
- Metric related to position measurement output frequency (Ef)

Specific metrics for warehouse picking scenario
- Metric related to collision with obstacles (Eo)
- Metric related to motions during picking work (Ep)

Proposed indicator: **EAG**
(Error Accumulation Gradient)

Positioning error per unit time based on discussion in

![Comprehensive evolutions (C.E.)](image)

- **eCDF**: Empirical Cumulative Distribution Function

![eCDF](image)
Special session (Sep 26) in IPIN 2018:
A Survey on Indoor Localization Competitions

(1) Onsite Visual SLAM Evaluation, H. Uchiyama (Kyushu University, Japan)
(2) Performance Evaluation of Indoor Positioning and Navigation Services during
PyeongChang 2018 Winter Olympic Games by using IPIN competition setup, S. Lee (ETRI, South Korea)
(3) NIST Indoor 3D Challenge, J. Benson (NIST, USA)
(4) PerfLoc Prize Competition for Development of Smartphone Indoor
Localization Applications, N. Moayeri (NIST, USA)
(5) Regular paper slot: 213242 - PerfLoc (Part 2): Performance Evaluation of the
Smartphone Indoor Localization Apps, N. Moayeri, C. Li, L. Shi
(6) Regular paper slot: 212811 - Review of PDR Challenge in Warehouse Picking
and Advancing to xDR Challenge, R. Ichikari, R. Shimomura, M. Kourogì, T. Okuma, T. Kurata
(7) The result of xDR Challenge for Warehouse Operations 2018
(8) Closing: Brief Survey on Indoor Localization Competitions
<table>
<thead>
<tr>
<th>Scenario</th>
<th>PerfLoc by NIST</th>
<th>EvAAL/IPIN Competitions</th>
<th>Microsoft Competition@IPSN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking/motion</td>
<td>walking/running/ backwards/sidestep/ crawling/pushcart/ elevators (walked by actors on planed path with CPs)</td>
<td>Walking/Stairs/Lift/Phoning /Lateral movement (walked by Actors on planed path with CPs)</td>
<td>Depends on operators (developers can operate their devices by themselves)</td>
</tr>
<tr>
<td>On-site or Off-site</td>
<td>Off-site competition and Live demo</td>
<td>Separated On-site and Off-site tracks</td>
<td>On-site</td>
</tr>
<tr>
<td>Target Methods</td>
<td>Arm-mounted smartphone based localization method (IMU, WiFi, GPS, Cellular)</td>
<td>Off-site: Smartphone base On-site : Smartphone base/ any body-mounted device (separated tracks)</td>
<td>2D:Infra-free methods 3D:Allowed to arrange Infra. (# of anchor and type of devices are limited on 2018)</td>
</tr>
<tr>
<td># of people and trial</td>
<td>1 person × 4 devices (at the same time) × 30 scenarios</td>
<td>Depends on year and track (e.g. 9 trials, 2016T3)</td>
<td>N/A</td>
</tr>
<tr>
<td>Time per trial</td>
<td>Total 16 hours</td>
<td>Depends on year and track (e.g. 15 mins (2016T1,T2), 2 hours (2016T3))</td>
<td>N/A</td>
</tr>
<tr>
<td>Evaluation metric</td>
<td>SE95 (95% Spherical Error)</td>
<td>75 Percentile Error</td>
<td>Mean error</td>
</tr>
</tbody>
</table>
### A Short Survey of Indoor Localization Competitions (1/2)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Ubicomp/ISWC 2015 PDR Challenge</th>
<th>PDR Challenge in Warehouse Picking in IPIN 2017</th>
<th>xDR Challenge for Warehouse Operations 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking /motion</td>
<td>Indoor pedestrian navigation</td>
<td>Picking work inside a logistics warehouse (Specific Industrial Scenario)</td>
<td>General warehouse operations including picking, shipping and driving forklift</td>
</tr>
<tr>
<td>On-site or off-site</td>
<td>Data collection: on-site Evaluation: off-site</td>
<td>Off-site</td>
<td>Off-site</td>
</tr>
<tr>
<td>Number of people and trial</td>
<td>90 people, 229 trials</td>
<td>8 people, 8 trials</td>
<td>34 people + 6 forklifts, 170 trials (PDR) + 30 trials (VDR)</td>
</tr>
<tr>
<td>Time per trial</td>
<td>A few minutes</td>
<td>About 3 hours</td>
<td>About 8 hours</td>
</tr>
<tr>
<td>Evaluation metric</td>
<td>Mean Error, SD of Error</td>
<td>Integrated Evaluation (EAG)</td>
<td>Integrated Evaluation (EAG)</td>
</tr>
<tr>
<td>Remark</td>
<td>Collection of data of participants walking. The data are available at HASC (<a href="http://hub.hasc.jp/">http://hub.hasc.jp/</a>) as corpus data</td>
<td>Competition over integrated position using not only PDR, but also correction information such as BLE beacon signal, picking log (WMS), and maps</td>
<td>Consists of PDR and VDR tracks. Referential motion captured by MoCap. also shared for introducing typical motions.</td>
</tr>
</tbody>
</table>
ISO/IEC 18305 is an international standard for testing Localization and Tracking Systems (LTSs). NIST initiated the development of this standard in October 2012 and led the development process through the completion of the project in November 2016 with the publication of the standard. Besides the members of the subcommittee ISO/IEC JTC 1/SC 31, Automatic identification and data capture techniques, which were directly responsible for the development of ISO/IEC 18305, many individuals from industry, various user communities, standard developing organizations, academia, and US federal government reviewed various drafts of the standard and made invaluable comments/contributions.

ISO has the copyright on ISO/IEC 18305. The standard may be purchased by visiting the relevant ISO web page. By clicking on the Preview ISO/IEC 18305:2016 button on that page, one can find the table of contents and the introductory sections of the standard. Among other things, the "Introduction" explains why ISO/IEC 18305 was developed.

NIST activities in LTS testing are based on ISO/IEC 18305. The testing activities are use cases for ISO/IEC 18305 and a means of validating the standard.

What’s the next action?

- Plan A: Sending a liaison to ISO/IEC JTC 1/SC 31 (Automatic identification and data capture techniques)/WG 4 (Radio communications)
- Plan B: Submitting the NWIP form ISO/IEC JTC 1/SC 24/WG 9 (but after preparing the first draft)
- Plan C: Observing activities in IPIN-ISC (International Standards Committee)