

Real-time stereo visual SLAM for autonomous underwater vehicles

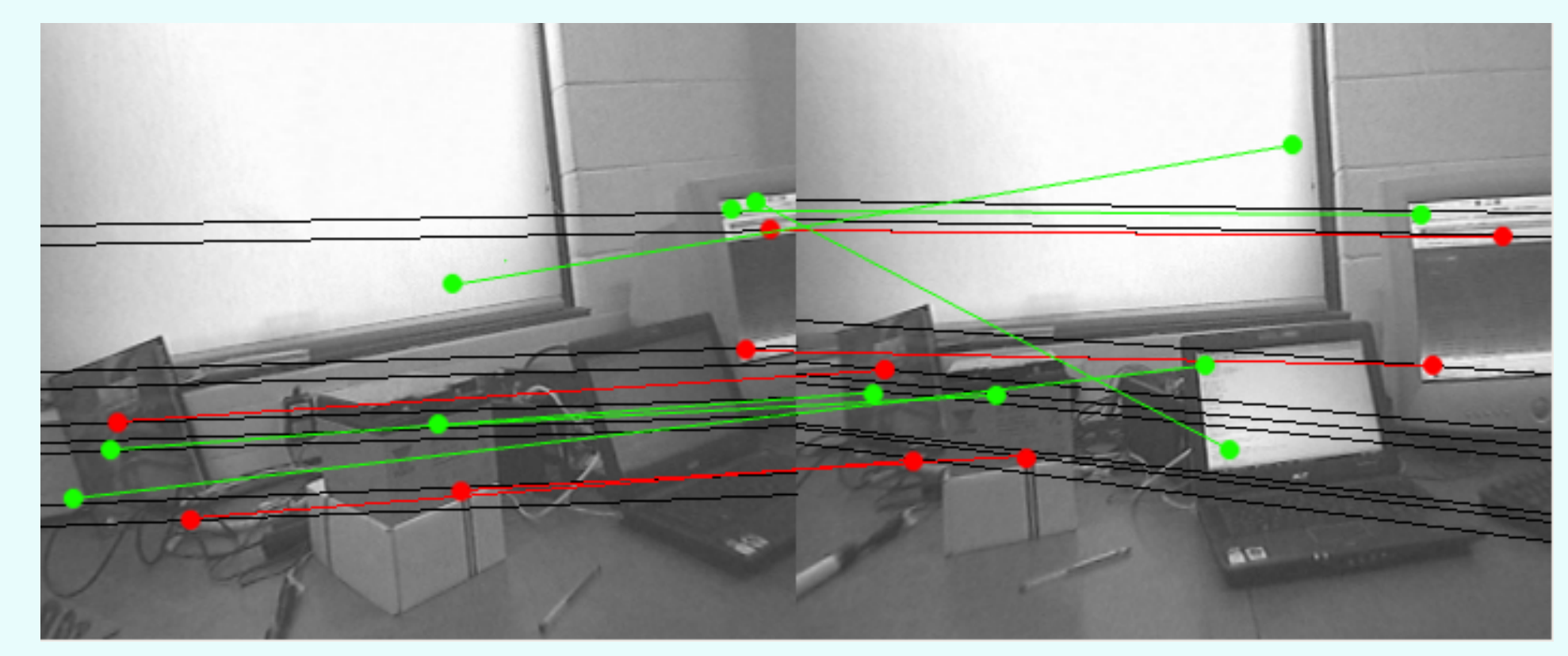
Introduction

Simultaneous localisation and mapping (SLAM) is an approach to localisation in which a vehicle incrementally constructs a map of its environment and simultaneously localises itself within this map. SLAM is necessary to bound localisation uncertainty in cases where satellite-based GPS is unavailable due to intentional blocking or natural attenuation of the signals. Visual SLAM systems are increasing in popularity as they are passive, cheap, light-weight, low power and have a long range, high resolution, excellent object recognition capabilities and can also provide visual odometry.

Contributions

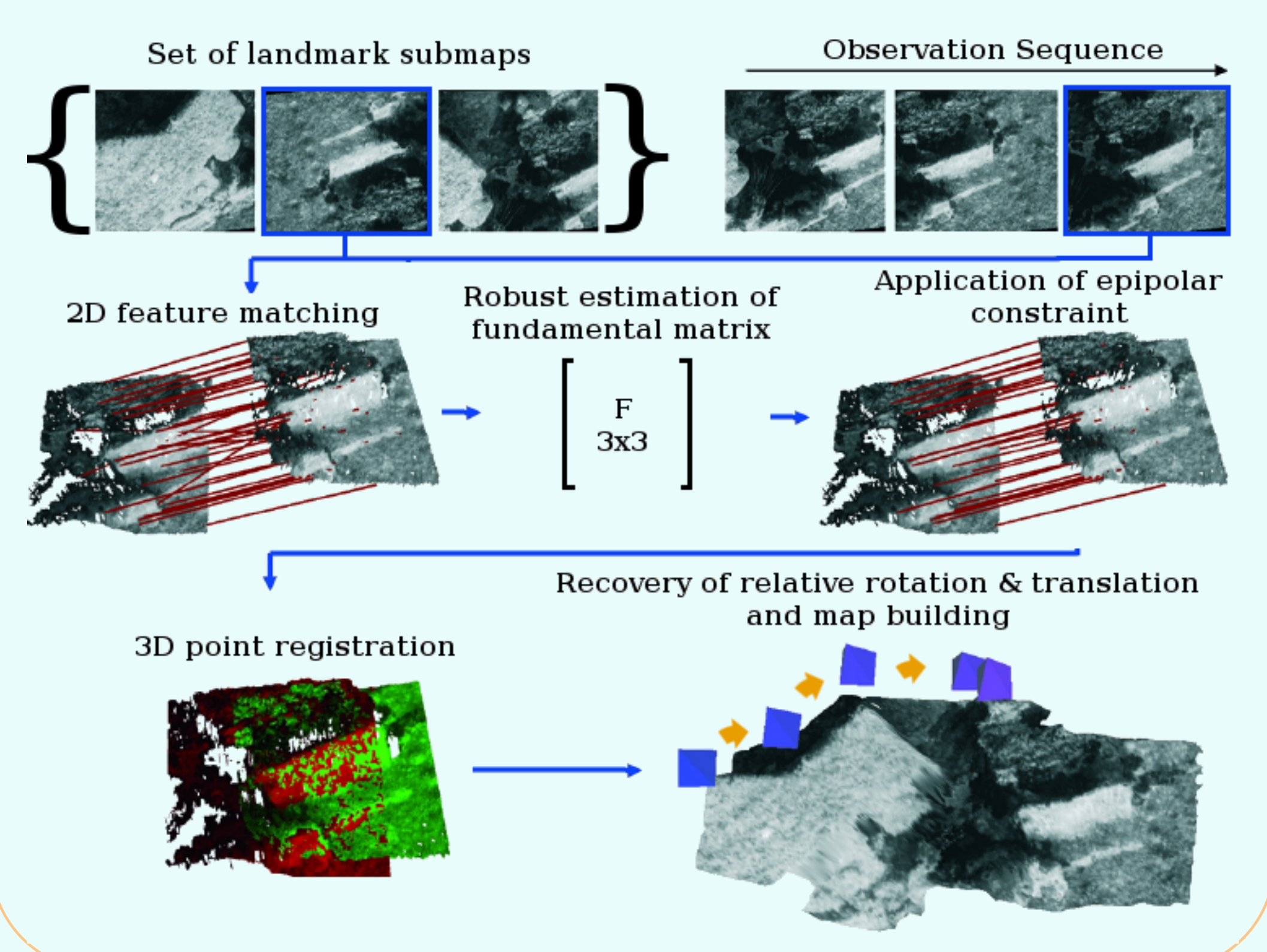
A visual SLAM system has been implemented and optimised for real-time deployment on an AUV. This system incorporates a novel approach to landmark description in which landmarks are submaps that consist of a cloud of 3D points and their SIFT/SURF descriptors. Landmarks are also sparsely distributed which simplifies and accelerates data association and map updates. In addition to landmark-based localisation the system performs visual odometry and predicts vehicle motion using a constant-velocity model. Both the extended Kalman filter (EKF) and unscented Kalman filter (UKF) have been implemented and their performance compared. This system represents an important contribution to 6DoF visual SLAM as it has the potential to operate in real-time as has comparable performance to existing implementations.

Step 1 - Landmark Observation

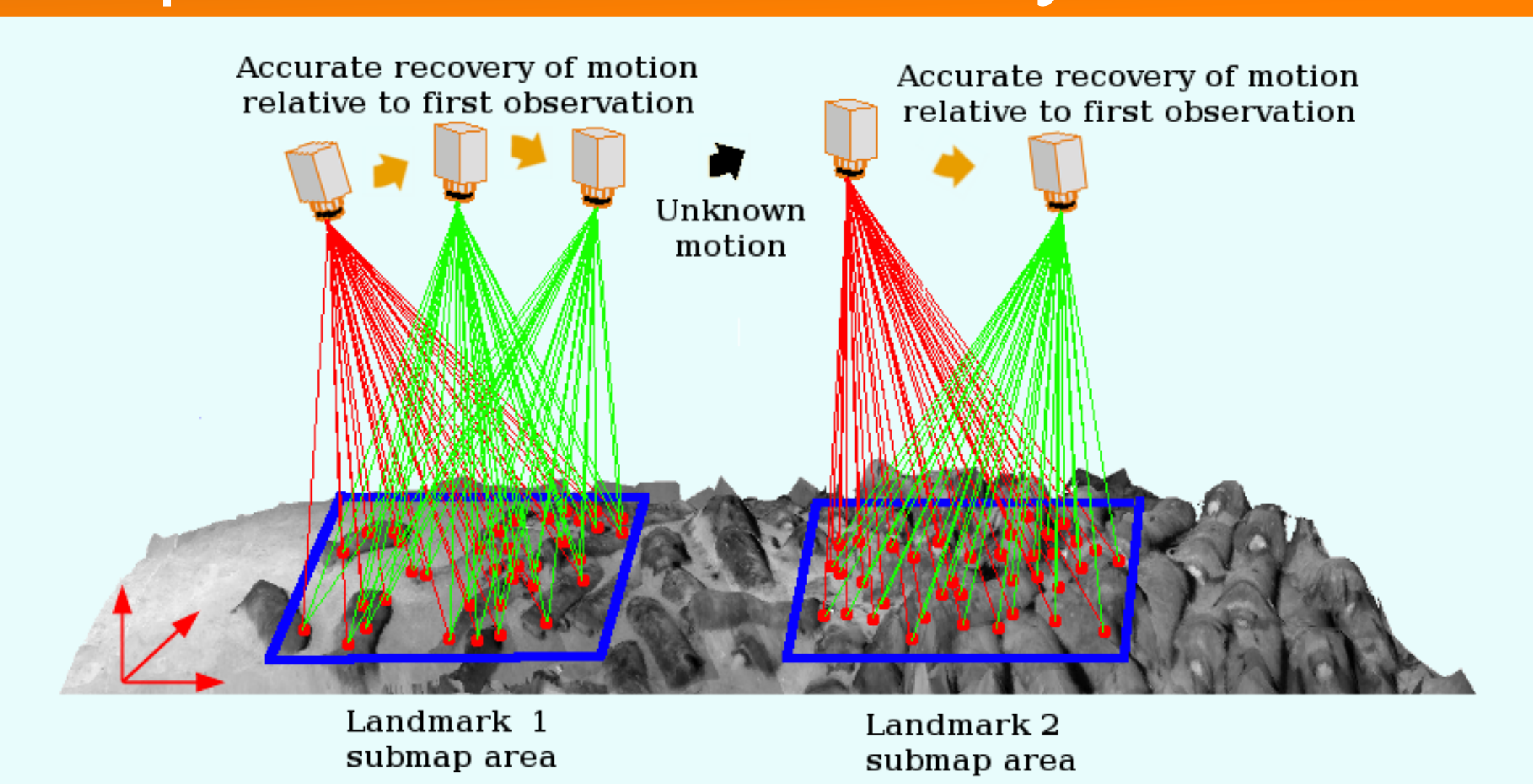


- Find Hessian/Gaussian scale-space maxima
- Generate SURF/SIFT feature descriptors
- Match descriptors using SSD and Gated NN
- Apply epipolar constraint to remove outliers
- Perform triangulation to recover depth
- Landmark = submap of 3D points + descriptors

Step 2 - Landmark Matching

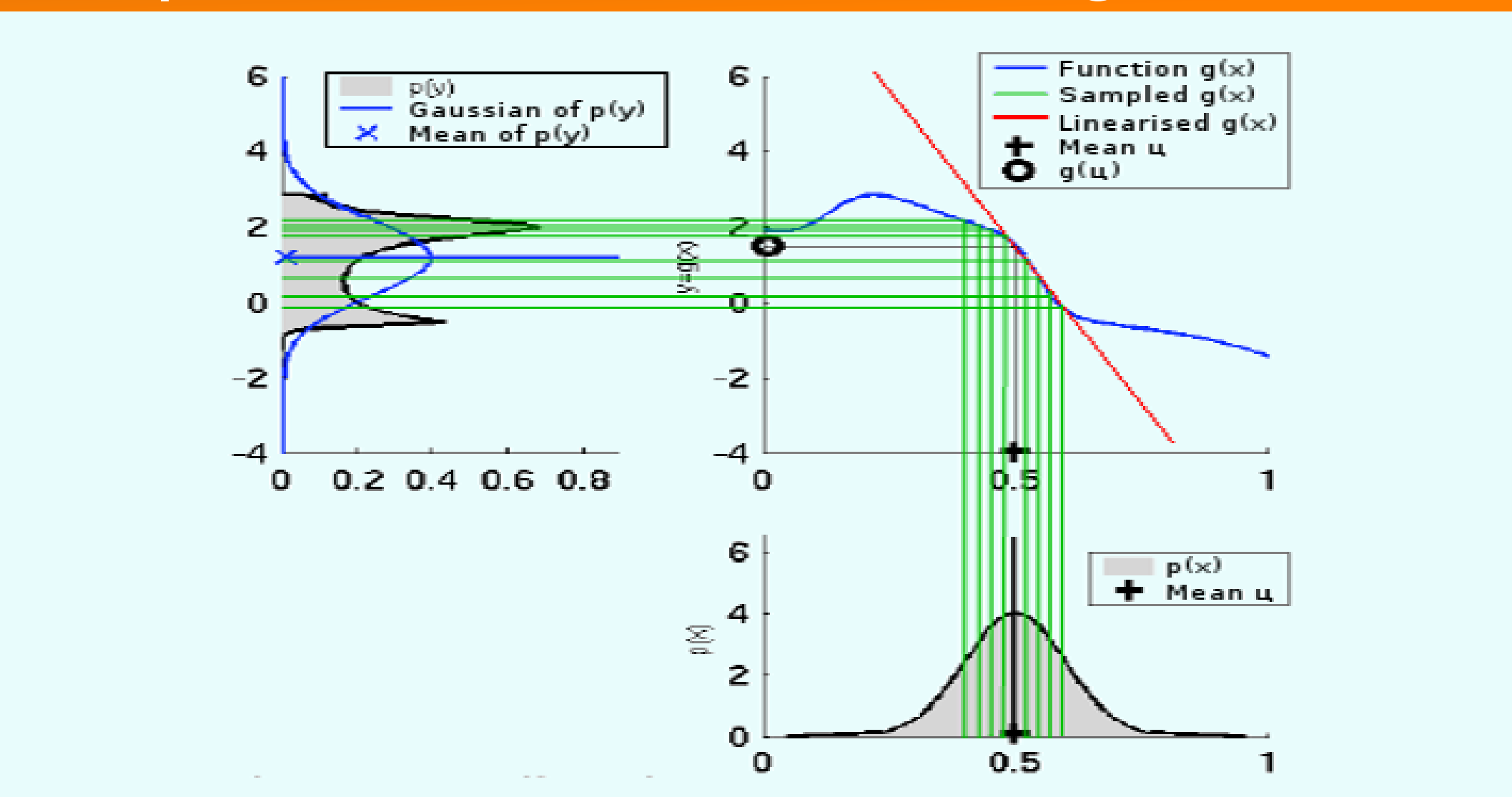


Step 3 - Visual Odometry



- Motion from registration or essential matrix
- If new/no landmark then motion is unknown
- Currently resort to using predicted state
- Future: overlap landmarks + active navigation

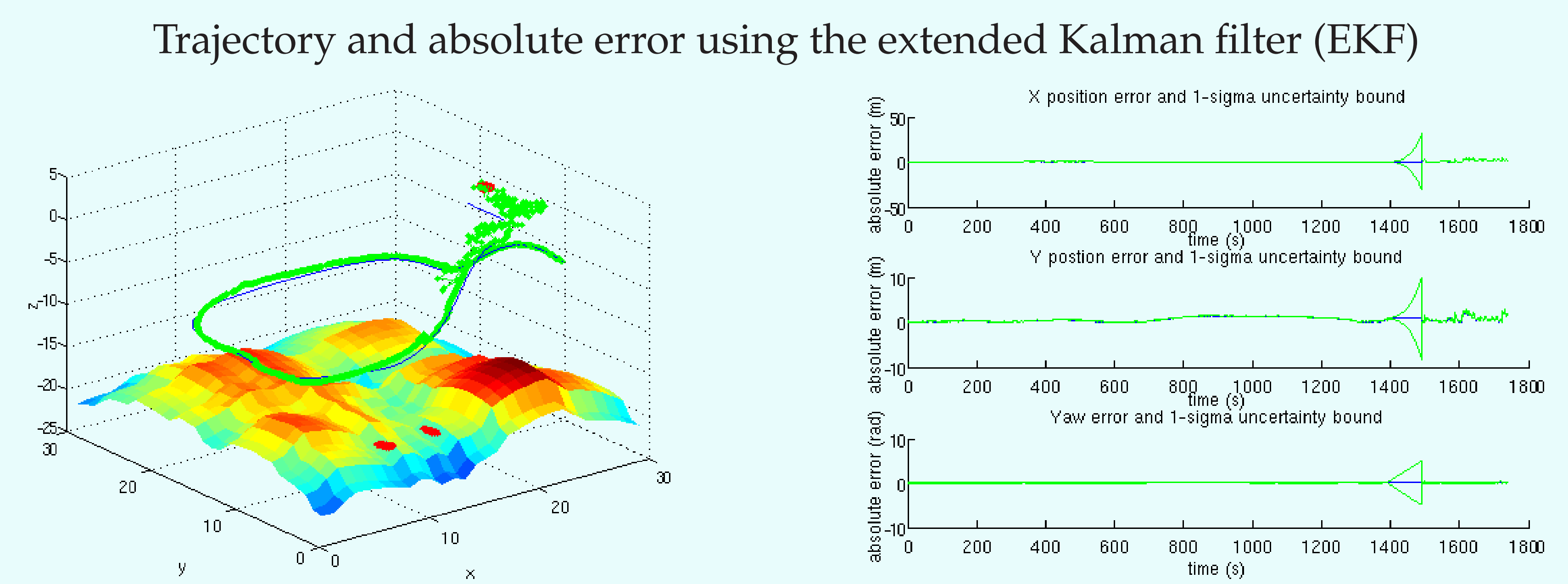
Step 4 - EKF/UKF Filtering



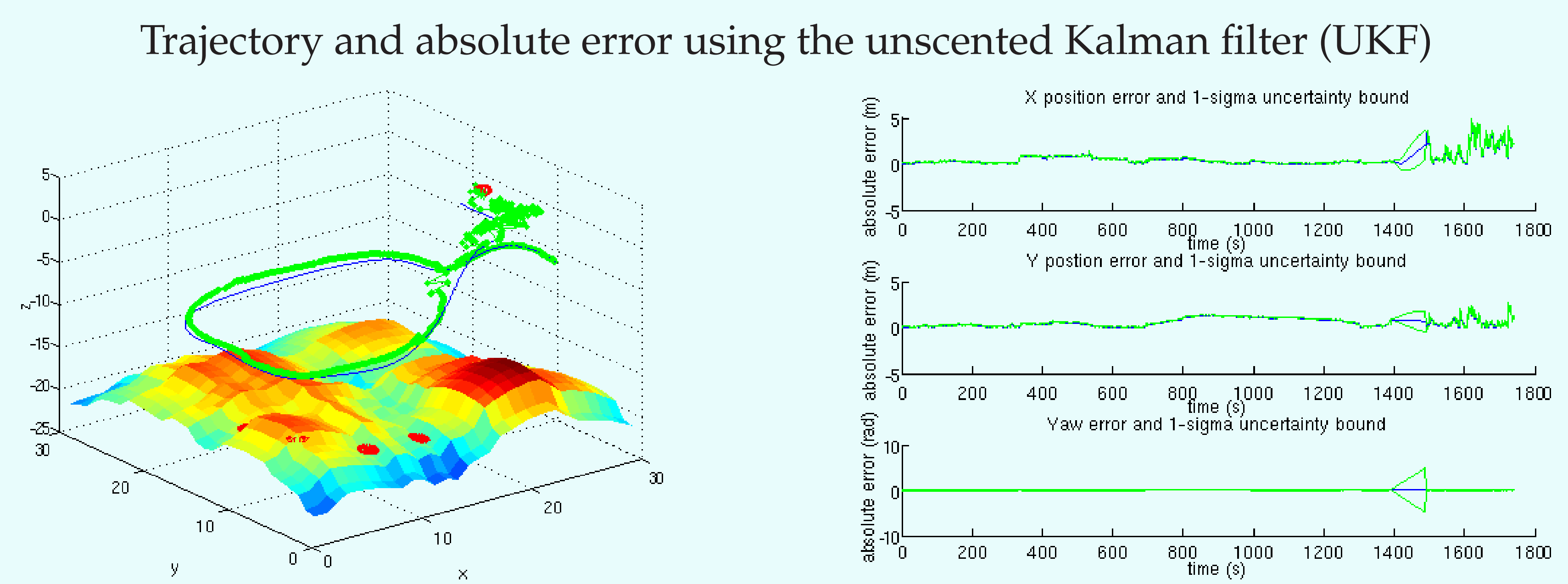
- Prediction using constant velocity model
- Augmented state prediction/landmark addition
- Quadratic complexity landmark re-observation
- Check for ill-conditioned matrices etc.

Results

A simulator was developed and system performance was evaluated using a 30x30x30m environment which has randomly distributed features with a uniform density of 50/m² with the exception of a 5x5m section. The results below are presented for a 87m loop trajectory with roll turbulence, observations at 0.05m intervals and Gaussian noise with $\sigma = 0.2\text{pix}$ added to stereo and landmark correspondences.



The mean squared position error for the EKF and UKF were 1.90 and 2.22 respectively. For the EKF the maximum absolute error in the roll, pitch and yaw angles were 27.4°, 16.0° and 14.9° respectively, and for the UKF the errors were 26.9°, 15.2° and 12.8° respectively. The EKF execution time was 79.4s for the 1739 observations, giving an average of 45.7ms per observation (worst-case time of 1012ms). In comparison, the UKF execution time was 118.0s, giving an average of 67.8ms per observation (worst-case time of 1071ms). While traversing the loop the EKF added 12 landmarks to the filter whereas the UKF added 13.



In summary, the EKF and UKF can handle noise with $\sigma \leq 0.25\text{pix}$ and $\sigma \leq 0.225\text{pix}$ respectively before the maximum absolute localisation error is greater than 7% of the distance travelled. With $\sigma = 0.1$ the EKF and UKF can handle up to 12.5% and 0% of outliers respectively. The EKF outperforms the UKF with respect to localisation accuracy, number of landmarks, execution time and stability. The worst-case update time is due to memory allocation when expanding the covariance matrix. Visual odometry prevents the localisation uncertainty growing while exploring, but odometry gaps result in overconfident estimates.

Conclusions

- Implemented an entirely vision-based 6DoF SLAM system for an AUV
- Based on EKF + novel approach to landmark description, data association and visual odometry
- Comparable performance to existing implementations and has potential for real-time operation