Hardware acceleration of a visual localisation system on the surface of Mars

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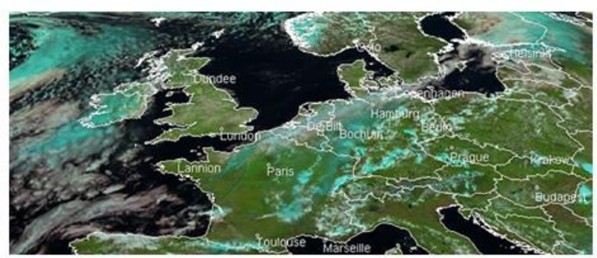


EXOMARS VISLOC

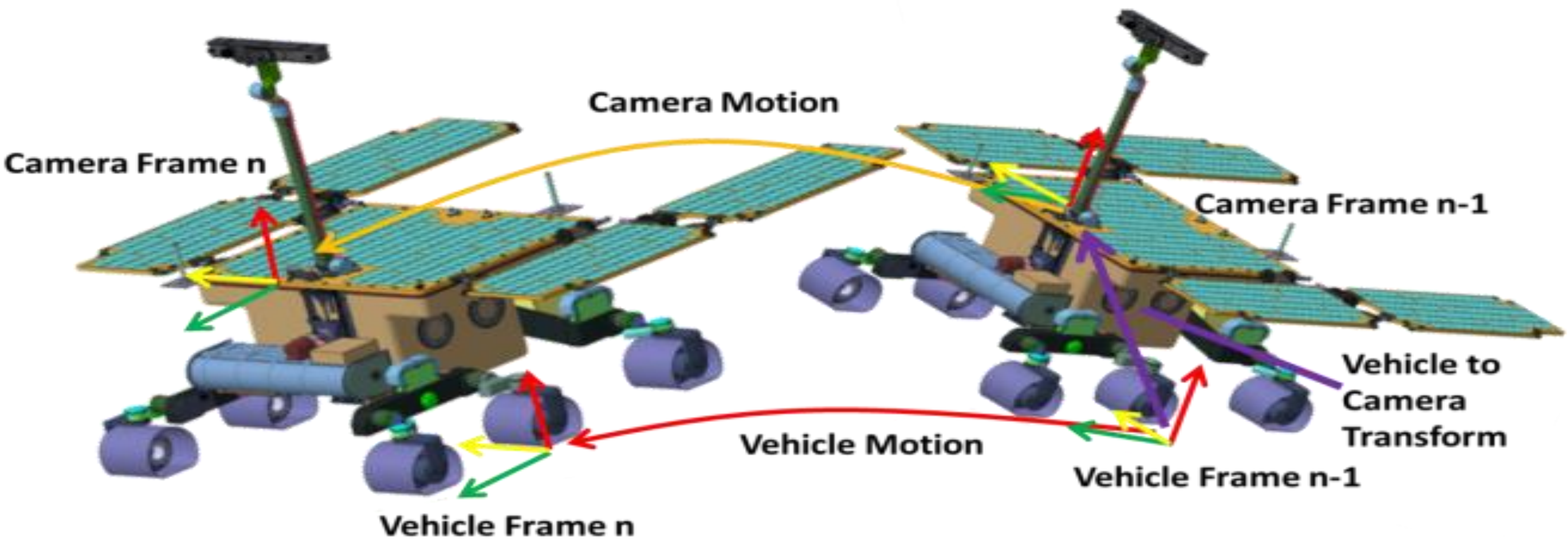
Introduction – VisLoc Algorithm

- Adapted from Oxford Visual Odometry (OVO) algorithm
- OVO originally created for use on autonomous vehicles
- SCISYS adapted it for use on Mars
- Validated using real data and simulated trajectories

SEEKER trial in Atacama Desert, Chile

SCISYS' rover Indie

Introduction – Visual Odometry



What is VO?

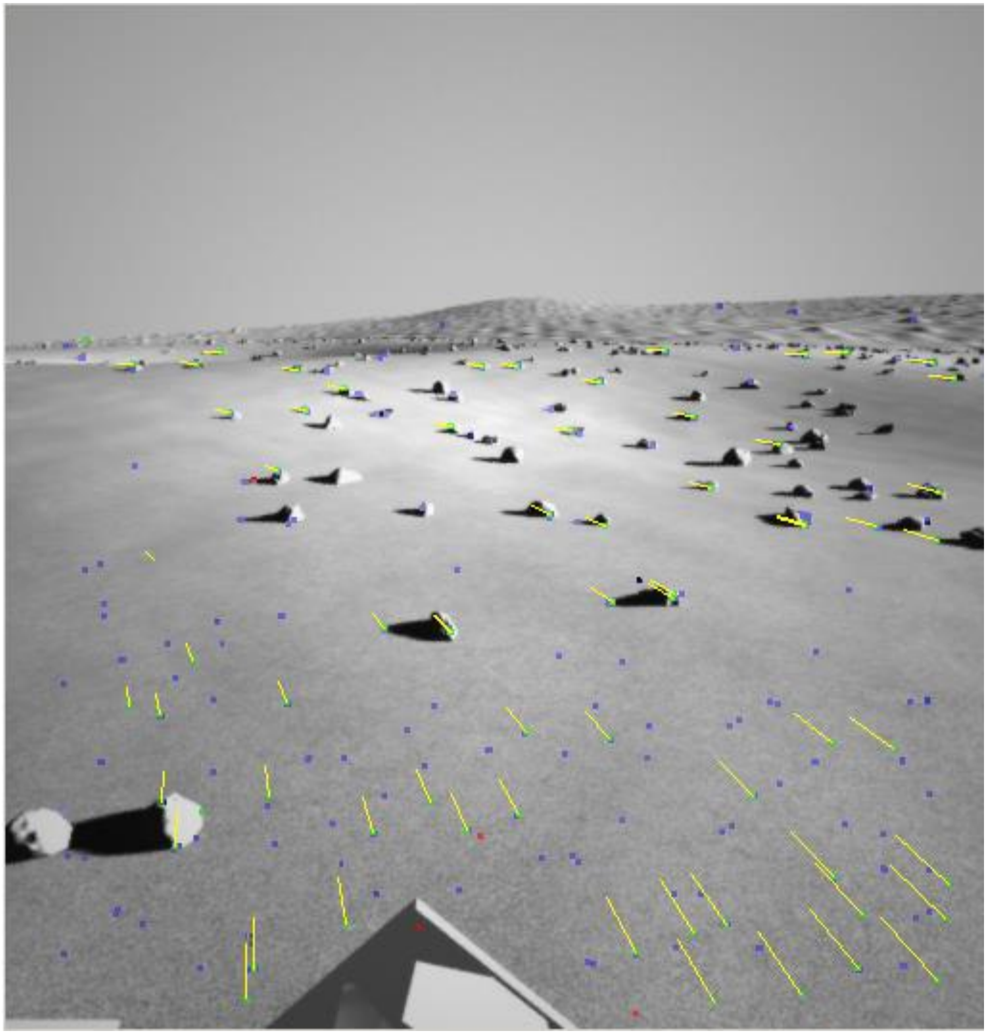
- Continuous self localisation in 6 DOF
- Necessary due to lack of orbital GPS
- Required for autonomous movement

Why VO?

- Accuracy
- Can handle difficult terrain
- Low power requirement
- Very low mass

The Algorithm - Overview

1. Feature extraction
2. Feature matching
3. Movement estimation
4. POSE integration



Graphical representation of matched features in a frame pair

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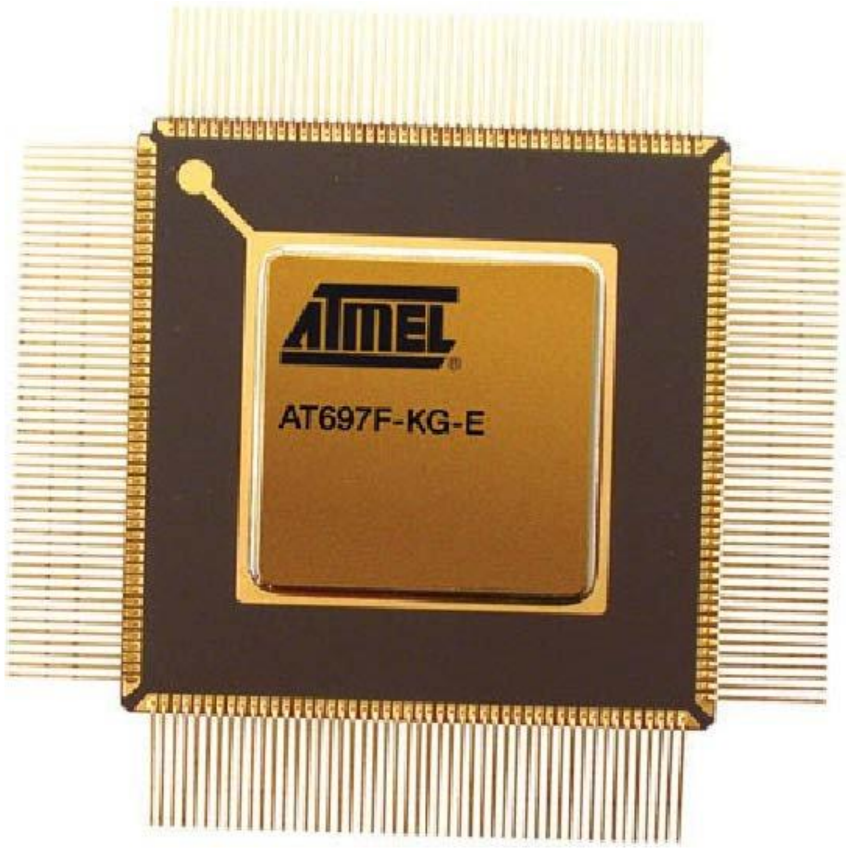
Introduction – ExoMars Rover

- ESA's first Mars rover
- ESA's first use of Visual Odometry in extra-terrestrial navigation

Challenges – ExoMars Hardware



- Maximum image processing time requirement of 4.25s on 96MHz CPU
- Accuracy within 1% of travel distance

Challenges – Software

- Images limited to 512x512px, including:
  - Shadows
  - Sky
  - Rover parts
  - Glare
  - Dust
  - Texture

Simulated heavily shadowed image

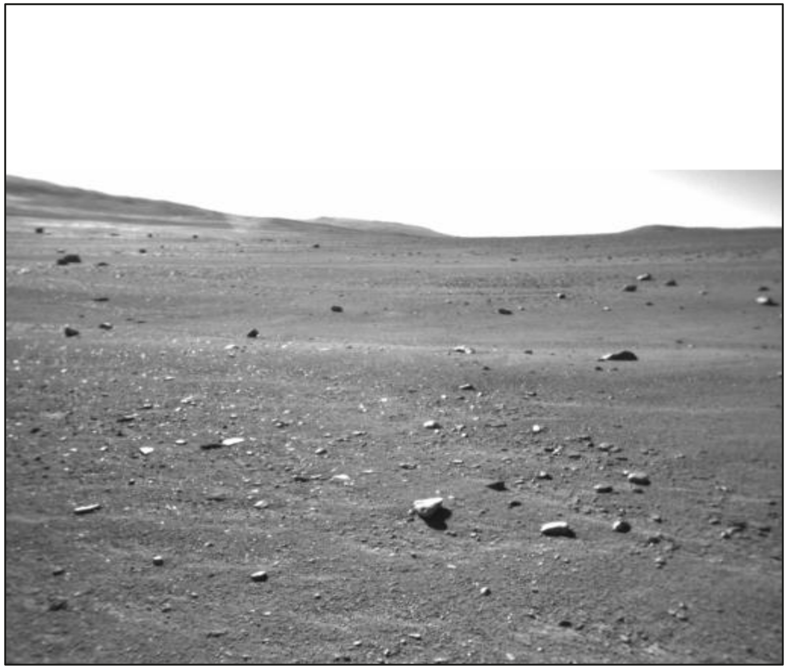
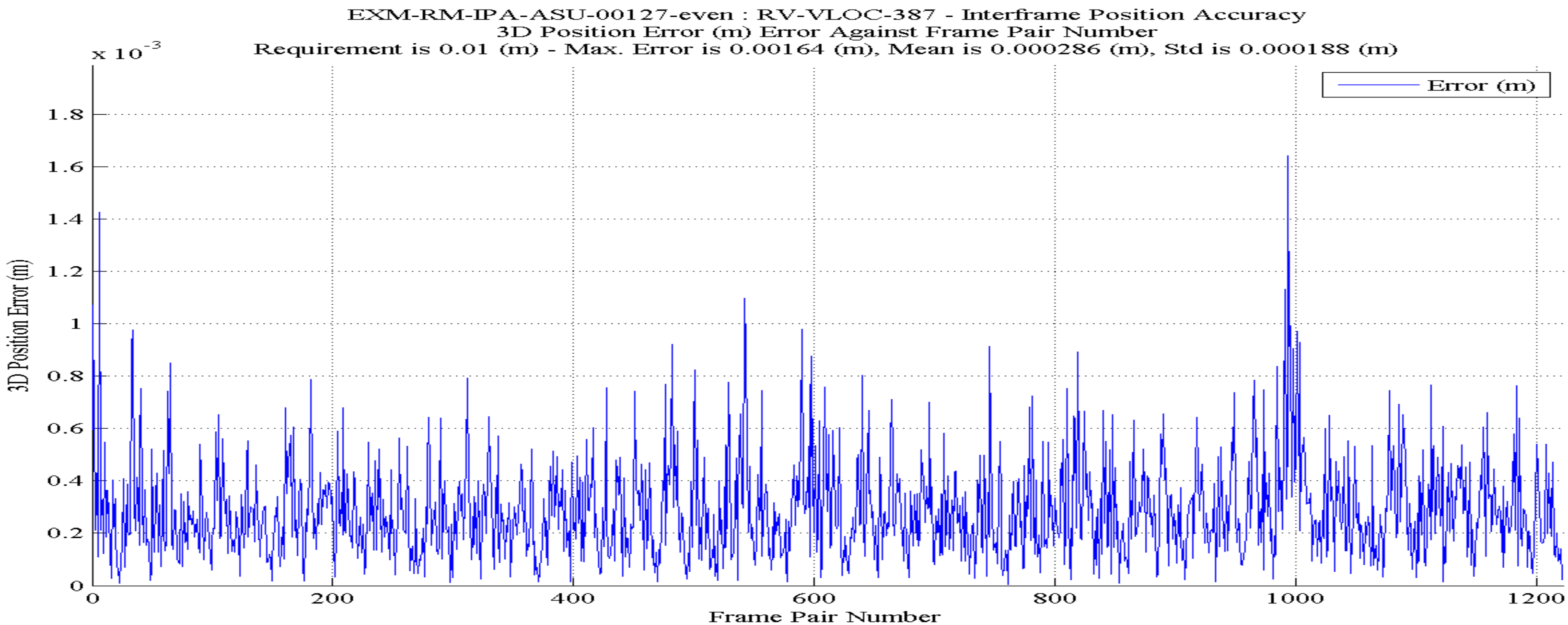


Image from SEEKER trials

Validation – Key Facts

- Over 3 million data points validated.
- Long traverse (>200m) accurate to the order of 0.1m.
- Inter frame typically accurate to the order of 10^{-4}m.



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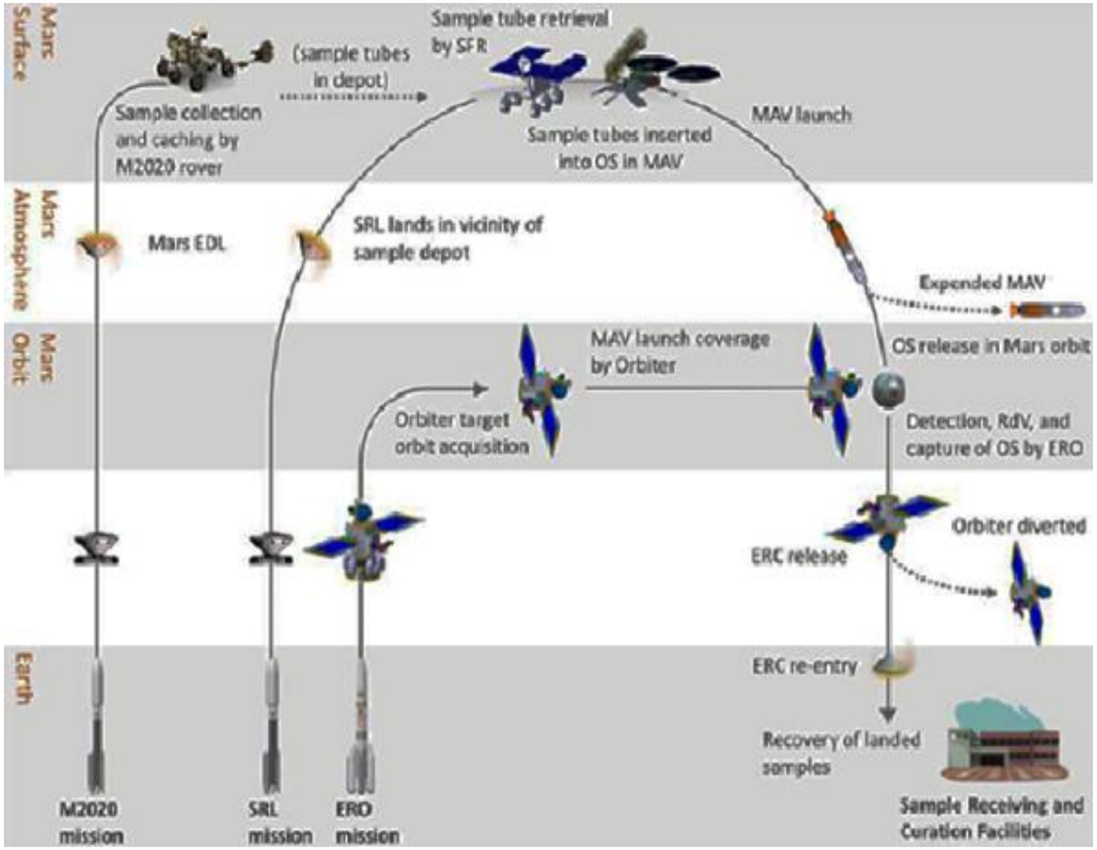
MARS SAMPLE RETURN & HARDWARE ACCELERATION

Introduction – Sample Fetch Rover

- Retrieving sample caches left behind by NASA's Mars2020
- Moving longer distances at greater velocity with less ground intervention
- Longer operational day



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Challenges – Sample Fetch Rover

- Higher frame frequency (1Hz)
- Longer days in more difficult light conditions
- Less consistent shutter speeds
- Even lower power usage
- 1% Accuracy

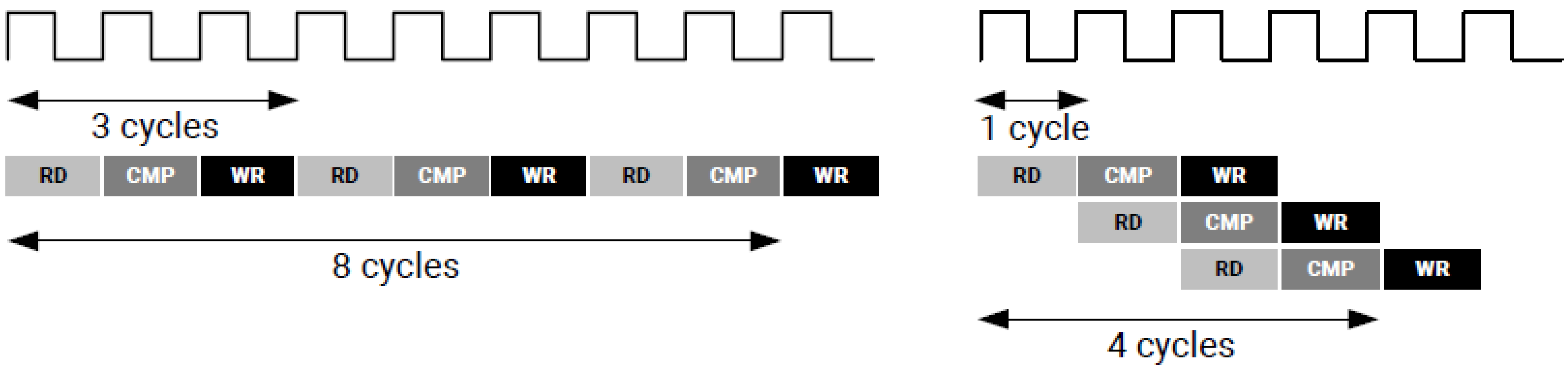
vs

- Using a faster LEON4 processor (~250MHz)
- Roughly consistent inter-frame distance

Acceleration - Hardware

FPGA based hardware acceleration:

- Reduces execution time
- Allows for parallel computation and pipelining

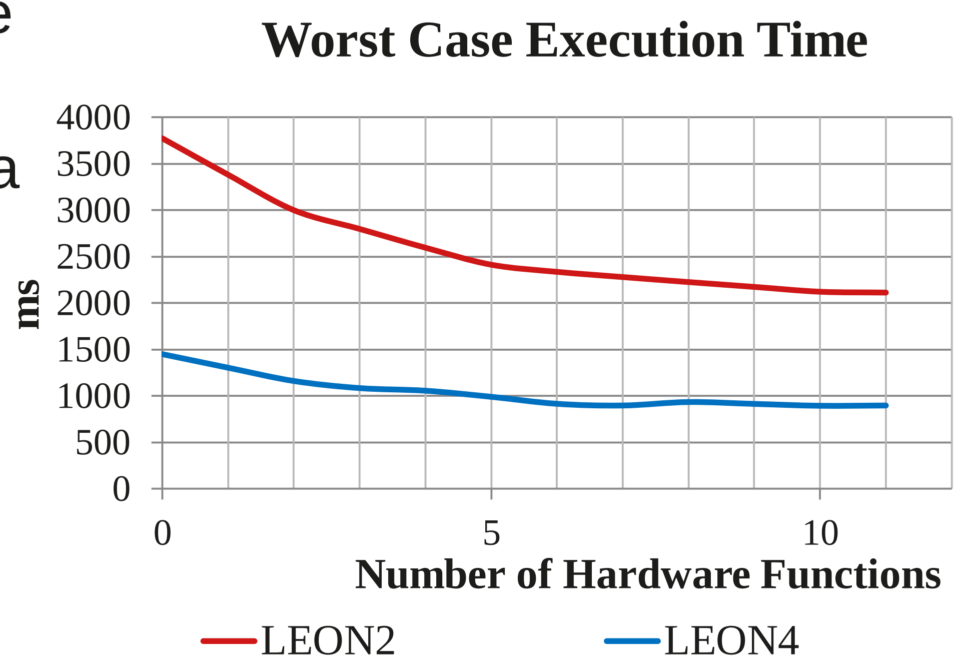


(A) Without Loop Pipelining (B) With Loop Pipelining

Source: Xilinx

Acceleration - Hardware

- Few software modules require the majority of execution time
- Hardware can save as much as 99% of execution time of a module
- Avg reduction of 88% on LEON2, 71% on LEON4
- Overall runtime reduction of 44% on a LEON2 with 11 hardware modules



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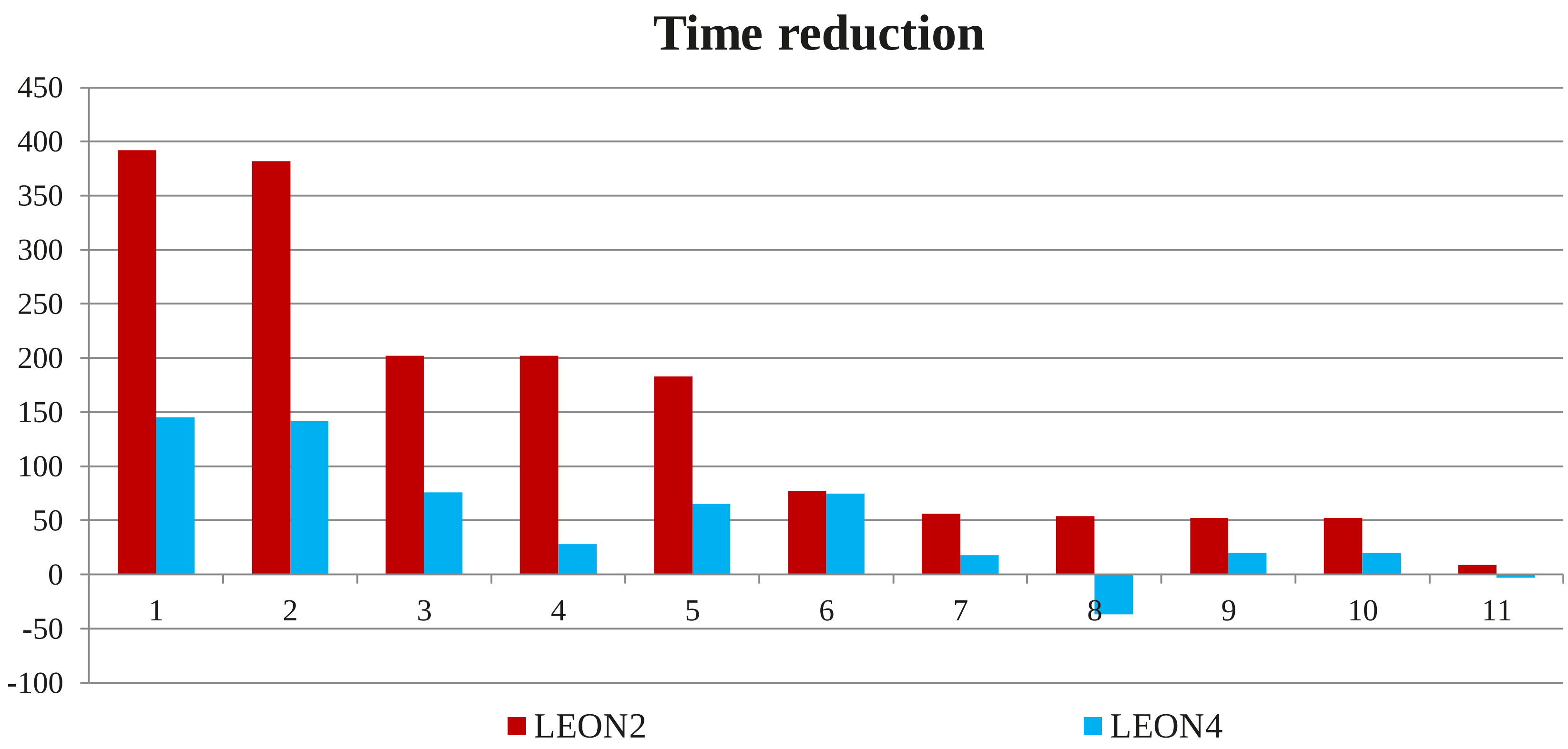
Acceleration – Hardware Suitability



- Main slowing factors:
  - » Dependencies
  - » Sequential Logic
  - » Data streaming interfaces
- Faster CPU reduces time gained

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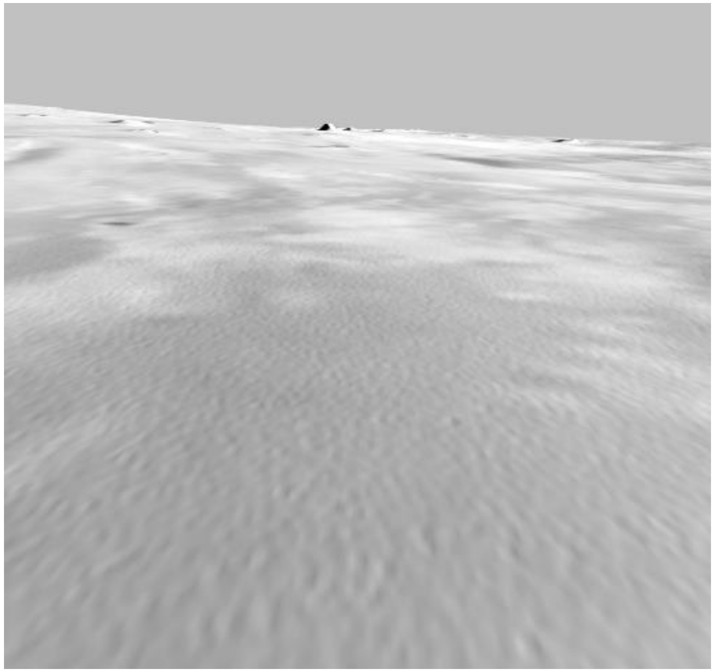
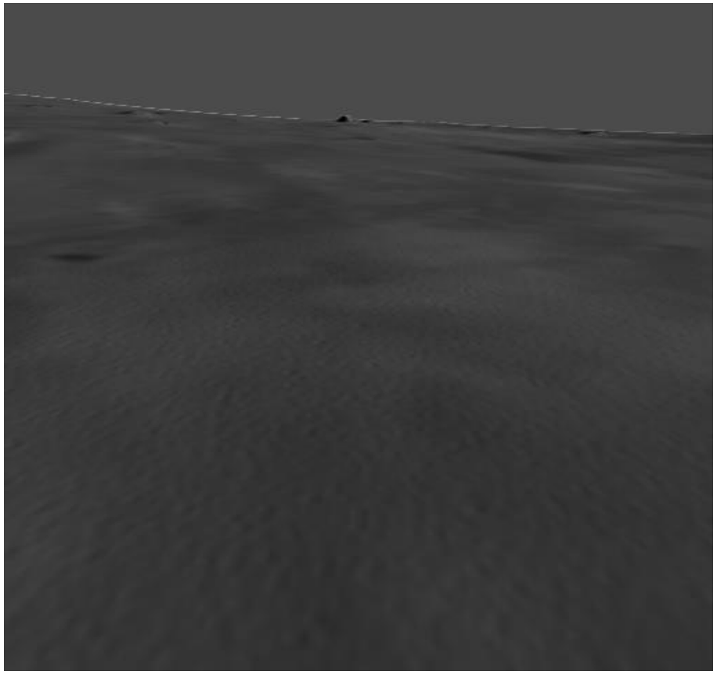
Acceleration – Hardware Testing

- Hardware accelerated version was validated using the same trajectories in comparative tests
- Hardware implementation retains full bit parity
- Tested under extreme conditions



Simulated image at shutter speed 150ms



Simulated image at optical depth 2.6

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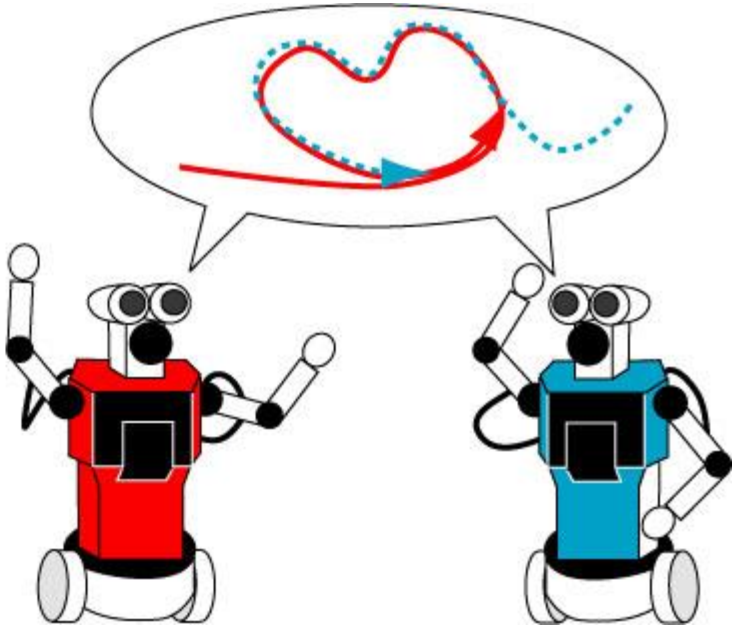
FUTURE APPLICATIONS

Future – VisLoc's Potential

Highly accurate real time self localisation for planetary exploration enables

- Covering of larger distances at potentially higher velocities
- Autonomous surveying of difficult terrain
- Reduction of required human input
- Robot to robot collaboration



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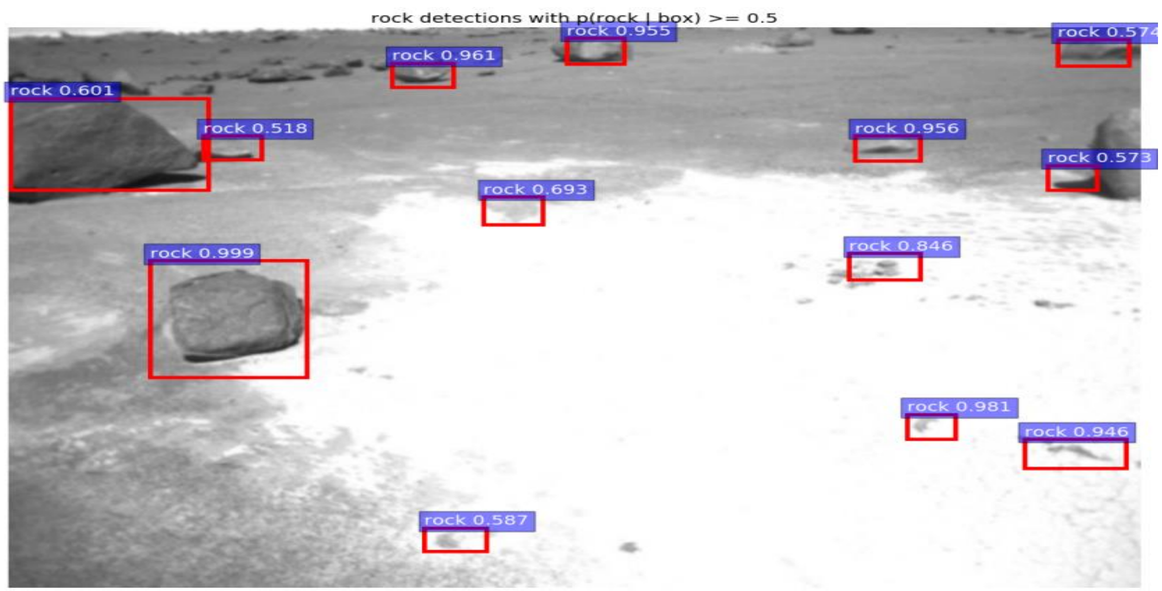
Future – FPGA's Potential

- Hardware acceleration could facilitate
  - Intelligent, real time environment interaction
  - Serendipitous scientific operations
  - On board data filtering and processing to reduce downlink utilisation



SEEKER Data, Deep-learning for detection

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Conclusion

VisLoc has a bright future:

- High TRL 8 – TRL 9 if ExoMars successful in 2020
- Can be configured for a wide range of missions in a wide range of environments
- Bread boarding for MSR on flight representative hardware is currently ongoing

FPGA Acceleration has a range of applications in space:

- Visual Odometry & Navigation
- Object identification & Novelty detection
- Agile on-board science

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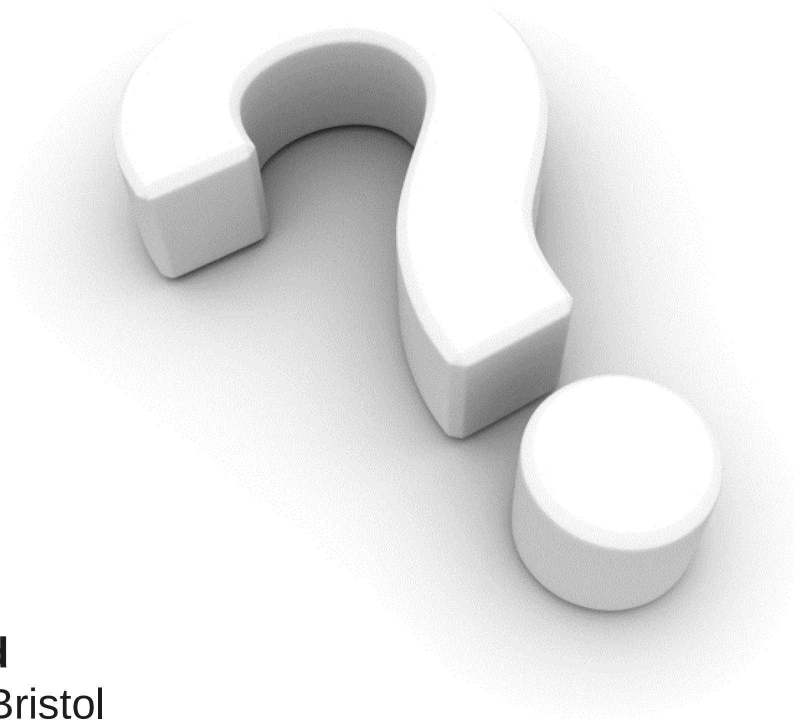
Thank You for your Attention - Any Questions?



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