UNMANNED SYSTEMS LAB

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AutoCone: An OmniDirectional Robot for Lane-Level Cone Placement

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Presentation Outline

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- Background and Problem
- System Architecture
- Kinematics
- Filtering
- Results

Motivation

In the US from 2011-2017:

- Transportation events caused 76% of roadway work zone fatalities[1]
- In 60% of these events, the worker was struck by a vehicle in the work zone.

To improve worker safety:

- Traffic control devices should be used
- Signage, barrels, or cone delineators are effective.

However:

- Placing control devices itself is dangerous
- Temporary structures are hard to implement

Therefore:

- Automatically deploy cones from work vehicle

[2]

Problem Formulation

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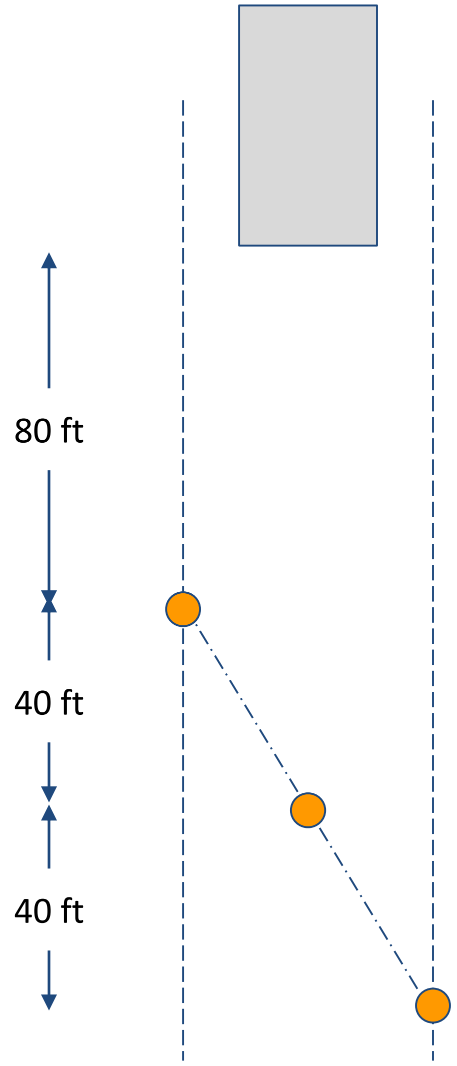
System Requirements:

- Place three cones in 40 foot increments in a wedge
- Begin the wedge 80 feet from the end of the vehicle
- Operate on highway surfaces unaffected by small debris
- Remain within the lane despite road curvature
- Not rely on road-embedded sensors
- Cost less than $1,500 per cone unit



Platform Selection

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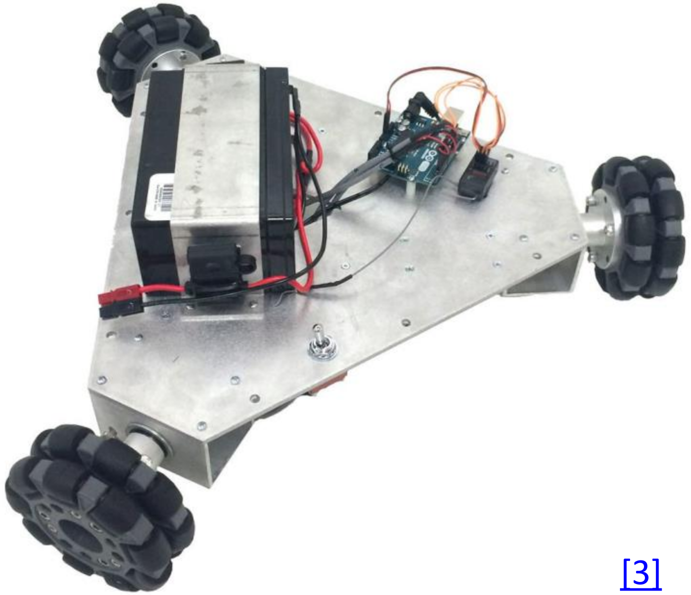
Design Considerations:

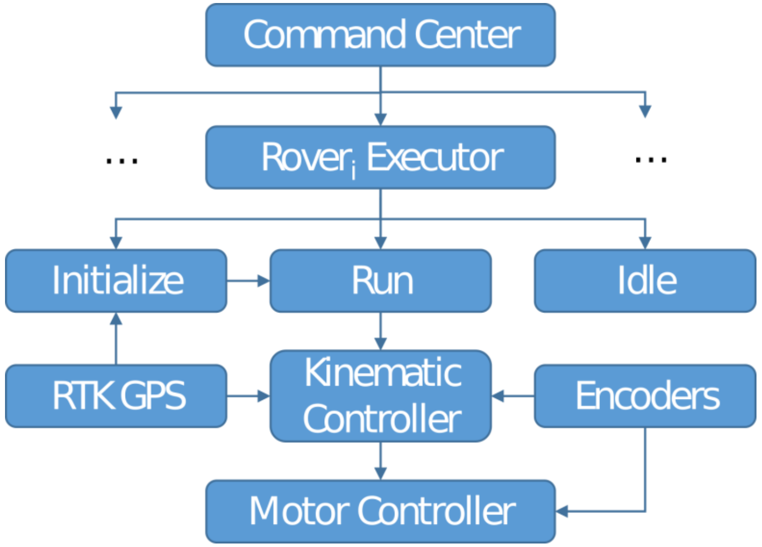
- Cost was a major factor
- Holonomic systems can easily fix operator error
- Three wheeled omni wheeled systems are lower cost than Mecanum wheel systems
- Motor with encoders would aid in dead-reckoning
- New Ardusimple RTK GPS gives low-cost, high accuracy positioning
- Cameras and LiDAR considered, not chosen

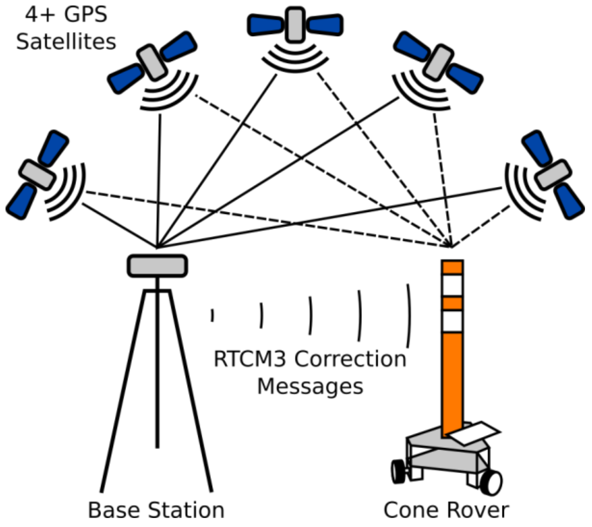


[3]

System Architecture

- Control deployment and retrieval from main vehicle
- Each cone runs a ROS core
- nimbro_network to pass information between ROS cores on each cone
    - Collision avoidance
    - Eventual cooperative localization
- RTK base station sends RTCM corrections to cones

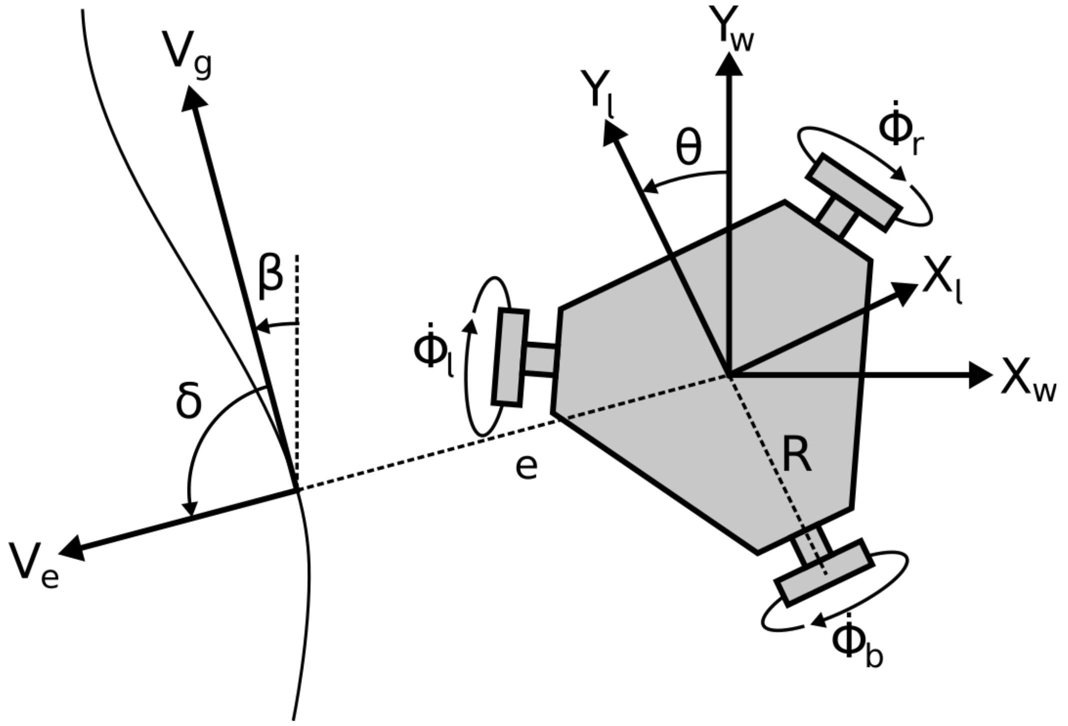




Kinematics

$$\begin{bmatrix}\dot{\Phi}_l\\ \dot{\Phi}_b\\ \dot{\Phi}_r\end{bmatrix} = \frac{1}{r}\begin{bmatrix}-\frac{1}{2} & -\frac{\sqrt{3}}{2} & R\\ 1 & 0 & R\\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & R\end{bmatrix}\begin{bmatrix}\dot{x}_l\\ \dot{y}_l\\ \dot{\theta}_l\end{bmatrix}$$

$$\begin{bmatrix}\dot{x}_l\\ \dot{y}_l\\ \dot{\theta}_l\end{bmatrix} = \frac{r}{3}\begin{bmatrix}-1 & 2 & -1\\ -\sqrt{3} & 0 & \sqrt{3}\\ \frac{1}{R} & \frac{1}{R} & \frac{1}{R}\end{bmatrix}\begin{bmatrix}\dot{\Phi}_l\\ \dot{\Phi}_b\\ \dot{\Phi}_r\end{bmatrix}$$



Extended Kalman Filter

- The forward kinematics form the state prediction equation
- Measurement updates are given by the RTK GPS

$$\hat{\boldsymbol{x}}_{k|k-1} = f(\dot{\boldsymbol{\Phi}}_{k-1})$$

$$\boldsymbol{P}_{k|k-1} = \boldsymbol{F}_k \boldsymbol{P}_{k-1|k-1} \boldsymbol{F}_k^T + \boldsymbol{Q}_k$$

$$\bar{\boldsymbol{y}}_k = \boldsymbol{z}_k - h(\hat{\boldsymbol{x}}_{k|k-1})$$

$$\boldsymbol{S}_k = \boldsymbol{H}_k \boldsymbol{P}_{k|k-1} \boldsymbol{H}_k^T + \boldsymbol{R}_k$$

$$\boldsymbol{K}_k = \boldsymbol{P}_{k|k-1} \boldsymbol{H}_k^T \boldsymbol{S}_k^{-1}$$

$$\hat{\boldsymbol{x}}_{k|k} = \hat{\boldsymbol{x}}_{k|k-1} + \boldsymbol{K}_k \tilde{\boldsymbol{y}}_k$$

$$\boldsymbol{P}_{k|k} = (\boldsymbol{I} - \boldsymbol{K}_k \boldsymbol{H}_k) \boldsymbol{P}_{k|k-1}$$

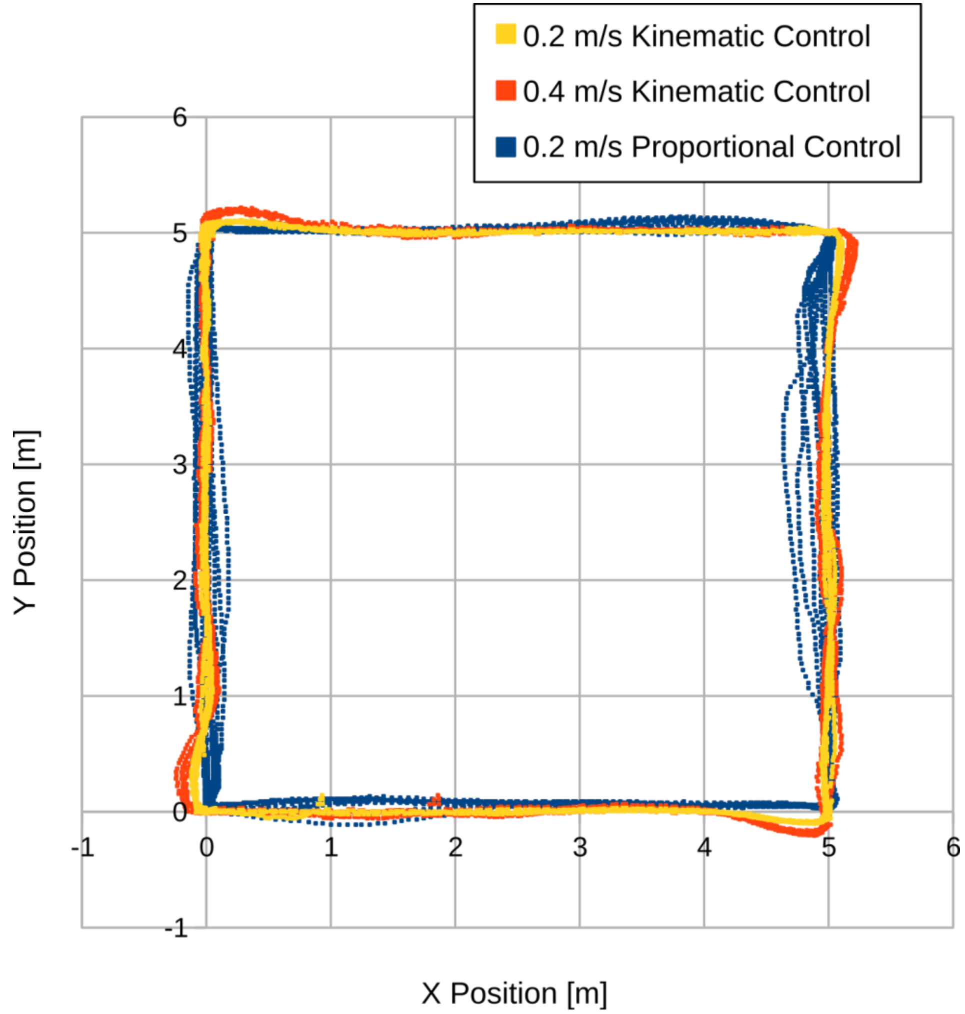
Control Schema

Proportional Control

- Only utilize position error
- No understanding of path information
- Simpler to use
- Affected by motor spool up/down
- 0.5 meter maximum error

Kinematic Control

- Incorporates path information
- Lower lateral errors
- 0.2 meter overshoot error
- Overshoot errors can be reduced with tuning



GPS-Denied Environments

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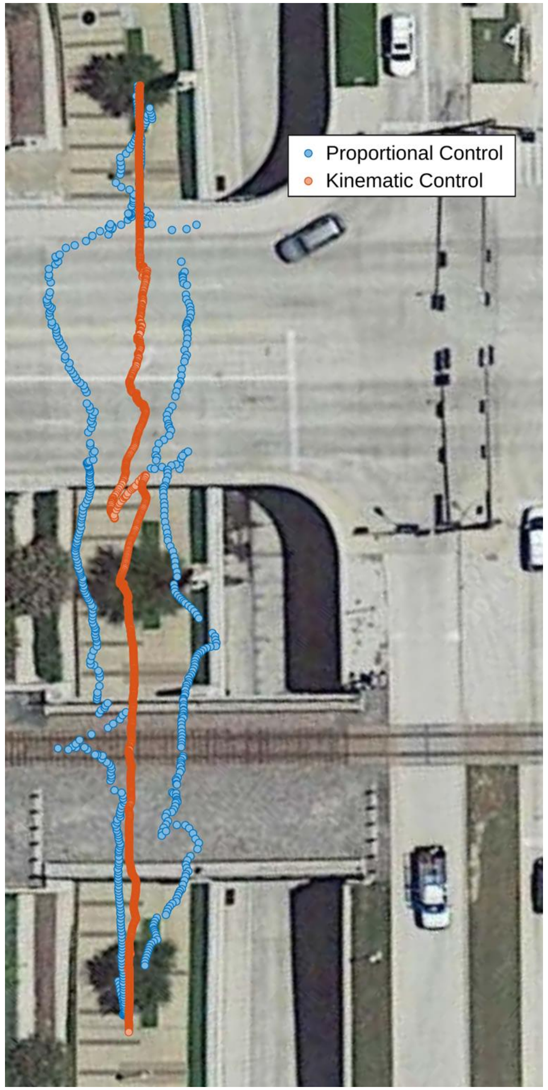
On highways, GPS is not always available
- Overpasses and bridges obscure GPS constellation
- Dead-reckoning can be subject to drift

Proportional Control Schema
- Susceptible to GPS errors
- Maximum error of 7.72 meters

Kinematic Control Schema
- Even with poor GPS data, performs well
- System remained within lane width throughout deployment
- Maximum error of 1.97 meters



Future Work

Texas A&M University

Estimation Improvements

- Consider the addition of Ultra-wideband ranging
- Landmark-based corrections and knowledge of home vehicle

Lanelet Incorporation

- Utilize lanelet information (e.g. OpenMapBox) for path data
- Lane dependent paths

[4]

Conclusions

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- System Cost: $1,600
- Operable on highway surfaces
- Not subject to operator initialization error
- Lane level wedge placement achievable
- Multi-robot coordination
- RMS error of 0.46 meters in GPS-denied environment

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