Literature Review: Firefighting Robots

Jake Kremer – 13 December 2024

Journal Papers Covered

“A Multipurpose Mobile Manipulator for Autonomous Firefighting and Construction of Outdoor Structures”

- From Field Robotics Journal
- Details a UGV for firefighting and construction with a 6 DOF manipulator arm, built to compete in the 2020 MBZIRC robot competition

“Designing and Control of Track-Belt Robot for Firefighting Tasks”

- From IEEE
- Details a UGV for firefighting purposes with track-belts for climbing stairs

Application

Firefighting

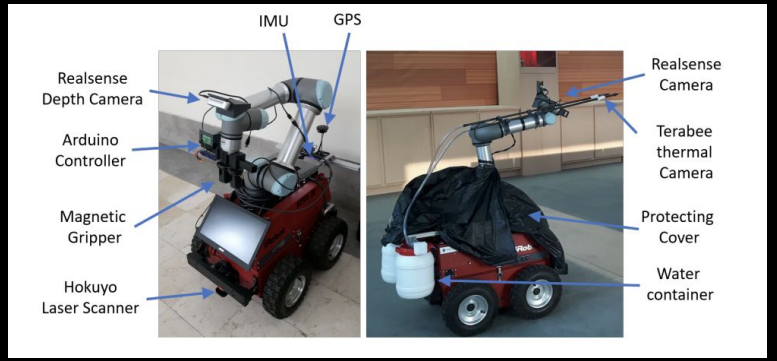
- Increased presence of fires, especially here in California
- High risk career, ~100 firefighters die due to duty-related incidents each year
- Hard to reach areas, chaotic environment
  → unmanned systems

Apartment Fire in Chinatown, LA, September 2024

Physical Characteristics – UGV w/ Manipulator

Four-wheeled mobile base with 6 DOF manipulator arm and water pump system

- Composed of: aluminum, rubber wheels
- Weight: 160 lbs unloaded
- Dimensions: 1.6’ L x 3’ W x 2’ H
- Mobile base: iRobot ATRV-Jr
- Manipulator arm: Universal Robotics UR5e

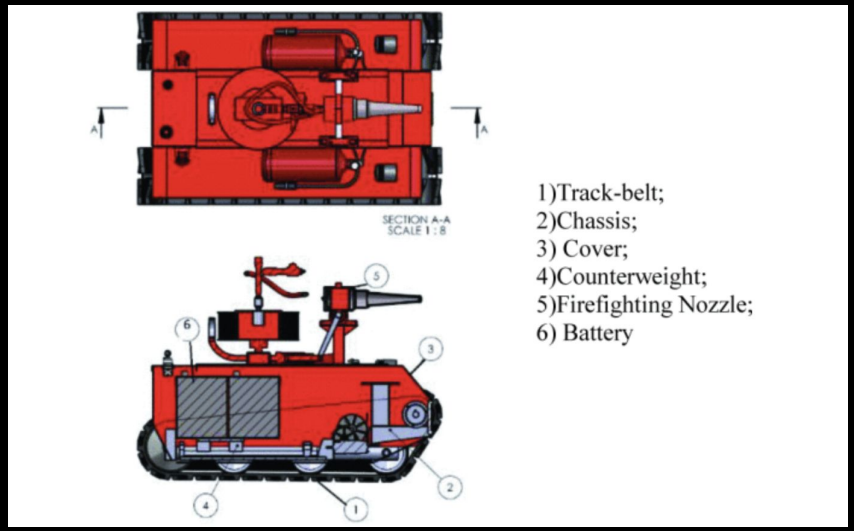


UGV w/ Manipulator

Physical Characteristics – Track-Belt UGV

Dual fireproof rubber tread-wheel robot with firefighting spray system

- Composed of: steel and aluminum
- Weight: 220 lbs unloaded
- Dimensions: 2’ L x 2.6’ W x 3.3’ H
- Temperature resistance: 572℉
- Watertight and waterproof
- Movable counterweight for climbing stairs up to 35°



UGV Track-Belt Firefighting Robot

Sensors and Actuators – UGV w/ Manipulator

Actuators

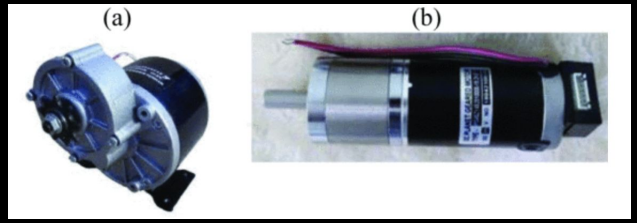
- Base: 2 High Torque 24V motors
- Manipulator: 6 rotational motors
- One pump on each water tank

Sensors

- Pixhawk 2.1 IMU
- Hokuyo UTM-30LX laser scanner for positioning
- RealSense D435 camera
- Terabee thermal sensor for identifying fires

Universal Robotics UR5e

Sensors and Actuators – TB-UGV



Drivetrain (a) and Counterweight/Sprayer (b) Motors

Actuators

- Two 24V, 350W belt-driving motors each with an encoder
- One 24V, 90W motor which moves lead screw to control counterweight position
- One 24V, 90W motor to operate firefighting sprayer pump

Sensors

- Intel RealSense Depth Camera 435i
- EfficientDet Neural Network, training for fire and smoke detection

Fire and Smoke Identification

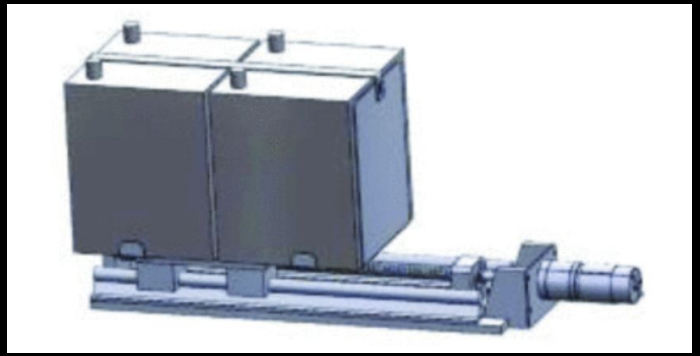
Power Sources

UGV w/ Manipulator –

- Two LiFePO4 24V 20Ah batteries for >5 hours of operation

Track-Belt UGV –

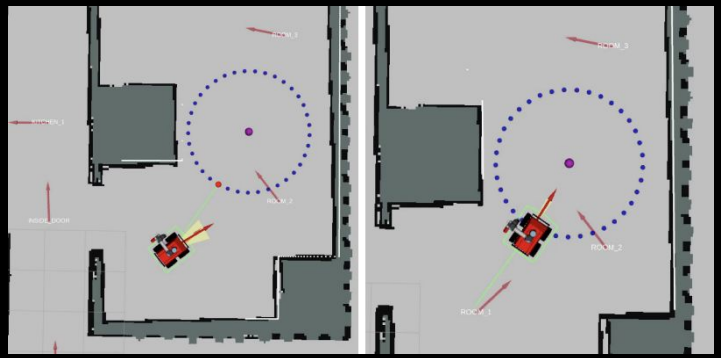
- Two 24V, 200Ah batteries for total runtime of >4 hours
- Battery weight also functions as part of the counterweight



UGV Battery Counterweight Integration

Controls – UGV w/ Manipulator

- When indoors, robot uses Adaptive Monte Carlo Localization to update position frame relative to surroundings (more on this later)
- Moves to waypoints and scans for fires
- TinyYOLO neural network to detect fires with camera and thermal sensor



Robot Positioning Itself to Put Out Fire

Algorithm 5. Challenge 3 routine

Result: Fire detected and put out by the mobile UGV
input: map, waypoint_list[], initial_position

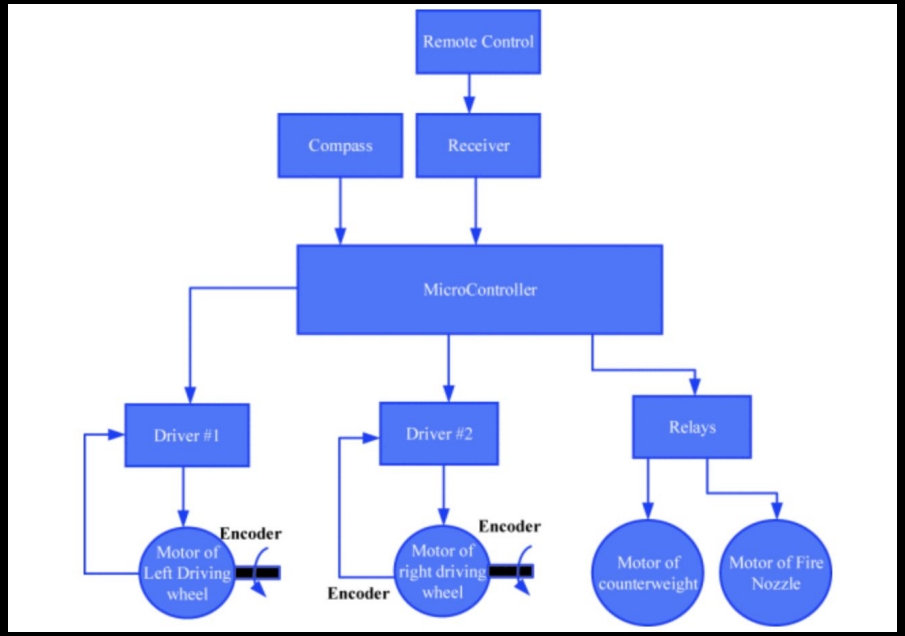
```
1  begin
2      switch_localization('outdoors', None);
3      move_to(waypoint_list["Door"]);
4      switch_localization('indoors', initial_position);
5      move_to(waypoint_list["Check Fire 1"]);
6      if detect_fire(timeout = 5) is false then
7          move_to(waypoint_list["Check Fire 2"]);
8          if detect_fire(timeout = 5) is false then
9              Go back to line 5;
10         end
11     end
12     align();
13     shoot_water();
14     move_to(waypoint_list["Door"]);
15     switch_localization('outdoors', None);
16     move_to(waypoint_list["Origin"]);
17 end
```

Firefighting Control Algorithm

Controls – Track-Belt UGV

Components

- Remote control FlySky I6S
- Receiver FS-I6AB
- Microcontroller Arduino MEGA 2560
- Motor drivers and relay units



UGV Control System Hierarchy

Project Cost and Current Status

UGV w/ Manipulator –

- Estimated cost: $80,000 in components
- Current status: Constructed for competition, won the firefighting portion, current status unknown

Track-Belt UGV –

- Estimated cost: $40,000 in components
- Current status: Experimental prototype, project status unknown

Similarities and Differences

Track-Belt UGV	Similarities	UGV w/ Manipulator
- Temperature resistance up to 572℉ - Can traverse stairs - Remote-controlled - Pressurized extinguisher system - Meant for real application - Track-Belt	- Firefighting purposes - Fire extinguisher system - Intel RealSense camera	- Manipulator arm - Thermal camera - Fully autonomous - Pump extinguisher system - Meant for competition - Wheels - Additional applications

Connection to MAE C263A

Reference Frames

- Map Frame: Global reference for the environment
- World Frame: Robot's starting position in the environment
- Base Frame: Robot's current pose (position and orientation) relative to its reference

Adaptive Monte Carlo Localization

- Uses laser scans, wheel odometry, and a pre-mapped environment info to estimate the robot's position
- Continuously calculates the transformation between the map and world frames
- Updates the world-to-base transformation using accumulated odometry and continuous scans

Journal Paper Links and References

Journal Paper 1 (“Multipurpose Mobile Manipulator for Autonomous Firefighting and Construction of Outdoor Structures”):
https://fieldrobotics.net/FR/Papers_files/4_Basiri.pdf

Journal Paper 2 (“Designing and Control of Track-Belt Robot for Firefighting Tasks”):
https://ieeexplore.ieee.org/document/10221617

[1] Meysam Basiri, João Gonçalves, José Rosa, Rui Bettencourt, Alberto Vale and Pedro Lima, “Multipurpose Mobile Manipulator for Autonomous Firefighting and Construction of Outdoor Structures,” Field Robotics Journal, Special Issue: The Mohamed Bin Zayed International Robotics Challenge (MBZIRC) 2020, Lisbon, Portugal, 2021, pp. 102-126, 10.55417/fr.2021004.

[2] S. Hoang, A. P. T. Nguyen and N. X. Nguyen, "Designing and Control Track-Belt Robot for Firefighting Task," 2023 7th International Conference on Robotics and Automation Sciences (ICRAS), Wuhan, China, 2023, pp. 53-57, doi: 10.1109/ICRAS57898.2023.10221617.