RoboCon System Concept

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1. Introduction

This document describes the high-level characteristics and function of a proposed robotic convoy system called RoboCon.

1.1. Purpose

The purpose of this document is to record the decisions agreed to by RoboCon stakeholders and serve as a basis for detailed system requirements specification and documentation.

1.2. Product Scope

RoboCon consists of a variable number of robots that form a convoy and follow a leader robot to a specified destination. In most usage scenarios, the convoy will include at least four robots, but at least two robots are required:

- One robot in the convoy is designated as the *leader* robot. The leader robot is provided with a path to follow in the form of a series of spatial coordinates called *waypoints*.
- All other robots in the convoy are *follower* robots. Each follower robot uses on-board sensors to track the robot immediately ahead of it in the convoy and follow it.

RoboCon will provide a demonstration and experimentation platform for CS568 Systems image processing and artificial intelligence algorithms. RoboCon will:

- Allow CS568 Systems to conduct internal evaluation of alternative algorithms in different operational scenarios.
- Provide a platform for CS568 Systems to showcase the performance of new algorithms to customers.

This type of autonomous convoy is a common use-case for CS568 Systems algorithms, having applications in transportation, inventory management, automated farming, and other areas. For example, a set of trucks could be placed in a convoy to transport goods. A human driver could drive the leader truck, and the follower trucks could be driven automatically. Similarly, farming equipment could be made to automatically drive over fields to harvest crops without a human driver.

1.3. Document Structure

This document is organized as follows:

- Section 2 describes the RoboCon stakeholders and usage scenarios.
- Section 3 provides an overview of the RoboCon system structure and functionality.
- Section 4 provides supplemental information, such as definitions and references.

2. System Overview

This section enumerates the system stakeholders (Section 2.1) and usage scenarios (Section 2.2).

2.1. Stakeholders

The following people are RoboCon stakeholders:

- The RoboCon development team.
  The RoboCon development team is responsible for building the RoboCon System. The development team has indicated that their primary goal is to successfully complete the project on-time and on-budget.

- CS568 Systems algorithm developers (RoboCon users).
  CS568 Systems algorithm developers will be the primary users of RoboCon. The algorithm developers have indicated that their primary goals are for the system to: (1) be easy to extend with new image processing and artificial intelligence algorithms, (2) be simple to configure for different experiments, and (3) provide rich, meaningful metrics of algorithm performance.

- CS568 Systems management.
  CS568 Systems management will oversee the planning and funding of the RoboCon development. Management has indicated that their primary goals are: (1) the system has low maintenance costs over time, and (2) the system can be used to provide compelling demonstrations to customers of the value of RoboCon algorithms.

- CS568 Systems customers.
  CS568 Systems customers will view RoboCon demonstrations that showcase the performance of CS568 Systems algorithms. Their primary goal is to gain an understanding of how they can incorporate CS568 Systems algorithms into their own products to provide their customers with more value.

2.2. Usage Scenarios

The RoboCon system has two high-level usage scenarios: experimentation and demonstration.

First, RoboCon will be used internally by CS568 Systems algorithm developers to experiment with different image processing and artificial intelligence algorithms. In this usage scenario, the algorithm under test will be implemented in a component that plugs into the RoboCon software. The RoboCon system will then be configured for a particular experiment (*e.g.*, the number of robots, the starting and destination locations, the lighting conditions, etc.). As the experiment executes, the RoboCon system will record performance metrics such as battery usage, total travel time, number of messages exchanged, etc. After the experiment completes, the algorithm developers will analyze the recorded data to evaluate the algorithm's performance.

Second, RoboCon will be used to demonstrate CS568 Systems algorithms to external customers. In this usage scenario, RoboCon's best-performing algorithms will be plugged into the RoboCon software and the system will be configured for a demonstration that illustrates how CS568 Systems algorithms outperform the competitors' algorithms. For example, a demonstration might illustrate how a CS568 Systems image processing algorithm is able to function in a low-light environment.

3. System Description

This section provides a description of the RoboCon system. Section 2.1 describes the high-level structure of the system. Section 2.2 explains the envisioned system functionality in terms of different operational modes.

3.1. System Components

RoboCon consists of multiple robots called RoboCon Units (RCUs) and one Administrative Control Unit (ACU).

- Each RCU consists of a robotic hardware platform and a software controller.
  - The RCU hardware platform will be assembled from off-the-shelf (OTS) components. The RCU hardware platform is described in Section 3.1.1.
  - The RCU software controller will be custom-built by CS568 Systems. The RCU software controller is described in Section 3.1.2.
- The ACU consists of a standard PC and an administrator application. The ACU is described in Section 3.1.3.

3.1.1. RCU Hardware Platform

Each RCU is assembled from:

- An iRobot Create mobile programmable robot. The iRobot has wheels and a motor that can turn and move the robot. The iRobot also includes a front bumper sensor that detects when the robot has run into an obstacle.
- An eBox 3854 computer running Fedora Linux. The eBox contains all standard computer components, such as a processor, memory, flash storage, etc. The eBox also includes an 802.11 wireless local area network (LAN) adapter.
- A video camera.
- A Global Position System (GPS) receiver.
- An infrared (IR) receiver.
- An IR transmitter.

Pictures of assembled RCUs are shown below.

3.1.2. RCU Software Controller

Each RCU is controlled by a Controller software component that runs on the eBox with the Linux operating system (OS). The Controller provides the core logic that implements the convoy behavior. The Controller includes the following functions:

- Receives sensor data (such as video and IR readings) from the RCU sensors.
- Analyzes sensor data to determine the actions to be taken by the RCU (*e.g.*, move forward, turn, switch off camera, etc.).
- Sends commands to the RCU sensors and actuators to perform needed actions.
- Sends messages to other Controller instances to coordinate convoy activities.
- Records performance metrics for analysis by CS568 Systems engineers and transmits metrics to the Admin component (described below) for real-time visualization.

Each Controller instance will communicate with the camera, GPS, WiFi adapter, IR receiver, and IR transmitter using Linux drivers. Each Controller instance will communicate with other Controller instances running on other RCUs in a convoy via an ad-hoc WiFi network.

3.1.3. Administrative Control Unit

The Administrative Control Unit (ACU) is a standard PC running Microsoft Windows 7 and an Admin software application. The Admin provides a typical Windows graphical user interface (GUI) for performing various RoboCon management functions. The Admin includes the following functions:

- Allows a user to specify experiment and demonstration configurations.
- Uploads configurations to RCU Controllers.
- Receives real-time performance data from Controllers during an experiment or demonstration and displays the data in charts and tables.

3.2. Operational Modes

RoboCon supports the following operational modes:

- *Convoy formation*, in which RCUs placed in a staging area assemble themselves into a convoy. Convoy formation is described in Section 3.2.1.
- *Movement*, in which RCUs travel along a route in convoy formation. Movement is described in Section 3.2.2.
- *Recharge*, in which one or more RCUs recharge their batteries while the rest of the convoy waits. Recharge is described in Section 3.2.3.

3.2.1. Convoy Formation

At system startup, a set of RCUs will be positioned in a staging area. Each RCU will be configured to act as either the leader or a follower. Each follower will be configured to trail directly behind either the leader or one of the other followers, so the convoy will be single file. The RCU immediately in front of a follower is known as the follower's *guide*. Each follower has exactly one guide. The RCU immediately behind an RCU is known as the RCU's *tail*. Each RCU has exactly one tail, except the last RCU in the convoy, which has zero tails.

During convoy formation, the RCUs position themselves in a single file line. Each follower uses on-board sensors to locate its guide. Once a follower has located its guide, it sends a message to the leader indicating that it is ready to switch to movement mode. The follower then moves to position itself behind the guide. If the guide moves (to position itself behind its own guide), the follower moves accordingly to maintain its position behind the guide.

Once all followers have indicated to the leader that they are ready to switch to movement mode, the leader broadcasts a message to all followers indicating that the convoy is switching to movement mode.

3.2.2. Movement

In movement mode, the leader uses an on-board GPS device to find its location and determine a path to the next waypoint. When a waypoint is reached, the leader computes the path to the next waypoint. If the leader encounters an obstacle in its path, it can invoke an obstacle-avoidance algorithm to temporarily take it off the path to the next waypoint and navigate around the obstacle.

Each follower does not know the location of the waypoints, and must instead track and follow its guide (the RCU immediately in front of it in the convoy). Each follower has three different ways to track its guide: (1) it can track the guide using a camera, (2) it can track the guide using an IR sensor, or (3) it can request the guide's location over a WiFi link, use the GPS to get its own location, and compute a path to the guide's location.

If a follower is using camera following, and the area becomes too dark, the follower can automatically switch to GPS or IR following. Similarly, GPS following does not work indoors, while IR following does not work at large distances.

3.2.3. Recharge

Along the route, the convoy may encounter charging stations. Charging stations broadcast their location over WiFi. If the convoy passes within 10 meters of a charging station, each RCU will check its remaining battery power. If any RCU has less than 20% battery remaining, it will request over WiFi that all RCUs in the convoy stop temporarily. The convoy then switches to recharge mode. The RCU(s) that have low battery will then go to the charging station one-by-one and recharge their batteries. When an RCU finishes charging, the RCU will assume its position in the convoy and notify all other RCUs that it is ready for the convoy to switch back to movement mode and continue moving. Once all RCUs with low battery have finished charging, the convoy switches back to movement mode.

4. Supplemental Information

This section provides definitions (Section 4.1) and lists all used acronyms (Section 4.2).

4.1. Definitions

Follower: An RCU that does not know the waypoints of the route; uses on-board sensors to follow another RCU immediately preceding it in the convoy (see *guide*).

Guide: The RCU tracked and followed by a follower. A guide may be the convoy leader or a follower. All followers have exactly one guide.

Leader: The RCU that is provided with the route waypoints. The leader proceeds first in the convoy.

Tail: The RCU immediately behind a given RCU in the convoy. An RCU is the guide of its tail.

Waypoint: A set of spatial coordinates indicating a position that the convoy must pass through on its way to the destination of the route.

4.2. Acronyms

ACU: Administrative Control Unit
GPS: Global Positioning System
GUI: graphical user interface
IR: infrared
LAN: local area network
OS: operating system
OTS: off-the-shelf
PC: personal computer
RCU: RoboCon Unit