Enabling Robotic Operations in the Real World: A Cloud-based Visible Light Communication Approach

RIA

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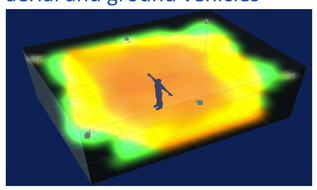
INTRODUCTION

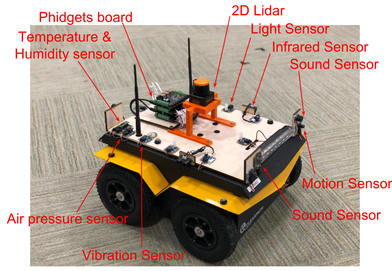
- **Localization and mapping** are necessary in order to enable **autonomous navigation** of unmanned aerial and ground vehicles
- Current tracking through motion capture systems (MOCAPs) is **expensive**, has **limited coverage**, and requires **constant re-calibration**



MOCAP has limitation on space margin

VLC LED lamp array setup

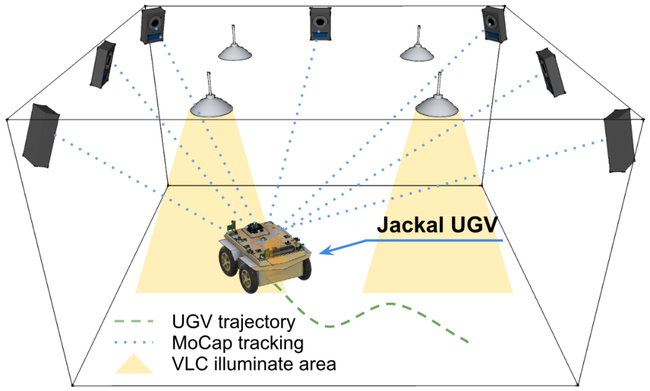
- **Visible light communications** (VLC) provides high positioning accuracy at lower costs both for energy and computation source
- A single robot equipped with different **sensors** can use VLC to manage self-localization and build maps of **different features** in the environment at the same time



The unmanned ground vehicle (UGV) equipped with different sensors

PROBLEM

- Develop a framework to enable robust localization, mapping, communication, and motion planning for autonomous robotic systems in GPS denied environments by leveraging visible light communication.



VISIBLE LIGHT-BASED INDOOR LOCALIZATION

- Measurement = optical received signal strength (**RSS**)
- Using optimized Particle Filter (**PF**) to localize the autonomous vehicle
- **Faster convergence** by removing the particles that: 1) are not under the same lamp as the robot and 2) have different orientation

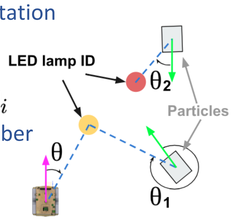
$$w_i = \frac{1}{2\pi\sigma^2} exp(-\frac{1}{2}\frac{(m-m_i)^2}{\sigma^2})$$

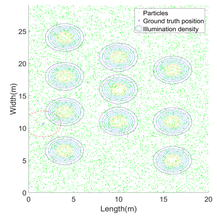
$$w_i = 0 \quad if \quad |\theta - \theta_i| > \epsilon \quad or \quad ID \neq ID_i$$

- **Boost** PF by dynamically changing the particle number

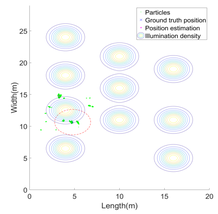
$$\sigma = \sqrt{\frac{1}{n}\sum_i((x_i - \overline{x})^2 + (y_i - \overline{y})^2)}$$

$$n_{i+1} = \lambda\sigma n_i$$

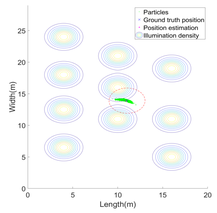




Particles are normal distributed at Initial state



Particles start gathering as UGV moves



Fine localization after beginning period

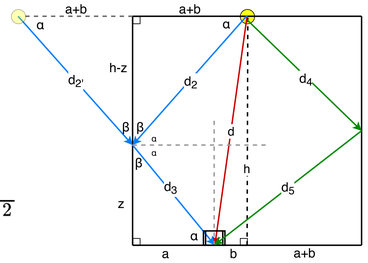
SIMULTANEOUS LOCALIZATION AND MAPPING (SLAM)

- Optical wireless channel (**OWC**) state information (**CSI**) can be used to build a physical map of the environment
- CSI consists of optical RSS and channel impulse response (**CIR**)
- *h* is known *a priori*
- Optical received signal strength (RSS) is used to calculate *d*

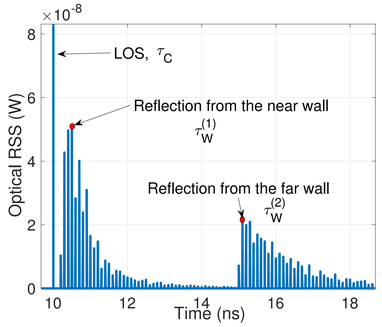
$$d = \sqrt{\frac{H_{LOS} * P_T}{2\pi P_R}}$$

$$\sqrt{(2a+b)^2 + h^2} = \sqrt{(d_2 + d_3)^2}$$

$$b = \sqrt{d^2 - h^2}$$



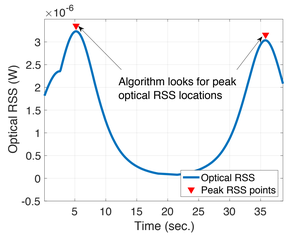
Specular reflection geometry [1]



VLC-CIR [1]

- Time-of-flight (TOF), τ, is obtained from CIR

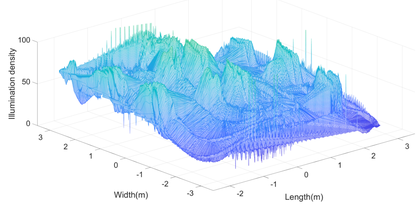
$$d_2 + d_3 = C * \tau_W^{(1)}$$



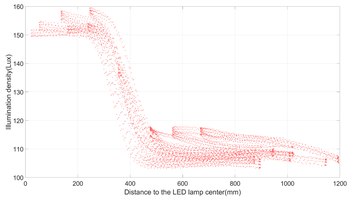
VLC-RSS [1]

SIMULATION AND EXPERIMENTAL RESULTS

Building light distribution map experiment

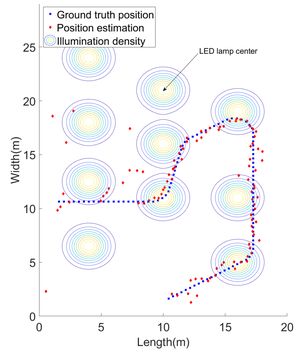


Illumination density map measured by light sensor

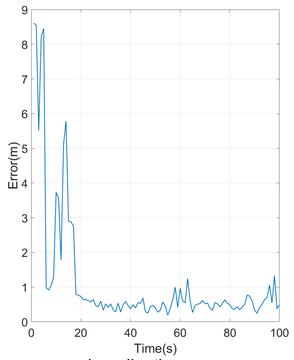


Single lamp illumination density model

Localization - simulation results

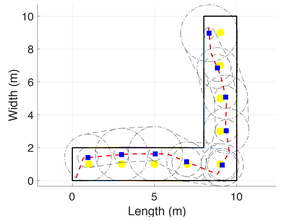


Localization of UGV

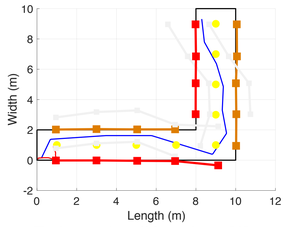


Localization error

Mapping using CSI - simulation results



Data association using circle tangent points [1]



Estimated wall locations [1]

FUTURE WORK

- Build a complete map that include physical and environmental features
- Integration of VLC-based PF with VLC-CSI for mapping application
- Testing of VLC performance in SLAM mapping compared to motion capture system
- Testing of cloud robotics with VLC throughput
- Testing of multi-agent cloud-based communication through VLC

REFERENCES

[1] Z. Vatansever, J. Lian, M. Brandt-Pearce, "Indoor mapping using the VLC channel state information", 2018 ASILOMAR Conference on Signals, Systems, and Computers, 2018