Fast High-Resolution Disparity Estimation for Laparoscopic Surgery

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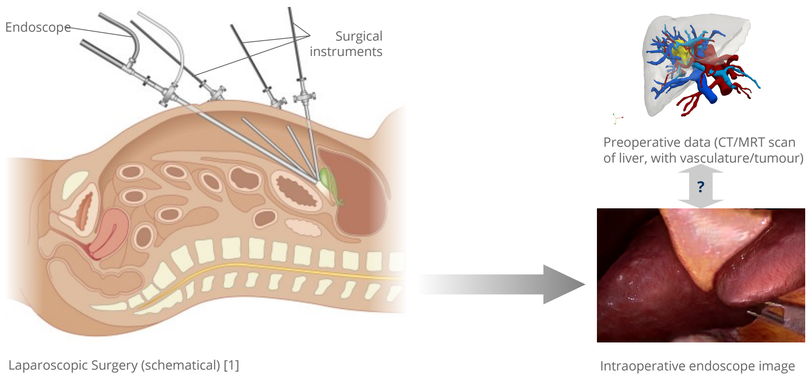
Laparoscopic Liver Surgery



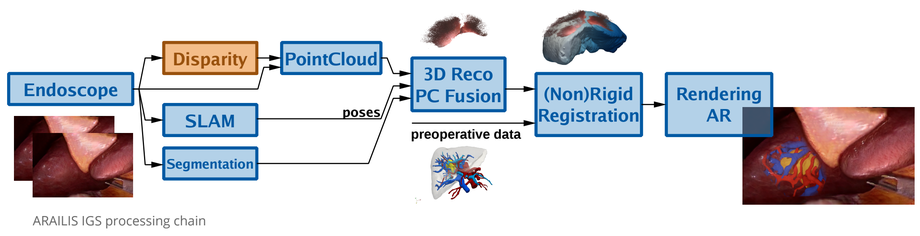
Advantages
- minimally invasive
- lesser morbidity
- faster patient recovery

Problems
- correlation image MRT/CT data
- location of vasculature/tumours
- motion/alterations of organs

→ Image Guidance System

Intraoperative Image Guidance System

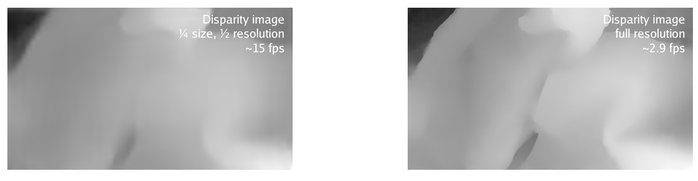
ARAILIS project: Augmented Reality and Artificial Intelligence supported Laparoscopic Imagery in Surgery



ARAILIS IGS processing chain

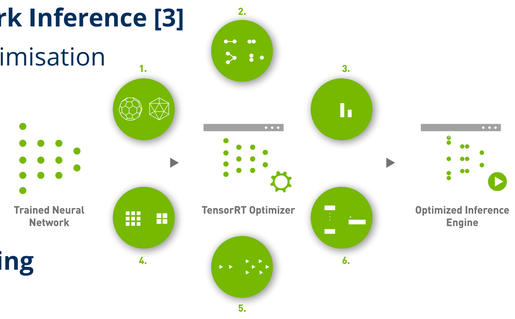
- Point Cloud generation/fusion requires *dense accurate* disparity estimation
- endoscope's *full framerate* at *FullHD resolution* necessary for smooth rendering

Disparity Estimation: Hierarchical Stereo Matching (HSM) neural network [2]



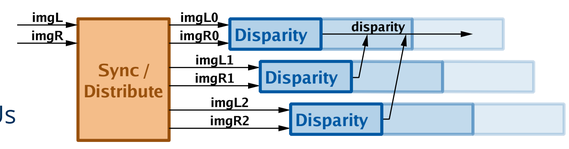
Acceleration Methods

NVIDIA TensorRT: Optimise Network Inference [3]
- GPU/CUDA-centric acceleration/optimisation
- layer/tensor fusion
- memory footprint minimisation
- mixed-precision data (FP32, FP16, INT8)



NVIDIA DALI: Network Pre-Processing
- pipelined input processing on GPU: image transposition, conversion, normalisation, padding/cropping
- streaming data transfer

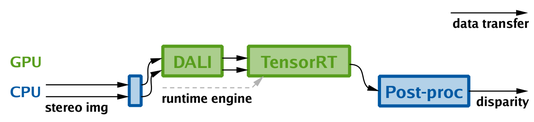
Multithreading/Multi-GPU
- time *synchronisation* of stereo images → pairs
- tagging of stereo pairs → *distribution* to threads / GPUs



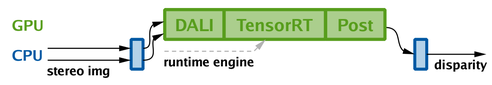
Implementations

ROS (Robot Operating System) Integration
- ROS/python callback function
- interface, inference, output

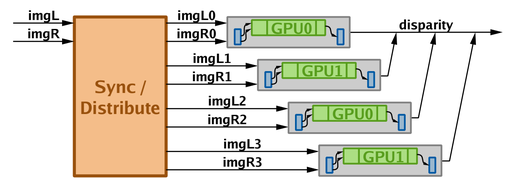
TensorRT & DALI
- build runtime engine once
- integration in ROS infrastructure
- DALI pipeline: DMA interface



GPU-centric implementation
- post-processing on GPU
- minimum data transfer: direct operation on results



Multithreading
- syncing of images by time stamps
- thread tagging/renaming
- ROS scripts: assign threads to GPUs



Experimental Results

Quality: Disparity Error

Models

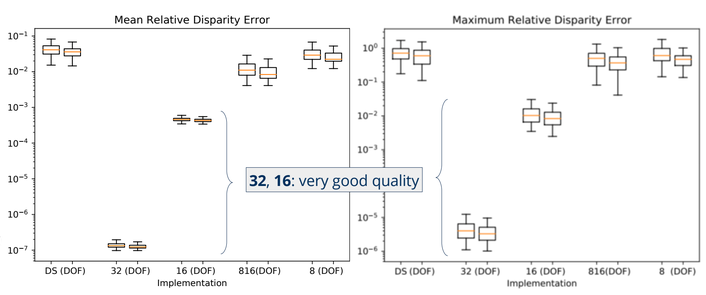
REF	original HSM algorithm, PyTorch, 32-bit float (FP32) data	FullHD resolution (1920×1080 px)
DS	original HSM algorithm (see REF), downscaled	1/16 of FullHD (480×270 px)
32	TensorRT engine & DALI pipeline, FP32 data only	FullHD
16	TensorRT & DALI, mixed-precision FP16 & FP32 data	FullHD
816	TensorRT & DALI, mixed-precision INT8 & FP16 & FP32	FullHD
8	TensorRT & DALI, mixed-precision INT8 & FP32	FullHD

Data Recording
- endoscope: EinsteinVision, frame rate 30 frames / s (fps), depth-of-field **DOF** [20 mm, 200 mm] → DOF disparity range [48.5, 485] px
- data set: 926 stereo images (31 s), with disparity range [3.24, 560] px

Error Measures
- disparity error to REF

$$e_d = \frac{d - d_{ref}}{d_{ref}}$$

- mean over image $\bar{e}_d$
- maximum in image $\hat{e}_d$ in whole image / DOF



Speed: Throughput

Setup
- workstation **XB:** CPU 2 × Xeon 4216, GPU 4 × RTX A5000
- measurement: average data volume (frames) per time (s)
- models, data set → see Quality, more workstations → see paper

Implementation model	Throughput / fps	
Original serial execution **REF** (single CPU/GPU)	2.9	
Downscaled serial model **DS** (single CPU/GPU)	14.9	downscaled for "acceptable" throughput
TensorRT & DALI (single GPU) Models **32** / **16** / **816**	8.3 / 21.5 / 27.3	significant acceleration
Multi-threaded / TRT & DALI (2 threads / 1 GPU)	- / 20.2 / 27.0	more threads no advantage
Multi-threaded / parallelised (2 threads / 2 GPU)	- / 42.9 / 51.0	full frame rate (> 30 fps)
Multi-threaded / parallelised (3 threads / 3 GPU)	- / 64.9 / 60.2	
Multi-threaded / parallelised (4 threads / 4 GPU)	- / 74.1 / 90.1	

throughput of model **8** very similar to model **816**

Distributed Processing
- frame grabber, stereo rectification on "front-end" workstation
- syncing/disparity estimation on "back-end" workstation **GRAPH?**

Recent & Current Work

- integration in processing chain of ARAILIS Image Guidance System
- latest measurement: model **16** on *single* GPU RTX 3090 Ti → 35 fps
- integration of Point Cloud calculation: on *single* RTX 3090 Ti → 32 fps
- reference measurements (on body phantom)

Summary & Conclusions

- improvement/acceleration of dense FullHD disparity algorithm
- model **16**: very good quality, full frame rate on 2 GPUs
  → more accurate 3D reconstruction & registrations
  → improved usability

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References

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[2] YANG, Gengshan, et al. Hierarchical deep stereo matching on high-resolution images. Proc. CVPR, 2019. pp. 5515-5524

[3] NVIDIA, "NVIDIA TensorRT documentation," https://docs.nvidia.com/deeplearning/tensorrt/, online, accessed 2022-06-01