LARGE SCALE DEMINING AND RELEVANT TECHNOLOGIES AT PUT

Presenter: Piotr Skrzypczyński

March 2024

Centre for Artificial Intelligence
and Cybersecurity
Poznan University of Technology, Poland

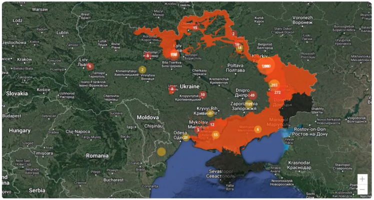
IRIM

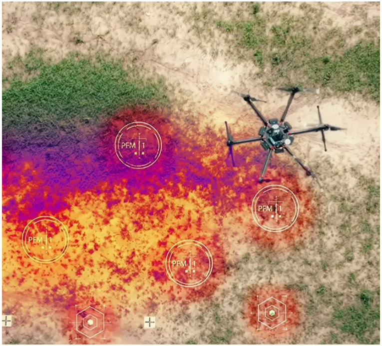
POZNAN UNIVERSITY OF TECHNOLOGY

LARGE SCALE DEMINING

DEMINING OF LARGE-SCALE AREAS

- Easy to use and low cost solutions for FAST nad RELIABLE demining.
- Mapping and localization of hazardous areas (areas of interest).
- Close-in detection of man-made objects.
- Supporting neutralization of anti-personal landmines and cluster munitions in an open and civil environment.
- Training solutions for personnel and tools for mine risk population education.





- The emergence of AI solutions (machine learning, data analysis) presents an opportunity to transform humanitarian demining by significantly improving its efficiency, speed, accuracy, and safety.
- Unstructured data about a Suspected Hazardous Area: satellite, aerial drone images or field reports.
- The integration of advanced data analysis techniques has the potential to revolutionize humanitarian demining by offering a more efficient, accurate, and safer alternative to traditional methods.

EARTH OBSERVATION AND REMOTE SENSING

EARTH OBSERVATION

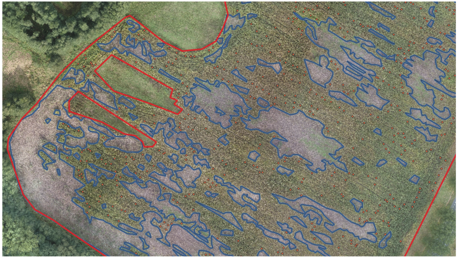
Aerial and satellite imagery land cover segmentation and object detection (M. Kraft)

- Custom earth cover segmentation covering multiple classes (crops, woods, water bodies, urban areas, buildings, roads, etc.)
- Detection of objects in aerial and satellite images
- Easily adjustable for other classes and objects, multispectral imaging, runs on embedded, on-board hardware
- Suite of QGIS-compatible tools for visualization, training, etc.,

Sample land cover segmentation and object detection results

Automated crop damage assessment (M. Kraft)

- Based on RGB images collected autonomously using a UAV
- Focused on wildlife-induced damage, can be easily modified for other purposes
- Accurate assessment might be used for insurance, damage control, etc.



UAV and the processing results shown in the ortophotoimage

REMOTE SENSING (AERIAL)

Crowd counting and analytics (M. Kraft)

- Based on RGB videos collected autonomously using a UAV
- Can be easily modified to different targets (e.g. farm animals) and modalities (e.g. to include thermal imaging data)
- Tested on embedded hardware, on-board processing capability

Sample crowd count and individual person locations, sample pedestrian trajectories

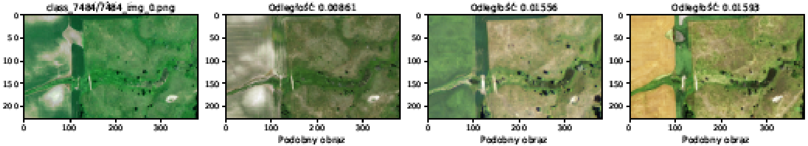
Place recognition for aerial images (M. Kraft)

- Deep learning-based visual navigation support for any aerial vehicle
- Fallback option in case of GPS/GNSS spoofing/jamming/other malfunction

Same places recognized despite significant appearance changes

Aerial imagery for detection and recognition in agriculture (M. Kraft)

- Localization of drones in GPS-denied scenarios
- Recognition of changes (e.g. diseases) in crop, forests, etc.
- Detection and localization of illegal garbage dumping



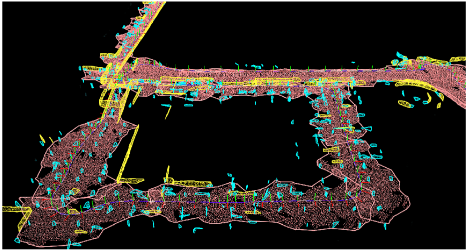
Recognition of aerial images over time and different seasons

M. Kraft, M. Piechocki, B. Ptak, K. Walas, “Autonomous, Onboard Vision-Based Trash and Litter Detection in Low Altitude Aerial Images Collected by an Unmanned Aerial Vehicle,” Remote Sensing, 13(5), p. 965, Mar. 2021

NAVIGATION AND MAPPING

SLAM for autonomous vehicles (P. Skrzypczynski)

- LiDAR-based SLAM system for automotive application
- A ROS-based DGPS/RTK localization solution
- Multi-sensory calibration (cameras, 3D laser scanner, AHRS, DGPS)

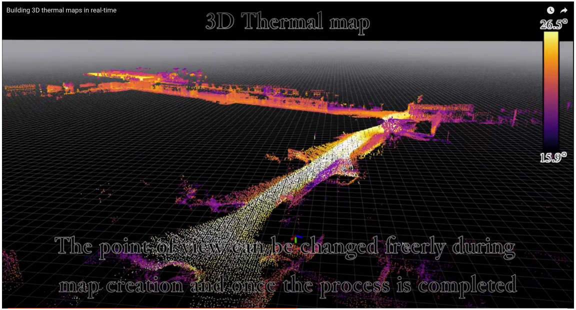


Test vehicles and a feature-based map of an underground car park

3D THERMAL MAPS

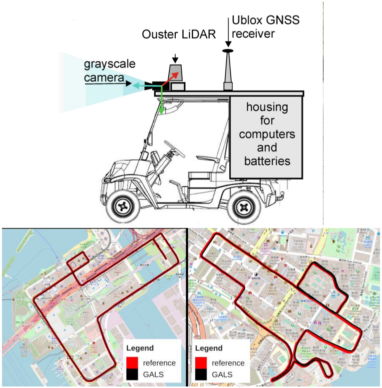
Building 3D thermal maps in real-time (M. Nowicki)

- 3D maps build using 3D LiDAR
- 3D LiDAR-thermal camera calibrated sensory stack
- Each map point annotated with a temperate
- youtube video



3D thermal map created in real-time

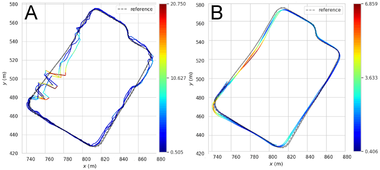
GNSS-augmented navigation (P. Skrzypczynski)



- Low-level understanding of GPS measurements.
- GPS fusion with LiDAR/visual odometry to improve accuracy.
- Localization implemented using factor graph framework and efficient optimization.
- Applications in autonomous vehicles, ADAS and precision/robotic agriculture.

K. Ćwian, M. R. Nowicki, P. Skrzypczynski, ”GNSS-Augmented LiDAR SLAM for Accurate Vehicle Localization in Large Scale Urban Environments”, 17th International Conference on Control, Automation, Robotics and Vision (ICARCV), Singapore, 2022

AUTONOMY IN THE (ROUGH) FIELD



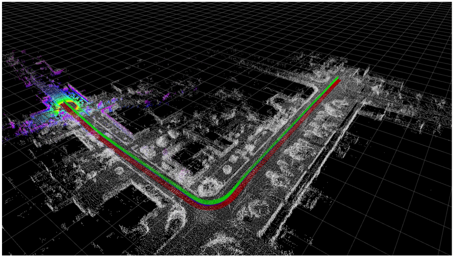
- Cooperation with Lukasiewicz-PIT (P. Skrzypczynski)
- Field robot for sowing and tending wide-row crops.
- Research aimed at turning this robot into a fully autonomous machine.
- GNSS-aided visual SLAM and machine learning applied in precision agriculture.

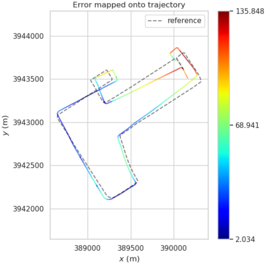
P. Skrzypczynski,K. Ćwian, “Localization of agricultural robots: challenges, solutions, and a new approach”, Automation 2023: Key Challenges in Automation, Robotics and Measurement Techniques. LNNS, vol 630. Springer, 2023, 118–-128.

The purpose of the research was to develop a system that provides accurate localization of a robot in urban environment

Motivation:

- **SLAM** systems are prone to drift
- Existing 3D **SLAM** systems can fail when the environment is too challenging
- Highly urbanized areas are problematic to **GNSS** (Global Navigation Satellite Systems)





Map and trajectory output of a 3D LiDAR SLAM (left), exemplary error of SLAM trajectory (right)

APPROACH TO INTEGRATION

Our **approach** is to perform integration of **SLAM** and **raw GNSS** measurements using factor graph optimization:

- The integration of GNSS may limit the drift of LiDAR-based SLAM
- LiDAR SLAM works well in urban environment with high-rise buildings

Exemplary trajectory obtained using the proposed GALS (GNSS-Augmented Lidar SLAM) system

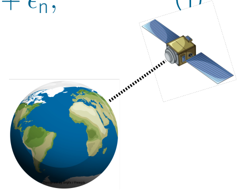
Main sensors used in our approach

GNSS LOCALIZATION

Raw GNSS measurements that we used in our system:

- **Pseudorange** - distance from the receiver antenna to the satellite calculated based on the signal travel time

$$p_n = \rho_n - (\delta_n^s - \delta_n^r) \cdot c + d_n^{ion} + d_n^{trop} + \epsilon_n^p, \qquad (1)$$



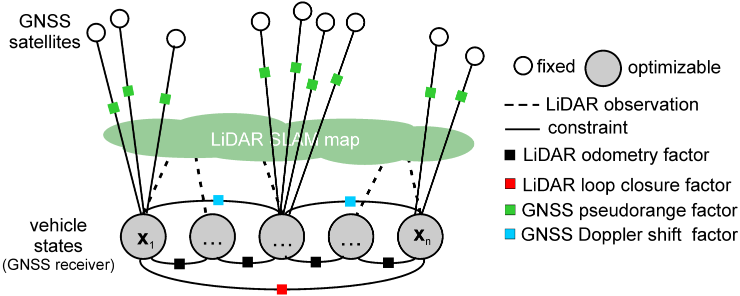
ρ_n - geometric range,
δ_n^s, δ_n^r - satellite and receiver clock biases,
c - speed of light,
d_n^{ion}, d_n^{trop} - ionospheric and tropospheric delays

- **Doppler shift**

$$v_n = \frac{c}{f_n} \cdot d_n, \qquad (2)$$

v_n - radial velocity,
f_n - frequency of carrier wave,
d_n-Doppler shift value

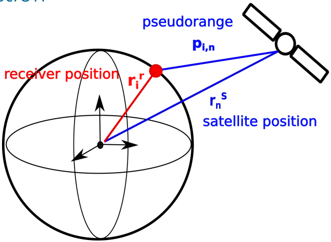
The structure of the proposed factor graph with optimizable nodes for each vehicle state and measurement constraints as edges:



Overall factor graph structure of the GALS approach to LiDAR-based vehicle localization augmented with GNSS measurements

Measurement **constraints** (edges) of the graph:

- **Pseudorange** error function



Visualization of pseudorange constraints in ECEF coordinate frame

$$e_i^p = p_{i,n} - [\rho_{i,n} - (\delta_{i,n}^s - \delta_{i,n}^r) \cdot c + d_{i,n}^{ion} + d_{i,n}^{trop} + \epsilon_{i,n}^p], \qquad (3)$$

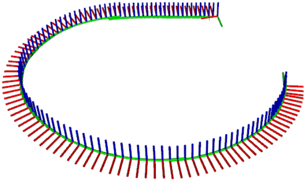
- **Doppler shift** error function

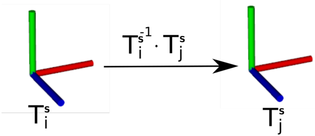
$$\mathbf{e}_{i,i+1}^D = \mathbf{r}_{i+1}^r - \mathbf{r}_i^r - \mathbf{v}_{i,i+1}^{r_D} \cdot t_{i,i+1} \qquad (4)$$

$\mathbf{v}_{i,i+1}^{r_D}$ - receiver velocity, $t_{i,i+1}$ - time between measurements

LIDAR CONSTRAINTS

- SLAM edges: 6-DOF transformations that connect subsequent poses
- Source of transformations: LOAM/LIO-SAM





- LiDAR Odometry/Loop Closure error function

$$\mathbf{e}^{s}_{i,i+1} = [(T^S_i)^{-1} \cdot T^S_{i+1}]^{-1} \cdot (T_i)^{-1} \cdot T_{i+1}, \quad (5)$$

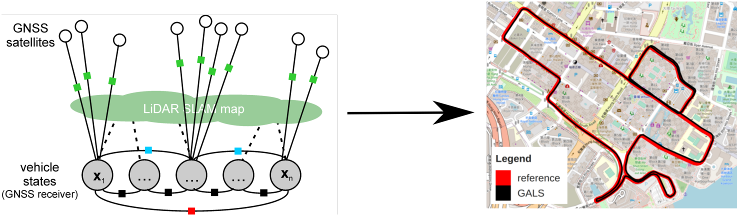
Optimization of all **GNSS** and **SLAM** measurements provides the final state estimates including the trajectory of a receiver:

- Estimated **state vector** (graph nodes):

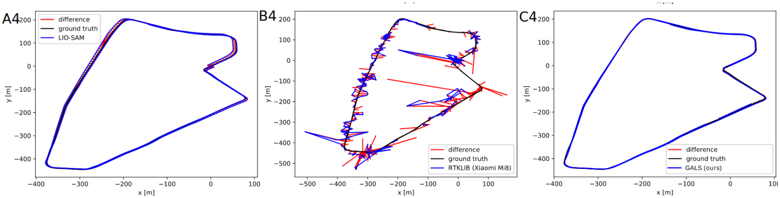
$$X_i = [T_i, \delta^r_{i,1}, \delta^r_{i,2}, \delta^r_{i,3}, \delta^r_{i,4}], \quad (6)$$

T_i - 6-DOF receiver pose, $\delta_{r,i,1...4}$ - clock biases

- Optimization is performed using **g²o** library
- GNSS measurements are processed by **RTKLIB** library



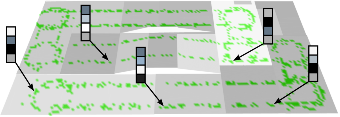
EVALUATION - GALS USING LIO-SAM AND XIAOMI MI8 DATA



Comparison between ATE calculated for LIO-SAM (A), RTKLIB (Xiaomi Mi8) (B), and proposed GALS (C) trajectories for TST sequence

dataset sequence	LIO-SAM $\mathrm{ATE}_{\mathrm{RMS}}$	LIO-SAM $\mathrm{ATE}_{\max}$	RTKLIB (Xiaomi Mi8) $\mathrm{ATE}_{\mathrm{RMS}}$	RTKLIB (Xiaomi Mi8) $\mathrm{ATE}_{\max}$	GALS (ours) $\mathrm{ATE}_{\mathrm{RMS}}$	GALS (ours) $\mathrm{ATE}_{\max}$
TST	11.07 m	21.59 m	84.38 m	683.60 m	**3.69** m	**6.27** m
Whampoa	10.03 m	26.27 m	48.18 m	263.07 m	**7.19** m	**16.44** m
Mongkok	4.88 m	19.44 m	93.84 m	665.07 m	**4.41** m	**9.14** m

ROBOTS AND EDGE COMPUTING



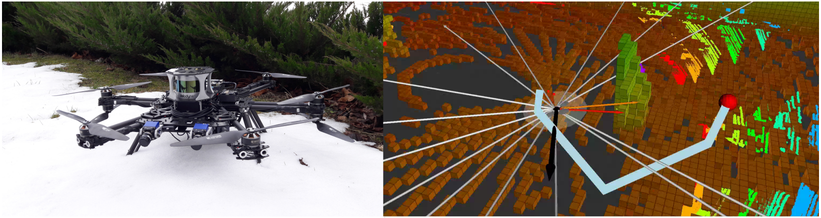
- **Legged inspection robots for mine environment (K. Walas, M. Nowicki)**
- New motion planning algorithms and terrain recognition for walking robots
- Haptic-only localization for harsh environments
- Scientific collaboration: ETHZ, U. Oxford, U. Edinburgh, U. Pisa

R. Buchanan, J. Bednarek, M. Camurri, M. R. Nowicki, K. Walas, M. Fallon, “Navigating by Touch: Haptic Monte Carlo Localization via Geometric Sensing and Terrain Classification”, Autonomous Robots, 45(6), 843–857, 2021

AUTONOMOUS DRONE FOR EXPLORATION

Perception and autonomy for drone exploration (M. Nowicki)

- Localization and map building in real-time
- Real-time planning to avoid obstacles
- Full stack: autonomous return, autonomous take-off, etc.



Autonomous platform and autonomy UI

Distributed data processing system for lunar activities (K. Walas, M. Kraft)

- Advanced spacecraft onboard data processing and reduction of the transmitted data payloads to the essential information, increasing the level of autonomy of rovers.
- Work was funded by European Space Agency OSIP, PO number: 4000138073, COGNITION project.

K. Walas, M. Cwiek, T. Strzalka, M. Wiejak, P. Bosowski, M. Kawulok, M. Przeliorz, D. Pieczynski, B. Ptak, K. Stezala, M. Bidzinski, M. Kraft, ”Cognition: distributed data processing system for lunar activities”, IEEE IGARSS 2023
M. Kraft, K, Walas, B. Ptak, M. Bidziński, K. Stężała, D. Pieczyński, “Integration of heterogeneous computational platform-based, AI-capable planetary rover using ROS 2”, IEEE IGARSS 2023

AUGMENTED REALITY

- **Meta XR Programs and Research Fund grant (P. Skrzypczynski)**
- Partnering with the Centre for Artificial Intelligence and Cyber Security.
- Part of the European Metaverse Research Network.
- Development of augmented reality and other technologies that can improve the quality of life of people susceptible to social exclusion, due to age, health or their family situation. Novel ways of participating in activities through a set of software and IoT-based solutions (ARPresence Development Kit).
- We are able to retrain an object detector to

Thank you for your attention!