Abstract

In harsh and long-term field robotic missions, communication loss may compromise the mission outcomes. We focus on the problem of autonomously recovering from wireless connection loss.

Our contributions are the following:
1. A dynamic online Radio Signal Strength (RSS) mapping using adaptive Gaussian Random Field (GRF) model;
2. A strategy to drive the robot to a position with high chances of regaining connectivity using a Resilient Communication-Aware Motion Planner (RCAMP) [1].

We demonstrate the proposed planner with extensive simulations in iREP and ROS based implementations.

Motivation and Objectives

Robots have a major potential in aiding first responders in Urban Search And Rescue (USAR) missions. Wireless networks can show severe limitations that can compromise the outcome of the USAR mission.

Example: In a recent Amatrice post-earthquake operations, the Wi-Fi Access Points (APs) supporting the robots had to be regularly relocated to re-establish disrupted communication.

Thus, connection loss needs to be tackled by the robots. Researchers approached this problem by introducing Communication-aware motion planners (CAMP) [2][3].

However, there are very few literature works that address self-recovery from communication loss.

Therefore, the objectives of this research are:
✓ Obtain an optimal path considering both communication and motion constraints;
✓ To quickly re-establish connection in case of a signal loss.

Inspired by the online Gaussian Process methods used in [4][5], we propose an adaptive GRF that maps the RSS in a dynamic environment where there are:

- Multiple (moving) Access Points
- Changes in environment conditions (LOS/NLOS)
- Intermittent connectivity issues

Background: RSS & GRF models

RSS depends on environmental factors such as distance (path loss), objects in the environment (shadowing) and spatio-temporal dynamics (multipath fading).

$$RSS_{ij} = RSS_0 - 10 \log_{10}(d_{ij}^{3}) + \psi_{ij} = \Omega_{ij}$$

The RSS map is modeled as a GRF with the following form:

$$\mathcal{E}[x] = \text{cov}(x) = \sum_{n=0}^{N} \mathbf{K}_n \mathbf{K}_n^T$$

$$\psi_{ij}$$ and $$\Omega_{ij}$$

The squared-exponential covariance kernel and the notations used are similar to the ones in [5].

However, instead of the mean function:

$$m(x) = RSS_0 - 10 \log_{10}(d_{ij}^{3}) \cdot$$

we chose to use a constant mean function, $$m(x) = C$$.

This reduces computational load and make the method adaptive to the environment or moving Access Points.

Real-time optimization of the hyperparameters is done by continuously re-training the GRF with measurements using dynamic training size depending on the connection status.

$$T = \alpha (N_k \cdot \text{K}^T \cdot N_k + \lambda_0) \cdot (y - m_k) \cdot$$

$$\lambda_k = \lambda_{k-1} + \lambda_0$$

The above prediction equations of the GRF model are used to repetitively obtain/update the RSS map.

Proposed Method

The proposed method is composed of two stages to achieve a self-recovery from a communication loss.

1. Wireless Map Generation (WMG): use measured RSS values to iteratively update the RSS map from GRF predictions.

2. Resilient Communication-Aware Motion Planning (RCAMP): use the RSS map and a traversability map from the SLAM system for mapping and point cloud segmentation, and calculate the traversability cost, $$\text{cost}(p) = \sqrt{RSS(p) + \text{traversable}(p)}$$.

$$\text{traversable}(p) = \frac{1}{d(C_{p}, C_{ego})}$$

Here, $$C$$ is the configuration space with goal configurations $$C_{ego}$$ and $$C_{p} = \{C_{1}, \ldots, C_{n}\}$$ is the distance metric, $$d(C_{p}, C_{ego}) = \min\left|\text{heuristic}_{C_{p}} - \text{heuristic}_{C_{ego}}\right|$$, the goal heuristics, and $$\text{RSS}(C) = \min$$ is the estimated RSS.

Experiments and Results

It can be seen from the results that the WMG+RCAMP enabled the robot to maintain an higher RSS value, kept the robot connected during Scenarios 1 and 2, and recovered the robot from a loss of communication in Scenario 3.

Summary

- We used an adaptive GRF estimation to map the RSS and integrated it with a motion planner (RCAMP) in order to find a feasible path that ensures traversability and communication quality.
- We proposed an efficient strategy to autonomously repair a communication loss by steering the robot towards a communication-safe position.
- We demonstrated the proposed framework through online simulations in ROS/iREP under realistic conditions and scenarios.

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References

[1] Caccamo, Sergio; Paruselaru, Romana, Freda, Luigi; Gianni, Mario; Ogren, Peter; “RCAMP: Resilient Communication-Aware Motion Planner and Autonomous Repair of Wireless Connectivity in Mobile Robots”, ROS 2017 (Accepted).