People Tracking for Enabling Human-Robot Interaction in Large Public Spaces
• This work was largely done at ATR Intelligent Robotics and Communication Laboratory Kyoto, Japan (1/2011 - 9/2016)
Motivation

- Motivation: bring social service robots into our everyday environments
- However, robots still have limited sensing abilities
- Solution: use sensors installed in the environment
Our previous solution

- Using multiple laser range finders
- Stable and quite accurate tracking can be achieved
- Issues:
  - sensitive to occlusion
  - only 2D position information (no height, orientation, etc.)
3D range sensors

- Measure the distance to the objects – 3D shape of the objects can be obtained

<table>
<thead>
<tr>
<th>Sensing principle</th>
<th>Scan area</th>
<th>Robustness to noise, interference</th>
<th>Price range</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereo camera</td>
<td>Few meters</td>
<td>××</td>
<td>Mid</td>
<td>BumbleBee</td>
</tr>
<tr>
<td>Projection</td>
<td>Few meters</td>
<td>×</td>
<td>Low</td>
<td>Kinect, Asus XTION</td>
</tr>
<tr>
<td>TOF camera</td>
<td>Few meters</td>
<td>×</td>
<td>Mid</td>
<td>D-IMager, SwissRanger</td>
</tr>
<tr>
<td>Rotating 3D laser scanner</td>
<td>Tens of meters</td>
<td>○</td>
<td>High</td>
<td>Velodyne</td>
</tr>
</tbody>
</table>
Examples of sensor outputs

Microsoft Kinect
(experimental room)

Panasonic D-IMager
(public space)
Basic pose estimation method

• Simple heuristic:
  – Division into layers and extraction of features
  – Robust to noise, missing data and low resolution

• Continuous tracking using PF
Tracking in a room
Evaluation (room tracking)

- Motion tracker data as ground truth and comparison with LRF (using CLEAR MOT metrics*)

<table>
<thead>
<tr>
<th>Number of persons :</th>
<th>2</th>
<th>4</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LRF</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision [mm]</td>
<td>95.17</td>
<td>116.79</td>
<td>124.79</td>
</tr>
<tr>
<td>Accuracy [%]</td>
<td>99.83</td>
<td>99.55</td>
<td>97.76</td>
</tr>
<tr>
<td><strong>3D</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision [mm]</td>
<td>74.48</td>
<td>82.50</td>
<td>73.60</td>
</tr>
<tr>
<td>Accuracy [%]</td>
<td>99.94</td>
<td>99.97</td>
<td>99.88</td>
</tr>
</tbody>
</table>

Installation in shopping mall [2012]

- Combination of different sensors

47 range sensors: 4 m above ground, on ceiling and pillars

2 Velodyne rotating laser scanners: 8 m height – for covering the square
ATC sensing environment

- Corridors / square – 900m² area
- Simultaneous tracking of up to 200 persons
Tracking in ATC

Tracking of persons in ATC shopping mall

ATR, 2012
Evaluation (ATC)

- Only accuracy (no ground truth)

<table>
<thead>
<tr>
<th>Day of week:</th>
<th>Weekday</th>
<th>Weekend</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy [%]</td>
<td>98.63</td>
<td>93.21</td>
<td>94.47</td>
</tr>
</tbody>
</table>

→ Comparable to state of the art RGB camera based tracking, while being robust to environment and lighting changes

Benefits

- Large area continuous real-time tracking
- Collection of statistics and modelling people’s behavior
- Enabled us to do experiments in the real world which were previously difficult
Statistic – usage of space

Density

Speed

Motion direction
Statistic – changes during the day

Example: corridor data

- Much more persons on weekend than during the week + walking slower
- Workers rush-hours on weekdays

Pedestrian behavior

- Also **microscopic** behavior of pedestrians:
  - Improved social-force model of pedestrian movement
  - Analysis of pedestrian groups and recognition
  - Effects of density, gender, age, etc. on group formation

F. Zanlungo, D. Brščić and T. Kanda, *Spatial-size scaling of pedestrian groups under growing density conditions*, Physical Review E 91.6, 2015, and other works of F. Zanlungo
Human-robot interaction

Distribution of flyers:

Human-robot interaction

Approaching people in need of information:

Human-robot interaction

- ASIMO as shopkeeper (Miraikan, Oct. 2013)
Issues

- Requirement for large and expensive installation
  - Low mobility
  - Limitation where and when can be used

→ Use onboard sensors instead
Onboard sensing

• Velodyne HDL-32E

• Sensing:
  – map built beforehand (using Slam6D package)
  – particle filter based 3D localization
  – tracking of all objects that are not in the map
Onboard sensing