Robust pipeline localization for an AUV using stereo vision and echo sounder data

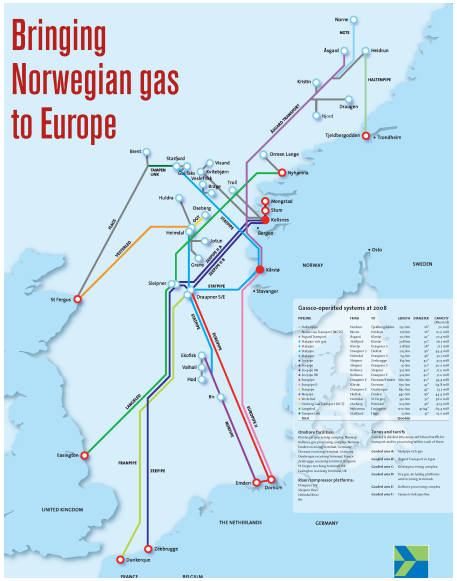
Gøril M. Breivik*, Sigurd A. Fjerdingen, Øystein Skotheim

SINTEF, Norway

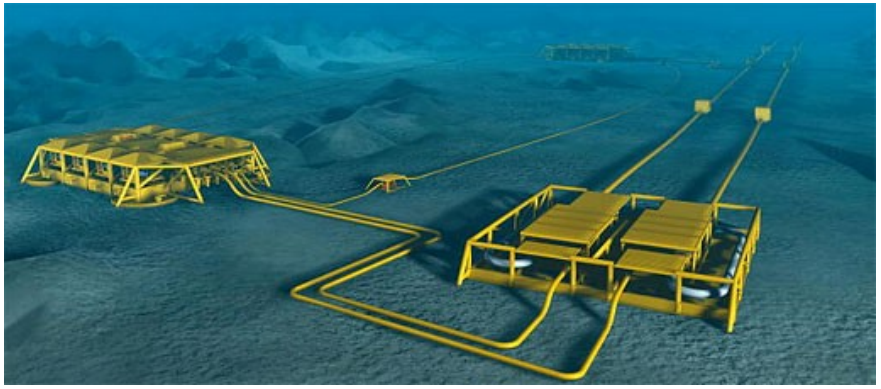
*gbre@sintef.no

Submarine pipeline shutdowns are costly

- Submarine pipelines
  - important network for oil/gas
  - connect offshore to onshore
- Example:
  - Gas field Ormen Lange meets 20 percent of UK's gas requirements
  - Pipeline Langeled of length 1,200 km connects the gas field to UK
- Pipes need to be inspected:
  - processing stops are costly and should be avoided
  - environmental harm should be prevented



www.gassco.no



www.hydro.com

Inspection can reveal pipe defects

- Possible pipeline defects:
  - corrosion
  - cracking
  - stress
  - bending
  - denting
  - movements
  - free spans
  - partial burial of the pipe

www.jee.co.uk

www.neptunems.com

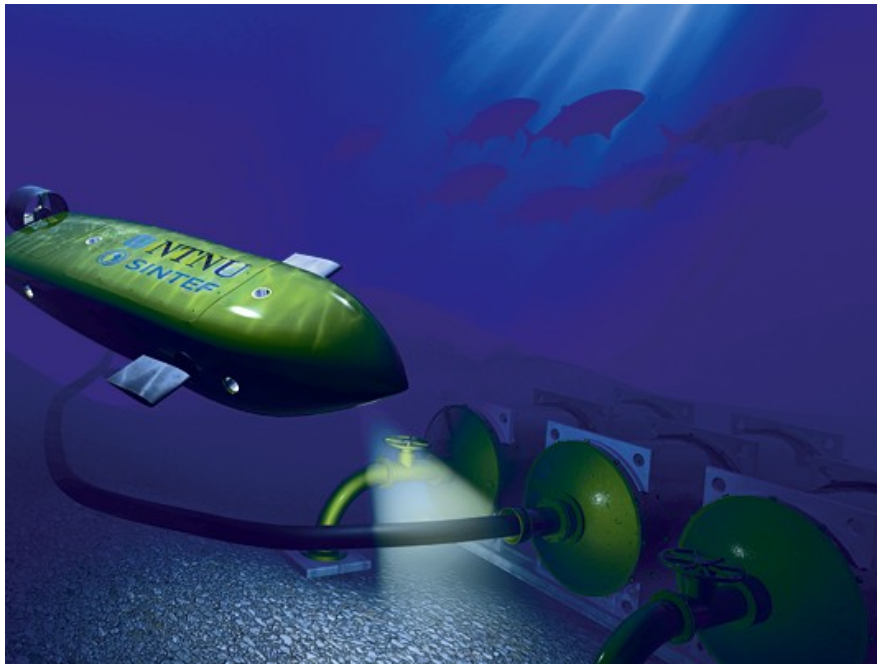
Submarine pipe inspection is cost and time consuming

- Inspection using remotely operated vehicles (ROV)
  - includes a manned support vessel
  - limited operating range
  - limited weather conditions
  - relatively slow speed

www.km.kongsberg.com

AUV is the solution to many cost issues

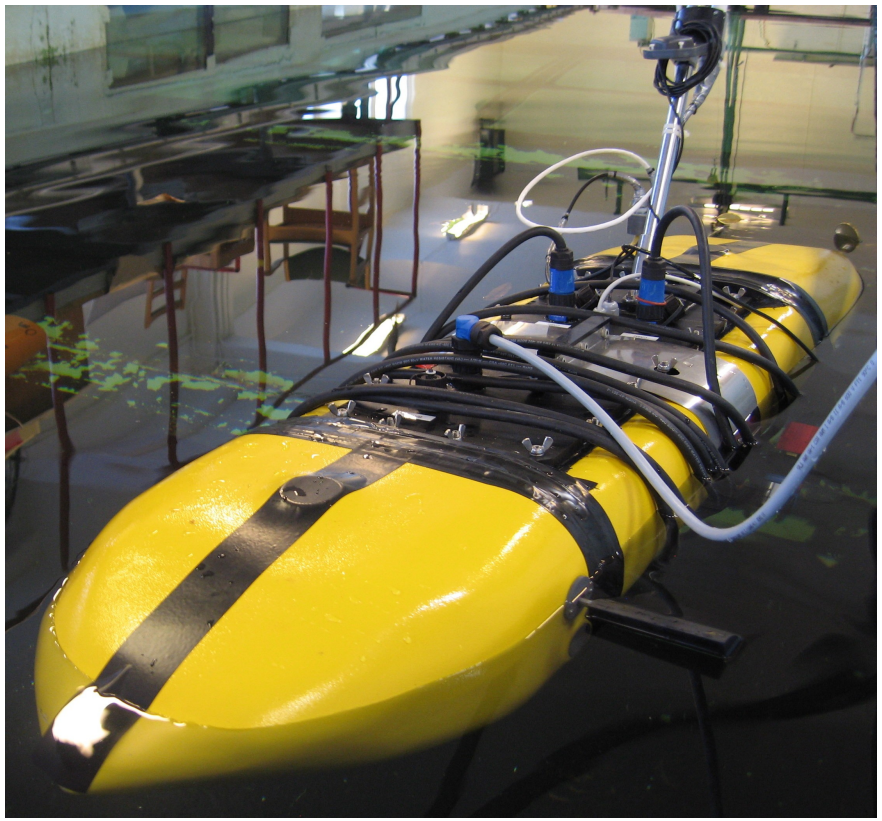
- Autonomous underwater vehicles (AUV):
  - unmanned
  - untethered
  - no support vessel
  - operate autonomously



www.ntnu.no/gemini/

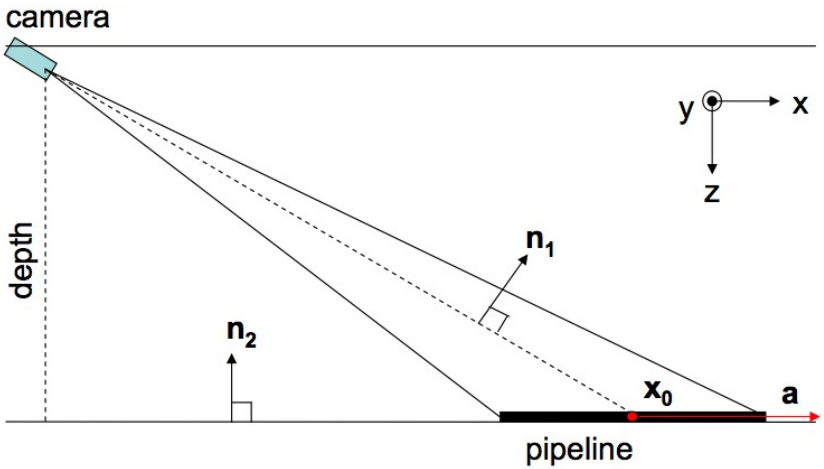
Pipeline tracking is essential to AUVs

- SINTEFs AUV
  - developed for research
  - several sensors:
    - two underwater cameras
    - echo sounder
    - sonar
    - IMU
    - GPS (for use in surface)
- Autonomous navigation:
  - how to localize pipeline relative to AUV?
  - how to robustly track pipeline position?

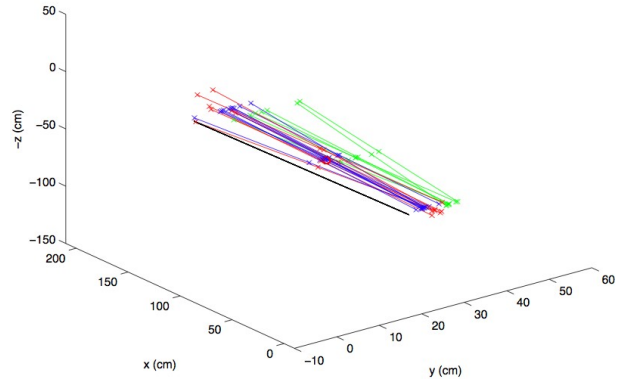


Three sensors ensure more continuous pipeline tracking in 3D

- Two sensor combinations:
  - one camera and echo sounder
  - stereo camera
- Recordings show that:
  - accuracy is equal for both sensor combinations
  - accuracy is good enough for our needs
  - using both combinations ensures more continuous pipe localization over time



Estimated pipe position in 3D



Outline

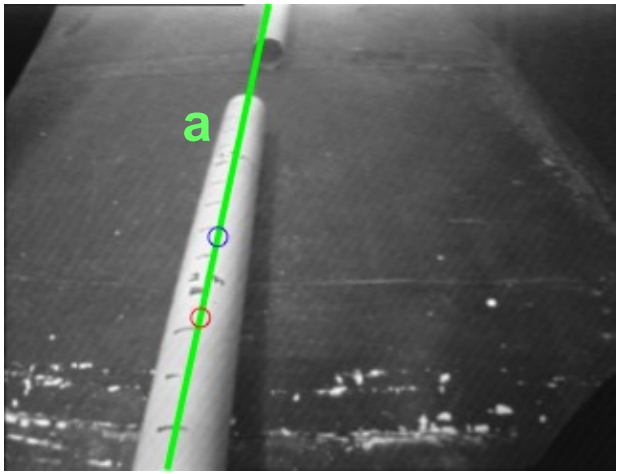
- 3D localization using one camera and echo sounder
- 3D localization using stereo cameras
- Experiments and results
- Conclusions

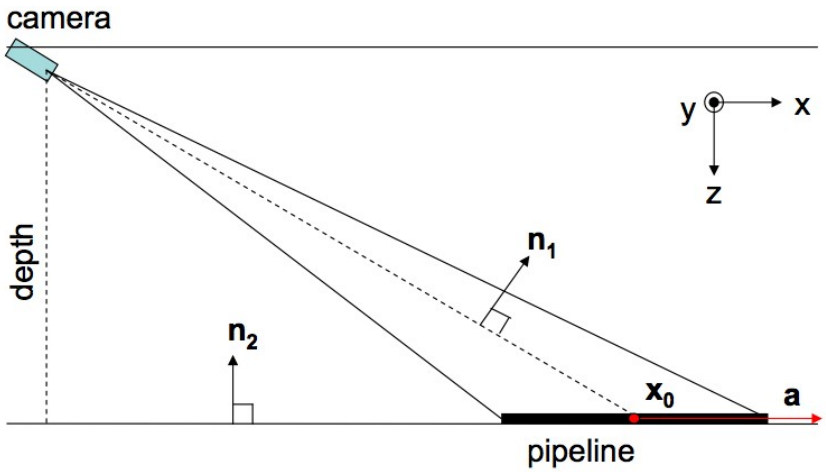
Outline

- 3D localization using one camera and echo sounder
- 3D localization using stereo cameras
- Experiments and results
- Conclusions

3D pipe position found using one camera

- Principle of algorithm:
  - pipe is a line in camera image
  - this line spans a plane in 3D when seen from the camera
  - sea floor is a second plane in 3D, given by depth measurements from the echo sounder
  - pipe position is found as the intersection line of the two planes in 3D
- Assumption:
  - the sea floor is assumed horizontal in the area of interest



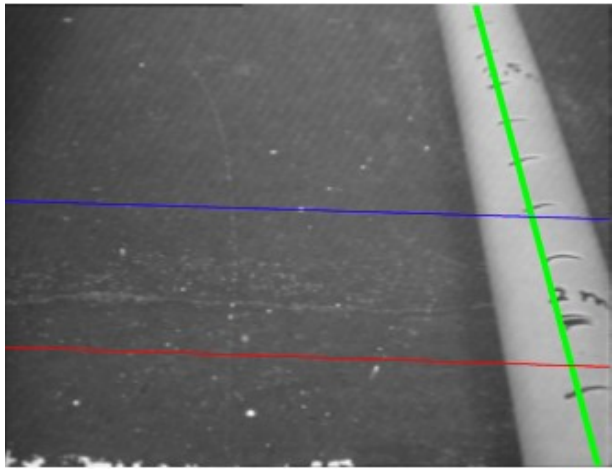


Outline

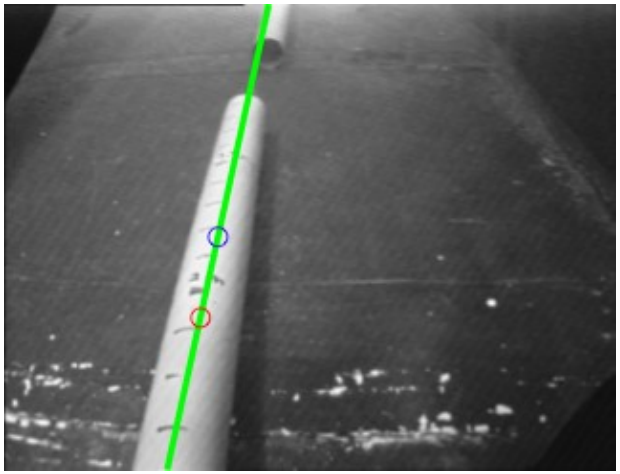
- 3D localization using one camera and echo sounder
- 3D localization using stereo cameras
- Experiments and results
- Conclusions

Epipolar lines give point pairs for stereo triangulation

left camera



right camera



- Principle of algorithm:
  - points correspond to epipolar lines
  - pick two points on pipe in right image (o and o)
  - epipolar lines (- and -) cross pipe in corresponding points
  - conventional stereo triangulation is used to find position in 3D
  - pipe position is defined as a straight line through the two 3D points

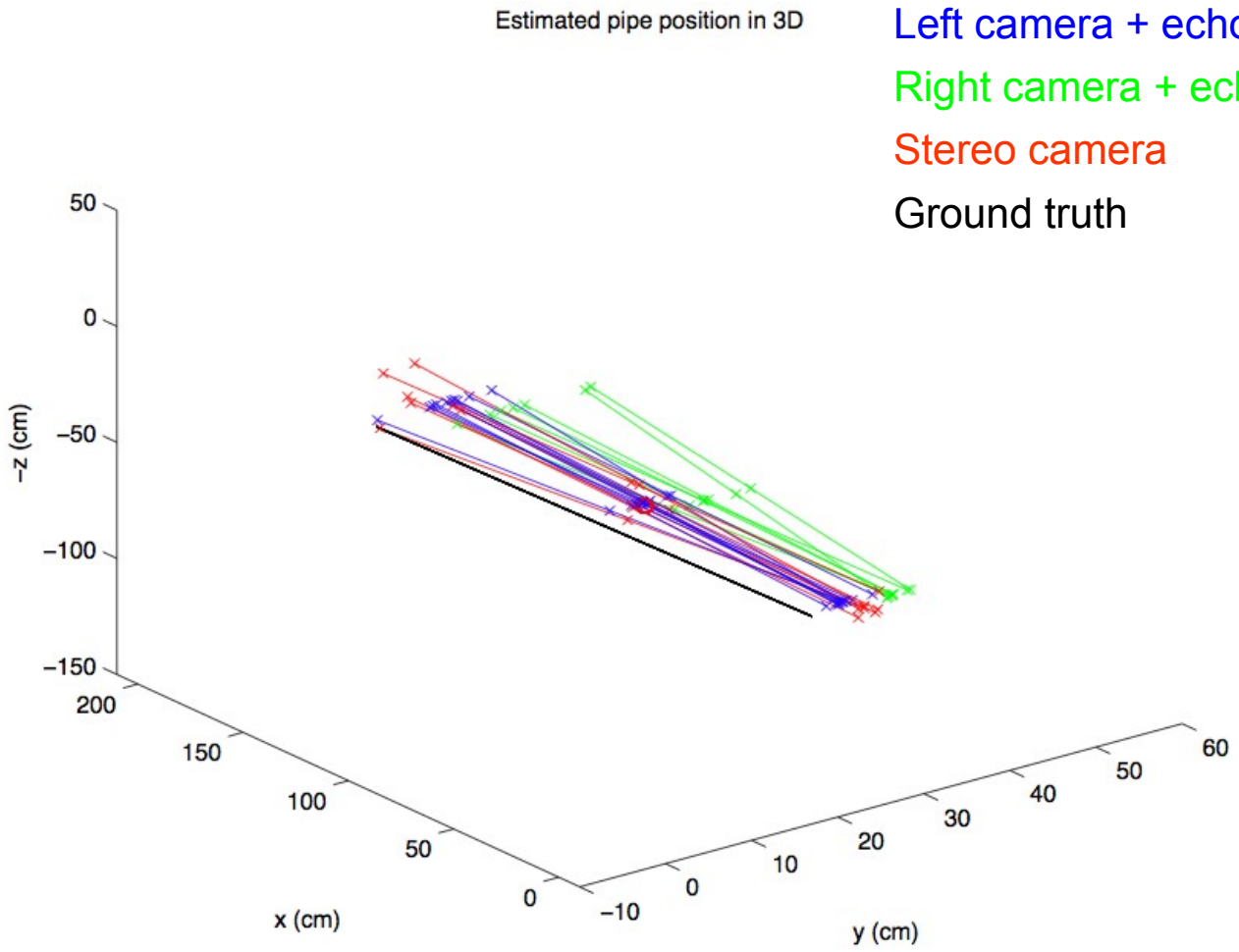
Outline

- 3D localization using one camera and echo sounder
- 3D localization using stereo cameras
- Experiments and results
- Conclusions

Pool experiments enable ground truth comparison

- Experiments from a pool
  - AUV kept stable in four positions relative to pipe
  - Sensor data recorded
  - Ground truth measured using a tape measure
- Three sensor combinations give three pipe positions:
  - Left camera + echo sounder
  - Right camera + echo sounder
  - Stereo camera

Estimated pipe positions lie close to ground truth



Left camera + echo sounder

Right camera + echo sounder

Stereo camera

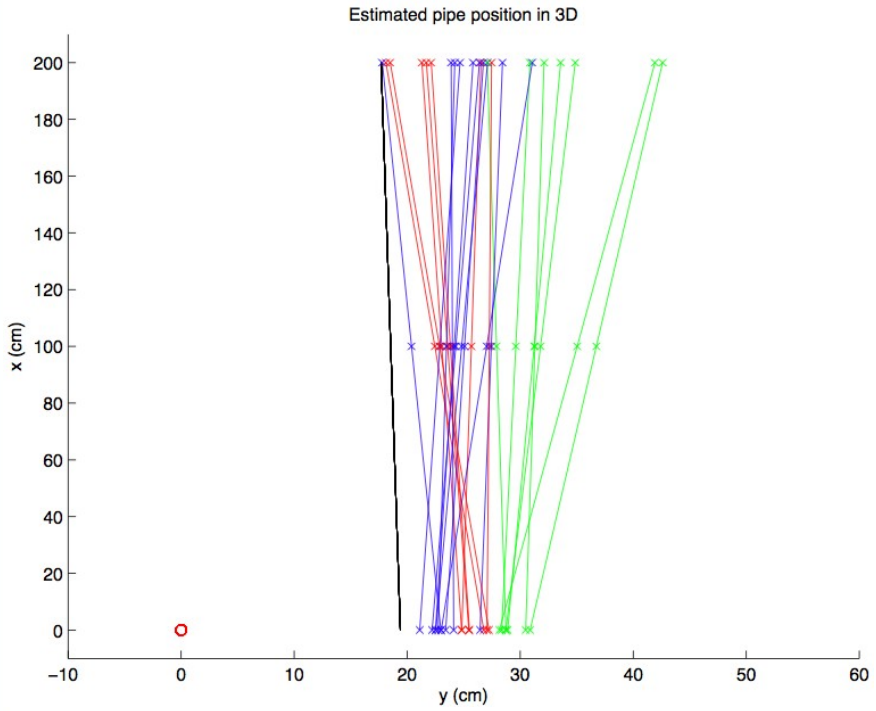
Ground truth

AUV (o)

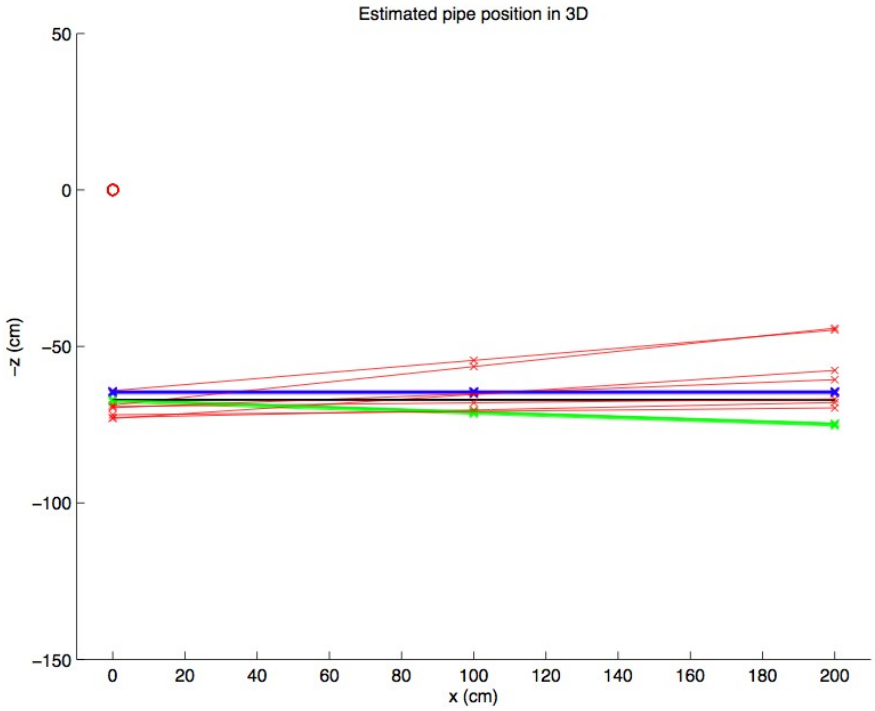
Pipe at 1 m depth, 20 cm right

Echo sounder approach gives pure horizontal pipe positions

Left camera + echo sounder
Right camera + echo sounder
Stereo camera
Ground truth
AUV in origin (o)



view from above



view from the side

Outline

- 3D localization using one camera and echo sounder
- 3D localization using stereo cameras
- Experiments and results
- Conclusions

Conclusions

- Equal accuracy for both algorithms:
  - mean: 8-17 cm (position) and 1°-3° (angle)
  - standard deviation: 3-16 cm (position) and 0°-9° (angle)
  - good enough for our needs
- More robust pipe tracking using both algorithms:
  - Echo sounder performs 2x better than stereo (true positives)
  - Stereo camera assumes pipe segmentation from two images
  - Echo sounder assumes horizontal sea floor

Final comments

- Measuring ground truth is challenging
- Adjusting for vehicle movement using intertial measurement unit data can improve results

Thank you!

www.sintef.com/omd