## Bosch Corporate Research SLAM (CR SLAM) – SUBMISSION TO HILIT SLAM CHALLENGE [1]

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At Bosch Corporate Research we have developed over the recent years a Slam pipeline for predevelopment projects for various robots, ranging from small household robots over industrial robots to autonomous driving applications. Key contributors over the years are in the authors' list. A commercialized version is also available.

The pipeline as presented here historically started as a 2D Lidar pipeline, and was later extended to support also 3D Lidar. Ground robot navigation is the main application and so the pipeline is optimized towards accurate and robust 2D (x, y, yaw) output as input for path planning.

In brief, the pipeline has the following main components

- 6DOF Odometry, can come from different possible sources, e.g. wheel odometry+IMU fusion or VIO. Here, we use fusion of IMU and a constant velocity filter of the Lidar Odometry output.
- Scan Preprocessing: Undistortion, levelling and downsampling, based on odometry input
- LidarOdometry, maintains a local map over a time window. New scans are registered to the local maps and key frames are selected
- Slam Graph, stores keyframes and associated information
- Loop Closures, finds loop closures between keyframes
- For structured indoor environments Manhattan world assumptions are used (on keyframe level), this includes the assumption of a common ground plane at constant height.
- Optimization of the Slam Graph via g2o.
- Scan matching (in lidar odometry and find loop closures) is NDT based.

The final trajectory output in the submission is calculated using the keyframe poses after the end of the run, intermediate poses are interpolated using the lidar odometry results (that is available for each input scan).

We used the Ouster Sensor and the Bosch IMU.

Run times were measured using rewritten bags (containing only lidar and imu messages with lz4 compression), on an Intel i7 platform using a single core. Total time is measured using the "time" command ("real" output), including startup and shutdown of process (includes e.g. saving the map). There is one scan per 100 ms, so the run time is safely above realtime in all runs.

| Run | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # Scans | 894 | 2002 | 2640 | 5814 | 1127 | 3307 | 3502 | 1347 | 1994 | 3990 | 4297 | 3747 |
| t [s] | 27,1 | 65,9 | 98,0 | 197,4 | 36,1 | 119,1 | 131,2 | 46,0 | 49,9 | 110,2 | 166,5 | 141,9 |
| t per scan [ms] | 30,3 | 32,9 | 37,1 | 34,0 | 32,0 | 36,0 | 37,5 | 34,1 | 25,0 | 27,6 | 38,7 | 37,9 |

Parameters are constant among the runs with the following exceptions:

- Manhattan world assumptions are active for indoor runs only.
- The parking dataset exhibited an unusually large z-drift along the first large loop on the parking deck, preventing a loop closure. Reasons for that are yet to be examined. This was solved here by treating this data set as an indoor data set, practically assuming the parking deck has a constant height ground plane (not knowing whether this is true).

Finally, we would like to thank the Hilti/UZH team for this high quality data set and setting up the challenge.

[1] Michael Helmberger, Kristian Morin, Nitish Kumar, Danwei Wang, Yufeng Yue, Giovanni Cioffi and Davide Scaramuzza, The Hilti SLAM Challenge Dataset, 2012, arXiv:2109.11316