Simultaneous Collaborative Mapping and Reasoning in Dynamic Unstructured Environments

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***Abstract*— Robots are expected to operate in dynamic environments, such as teaming up with human or searching for specific targets. In such cases, robots are required to perform collaboration environmental mapping and semantic reasoning . This abstract proposes a novel probabilistic framework for simultaneous collaborative mapping and reasoning (SCMR). For each mission, robots first apply heterogeneous sensor fusion model to detect humans and separate them from the static environment. Then, the collaborative mapping is performed to estimate the relative position between robots and local 3D maps are integrated into a globally consistent 3D map. Next, by leveraging the transformation relationship among the robots, collaborative dynamic reasoning can accurately analyze each person's motion by sharing observations from neighboring robots. The experiment is conducted in a rainforest with moving people. The results show the accuracy, robustness, and versatility of 3D map fusion and human uniqueness reasoning in multi-robot missions.**

I. Introduction

The human-robot teaming has garnered significant attention in recent years [1]. In static unstructured environment, the author considered multi-robot localization and collaborative mapping in RT-DUNE Workshop 2018 [2]. In more challenging dynamic environment, it is crucial that the multi-robot systems could analyze the dynamic human motions, and further reason their uniqueness [3]. On the other hand, accurate static mapping also requires the detection and filtering of dynamic objects in the environment. Then, robots can plan their motion by considering the motion of people. This abstract considers these two problems jointly and provides simultaneous collaborative mapping and reasoning (SCMR) as a possible solution.

The key novelty of this work is the mathematical modeling of the overall SCMR problem and the derivation of its probability decomposition. Specifically, by detecting and filtering out dynamic people in the environment, the robot can achieve more accurate relative positioning and global mapping. In addition, collaborative dynamic reasoning can accurately analyze each person's motion by sharing observations from neighboring robots and identify the unique people.

II. Distributed Collaborative Map Fusion

The objective of this abstract is to develop a framework for collaborative mapping and reasoning that simultaneously estimates the global map and the uniqueness of all detected human. The system architecture is consisted of three modules: *multimodal environmental perception, static environmental mapping*, and *dynamic environmental reasoning*.

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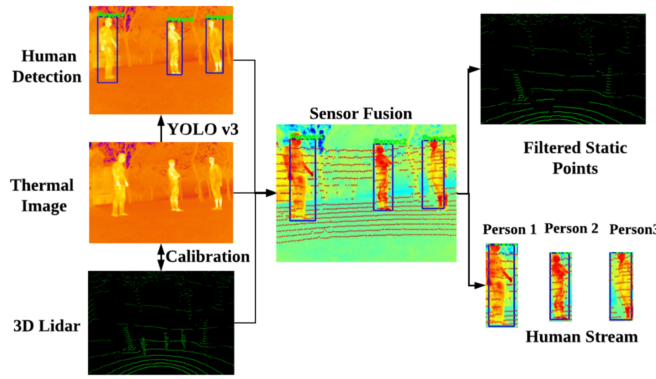

Fig. 1. Robot environmental perception results of fusing thermal image with 3D Lidar, static world and dynamic human are separated in the night forest environment.

A. Single Robot Level

In single robot level, each robot performs multimodal environmental perception. The heterogeneous sensors carried by each robot are calibrated and integrated. The object detection & tracking algorithms [4] are executed to separate the static point cloud and human stream in two parallel processes, as shown in Figure 1. Then, each robot performs static environmental SLAM given the input of filtered static point cloud, while conducts human uniqueness reasoning conditioned on the estimated single robot pose.

B. Multi-Robot Level

For multi-robot level, each robot communicate with neighboring robots to share local 3D maps, human states and unique role estimated by single robot. The multi-robot systems first perform collaborative static mapping, estimating relative position between all robots and global 3D map. Then, the global uniqueness is estimated conditioned on relative position between all robots, human states and single robot unique roles. The objective is to estimate fused global map M_t, set of relative transformation T_{r,R_r} and uniqueness of human I_t under a fully distributed network, given local maps $m_t^{(r,R_r)}$, human states $g_{1:t}^{(r,R_r)}$, and single robot human uniqueness $i_t^{(r,R_r)}$ from neighboring robots R_r.

$$p(M_t, T_{r,R_r}, I_t | m_t^{(r,R_r)}, i_t^{(r,R_r)}, g_{1:t}^{(r,R_r)}) \quad (1)$$