SLAMBench: A performance and accuracy benchmarking methodology for SLAM

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BMVA Meeting: Vision for Robotics, 3rd December 2014
Robot vision entering mass market
Death of Moore's law
PAMELA – A Panoramic View of the Many-core Landscape

- 5-year EPSRC Programme Grant
- Three partners: Edinburgh, Imperial, Manchester
- Groups specializing in:
  - Computer architecture
  - Domain specific optimization and languages
  - Compiler and runtime design
  - Robotic vision
- Holistic look at the entire software/hardware stack
- 3D scene understanding as the unifying challenge application
Need for a performance benchmark

Computer vision benchmarks only consider accuracy!
Where do we start?

- Simultaneous Localisation and Mapping (SLAM)
- Dense SLAM with a depth camera – KinectFusion
- Building block of large scale dense systems

[Chen et al., 2013]

[Whelan et al., 2012]
SLAMBench

- Multi-platform KinectFusion implementations
- Measure correctness on synthetic dataset [Handa et al., 2014]
- Kernel-level speed, and energy characterisation
- Enable multi-disciplinary cooperation
SLAMBench: Application pipeline

- Truncated Signed Distance Function (TSDF) representation for map (dense 3D reconstruction)
- Predict new depth map from reconstruction
- Align using Iterative Closest Point (ICP) algorithm
### SLAMBench: Application pipeline

<table>
<thead>
<tr>
<th>Kernels</th>
<th>Building Block</th>
<th>Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm2meters</td>
<td>Preprocess</td>
<td>Gather</td>
</tr>
<tr>
<td>bilateralFilter</td>
<td>Preprocess</td>
<td>Stencil</td>
</tr>
<tr>
<td>halfSample</td>
<td>Track</td>
<td>Stencil</td>
</tr>
<tr>
<td>depth2vertex</td>
<td>Track</td>
<td>Map</td>
</tr>
<tr>
<td>vertex2normal</td>
<td>Track</td>
<td>Stencil</td>
</tr>
<tr>
<td>track</td>
<td>Track</td>
<td>Map/Gather</td>
</tr>
<tr>
<td>reduce</td>
<td>Track</td>
<td>Reduction</td>
</tr>
<tr>
<td>solve</td>
<td>Track</td>
<td>Sequential</td>
</tr>
<tr>
<td>integrate</td>
<td>Integrate</td>
<td>Map/Gather</td>
</tr>
<tr>
<td>raycast</td>
<td>Raycast</td>
<td>Search/Stencil</td>
</tr>
<tr>
<td>renderDepth</td>
<td>Rendering</td>
<td>Map</td>
</tr>
<tr>
<td>renderTrack</td>
<td>Rendering</td>
<td>Map</td>
</tr>
<tr>
<td>renderVolume</td>
<td>Rendering</td>
<td>Search/Stencil</td>
</tr>
</tbody>
</table>
SLAMBench: Multiple platforms

Implementations
- C++
- OpenMP
- OpenCL
- CUDA
...

Platforms
- ARM
- INTEL
- NVIDIA
...

## SLAMBench: Multiple platforms

<table>
<thead>
<tr>
<th>Machine</th>
<th>Type</th>
<th>CPU cores</th>
<th>GPU FPU32s</th>
<th>GPU GFLOPS (SP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TITAN</strong></td>
<td>Desktop</td>
<td>4 (i7 Haswell)</td>
<td>2688</td>
<td>2250</td>
</tr>
<tr>
<td><strong>GTX870M</strong></td>
<td>Laptop</td>
<td>4 (i7 Haswell)</td>
<td>1344</td>
<td>1260</td>
</tr>
<tr>
<td><strong>TK1</strong></td>
<td>Embedded</td>
<td>4 (Cortex-A15) + 1</td>
<td>192</td>
<td>330</td>
</tr>
<tr>
<td><strong>ODROID (XU3)</strong></td>
<td>Embedded</td>
<td>4 (Cortex-A15) + 4 (Cortex-A7)</td>
<td>60</td>
<td>60+30</td>
</tr>
<tr>
<td><strong>Arndale</strong></td>
<td>Embedded</td>
<td>2 (Cortex-A15)</td>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>
SLAMBench: Accuracy

Correctness Verification

ICL-NUIM Dataset  Visualisation Tool

[Handa et al., 2014]
SLAMBench: Metrics

- Kernel-wise evaluation of compute time
- ODROID voltage/current sensors exploiting split power rails
- Knobs to vary different algorithmic parameters affecting accuracy, energy, and frame rate
SLAMBench Suite

- Publicly available
- Easy to understand and extend
- Early adopters include: ARM, IBM TJ Watson Labs, Intel
- ICRA submission [Nardi et al., 2015], available on arXiv.
Experiments

- ICL-NUIM dataset [Handa et al., 2014]
- Synthetic living room model (4.5 m x 4.5 m x 4.5 m)
- Kinect sensor noise added
- Trajectory manually recorded with a real sensor
Accuracy

- Total 17 platform, language combinations evaluated
- Platforms: TITAN, GTX870M, TK1, ODROID, Arndale
- Languages: C++, OpenMP, OpenCL, CUDA
- Absolute trajectory error in the range of 2.01-2.07 cm
- Not the same: due to multi-threaded execution and different hardware architectures!
Elapsed times and frame rates: Blocks
Percentage of time spent in each kernel

The graph shows the percentage of time spent in each kernel for different platforms. Each kernel has a different color and is represented by a bar that indicates the time spent on various tasks.

- **mm2meters**: Represented by blue bars
- **bilateral_filter**: Represented by light green bars
- **halfSampleRobust**: Represented by dark green bars
- **track**: Represented by dark blue bars
- **renderDepth**: Represented by brown bars
- **renderTrack**: Represented by light brown bars
- **depth2vertex**: Represented by purple bars
- **reduce**: Represented by orange bars
- **integrate**: Represented by light orange bars
- **raycast**: Represented by pink bars
- **solve**: Represented by pink bars
- **vertex2normal**: Represented by blue bars
Power consumption on ODROID

- A15: 0.8 W
- A7: 0.4 W
- A15+A7: 2.0 W
- A7: 1.2 W
- GPU+A15+A7: 5.5 W
- GPU+A7: 5.5 W

Types of Power Consumption:
- GPU
- DRAM
- A7
- A15
Conclusion and future work

- Accuracy + Computational performance + Energy
- Benchmark to compare hardware accelerators, software tools, and novel algorithms
- Future: Extension, Design-space exploration, domain specific languages and optimizations
Questions?

Google

SLAMBench
apt.cs.manchester.ac.uk/projects/PAMELA/tools/SLAMBench/
SLAMBench presents a foundation for quantitative, comparable and validatable experimental research to investigate trade-offs for performance, accuracy and ...

Introducing SLAMBench, a performance and accuracy ...
arxiv.org > cs
by L Nardi - 2014
8 Oct 2014 - In this paper we introduce SLAMBench, a publicly-available software framework which represents a starting point for quantitative, comparable ...