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Autonomous Power Distribution System

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Abstract: This paper describes path planning and control of an autonomous power distribution system. The aim is to study the use of the autonomous mobile power-grid systems after disasters to accelerate search, rescue, and recovery efforts. The concept is demonstrated through an autonomous electrical cabling and connection mission between a power source and a power load in a cluttered environment using lab-size platforms. The developed system will be scalable to real-size. The ultimate goal of this work is developing intelligent power electronics and a distributed autonomous mobile microgrid. It will be capable of regulating power flow at a desired voltage and frequency level, meeting load demands and adaptable to changes in situation, power demands, or generations.

1. INTRODUCTION

Recent search-and-rescue efforts following Colorado's floods brought back the memory of Hurricane Katrina's aftermath in 2005 and the importance of a prepared emergency-response system to work quickly and effectively in order to improve the chance of helping victims. Depending on the size and type of the disaster, the rescue operations are conducted from the air, ground, or even water; many times in parallel. In some cases, due to intensity of the disaster, the rescue efforts are complicated and require inter-agency rescue teams. A large-scale disaster relief operation requires: coordination of many teams of first responders, capability to assess the situation, brisk adaptation to changes in the environment, and ability to rapidly reorganize the teams.

These many factors emphasize the importance of the communication between rescue teams, rescue management, and area residents. In such incidents, any means of long-distance communication becomes very critical. Cellular phones are one of the most common and available communication methods today. These devices can be extremely helpful by accelerating first response activities and also the victim's ability to inform their status and whereabouts. Unfortunately, in such circumstances cellular towers are often rendered silent due to electrical power shut off following the event of a disaster. Cellular towers often have backup generators, but these generators have limited energy capacity and are often damaged during a disaster Kwasinski et al. [2009]. In order to overcome power shortage, personnel will take additional generators to the site as soon as possible. However, this response is delayed in many cases due to initial concerns of protecting life and property. The bigger issue is that a great number of communication nodes are usually located in remote or hard to reach places. This makes it even more difficult to access in the event of a disaster. Even after distributing power to the system, personnel have to continuously refuel the generators to keep the system up and running.

An autonomous microgrid system that can be deployed and re-establish electrical power for the crucial components of the communication system with minimal human interference can have a significant impact in these situations. This system can be more effective and enable recovery of the communication system faster than traditional methods if it 1) contains sources to generate electrical power and 2) has a self-configurable framework to reach optimal formation based on power demand. Such a system can also reduce the fuel delivery demands.

The idea of having an autonomous mobile power-grid is a recent application of autonomous vehicles and currently in its initial stages of research Weaver et al. [2012]. However, teams of autonomous robots have been used to assist first responders in search and rescue. These mobile robots have also been instrumental in restoration of communication networks at various disaster sites by creating ad-hoc nodes and networks. Our ultimate goal is to integrate vehicle robotics, intelligent power electronics, and electric power assets creating self-organizing, ad-hoc electric microgrids. These components ensure capability to quickly restore power to a critical area. Our first aim is to find and validate practical solutions for control of a mobile power-grid.

In this work, we pursue the idea of using autonomous microgrid systems for re-powering communication nodes and study the required components for achieving this goal. These communication nodes are typically served by 208 V_{ac} three-phase power diesel backup generators. However, in the case where the generators may not be available, the autonomous microgrid robots can be dropped on sight. For this application the robots would be equipped with 208 V_{ac} three-phase power sources, line connections and power conversion components Sannino et al. [2003]. The general steps that the system will take are:

(1) Robot assets arrive and assess the power requirements of the local system.
(2) Robots autonomously physically connect sources and loads into a microgrid structure.
(3) The on-board power electronics convert source energy to a common distribution level.
(4) Load connected robots convert the distribution voltage to the needs of the load.
(5) Robots re-configure system as energy assets and load change.

This concept requires extensive coordination of many distinct research disciplines, including path planning and coordination of autonomous vehicles, power electronics and microgrids, and disaster impacts and response.

This paper describes electrical cabling and connection mission between one power source and one power load using a lab-size autonomous vehicle platform in a cluttered environment with static obstacles. While accomplishing this task, the aim was to develop an infrastructure that can easily serve as a base for a real-size system. This development is the first step towards having a team of autonomous robots with different functions that make the team capable of performing as a mobile microgrid to power up multiple power loads. The hardware used in this work is detailed in Section 2. Section 3 describes the path planning and control algorithm. Results are presented in Section 4. Future work is discussed in Section 5.

2. HARDWARE SPECIFICATIONS

The following explains the detail of the setup for this work which was used to satisfy the basic needs of having a functional and consistent autonomous robotic system.

2.1 Ground Robot

For prototyping the algorithms, a small mobile robot platform known as DaNI was used. DaNI is part of the National Instruments Robotics Starter Kit and is made specifically for teaching and research purposes.

The DaNI is equipped with the National Instruments sbRIO-09632. The sbRIO (Single-Board Reconfigurable Input/Output) is an embedded controller designed with real-time processing and rapid prototyping in mind. It features a field-programmable gate array (FPGA) and I/O ports that allow communication with various sensors.

The sbRIO allows network traffic by means of both web and file servers. If needed it can also support communication via RS-232 serial port. The 256MB on-board non volatile memory was utilized in order to: store and run the obstacle avoidance, path planning, and path tracking.

For the close area obstacle recognition and distance measurement a simple IR sensor was used. This particular IR sensor has a range between 20 and 150cm. This sensor was mounted on a servo motor allowing a data return range between -75° to 75° in front of the DaNI.

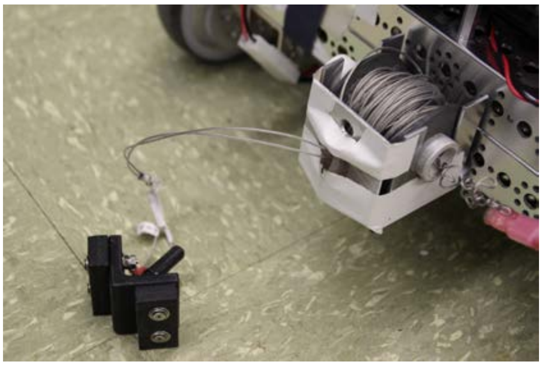

Fig. 1. Male magnetic connector with wire pulley

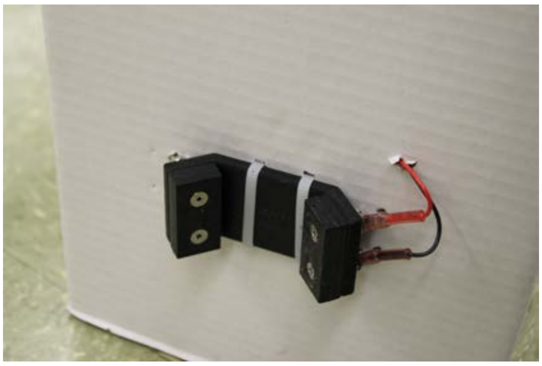

Fig. 2. Female magnetic connector

2.2 Power Source and Power Load Connections

The main task is accomplishing physical connection between an area known as a source and another classified as a load. Establishing a good electrical connection is a major factor, despite performing in cluttered unknown areas. In this project a magnetic connection was designed in order to reduce the risk of faulty connection. For this design, neodymium magnets with a protective coating was selected. The magnets have two countersunk holes which facilitate mounting electrical connections through the magnet while remaining shielded of the magnet. The polarization property of the magnets allow the electrical connectors to align properly for every connection. The angled design of magnet mounts also helps with eliminating the risk of misalignment. Each connection includes a male (Fig. 1) and a female part (Fig. 2). The male connectors are attached to the robot and female connectors are attached to power source or power load.

As the agent approaches the target, the male connector is absorbed by the female connector and pulls out of the mount on the agent and sticks to it. Two wires are connected to this male part that are rolled around a pulley (Fig. 1) and unwind as the agent moves away from the target. The other side of these wires go through the pulley and come out of the center of it and connect to another pulley with the same structure with another male connector.

2.3 Camera system

In order to accurately measure the position of the DaNI a Qualisys motion capture camera system is used. The