Ming Hsieh Department of Electrical Engineering

USC Viterbi School of Engineering

A Novel System for Localization and Tracking in Robotic Networks

Pradipta Ghosh, Jason Tran, and Bhaskar Krishnamachari

ANRG

- Solely RSSI based relative position sensing and movement control system
- Demonstrated <5m proximity with 99% empirical probability to a leader that is at least 1.8x slower

Problem Formulation

- Leader (L): Uncontrolled unknown path $Path_L$
  Location $Pos_L(t) = (x_L(t), y_L(t))$
- TrackBot (F): Controlled path $Path_F$
  Location $Pos_F(t) = (x_F(t), y_F(t))$

Goal: $P\left(||Pos_L(t) - Pos_F(t)||_2 \leq D_{th}\right) \approx 1 \; \forall \, t$

State Dynamics

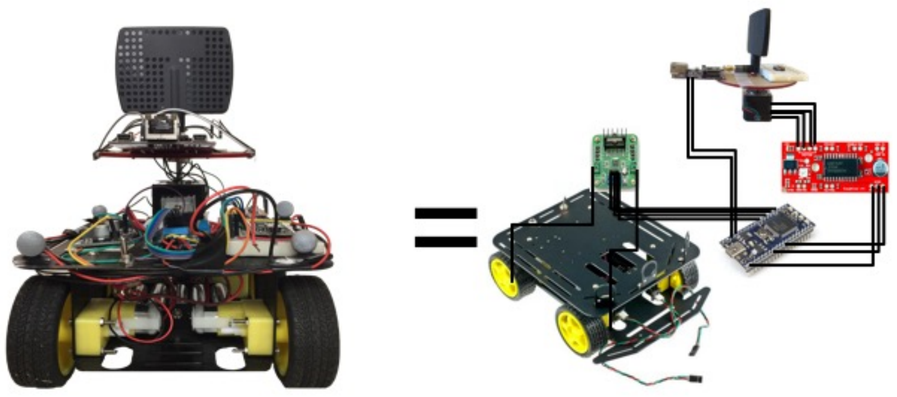
- State: $S(t) = [d^e(t), \; v^e_{rel}(t), \; \theta^e_{rel}(t)]^T$
- Observation: $O(t) = [d^m(t), \; v^m_{rel}(t), \; \theta^m_{rel}(t)]^T$
- System: $S(t+1) = AS(t) + BU(t) + Z(t)$
  $O(t) = CS(t) + W(t)$

$$\mathbf{A} = \begin{bmatrix} 1 & -\delta t & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \mathbf{B} = \begin{bmatrix} 0 & -\delta t & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix}, \mathbf{C} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

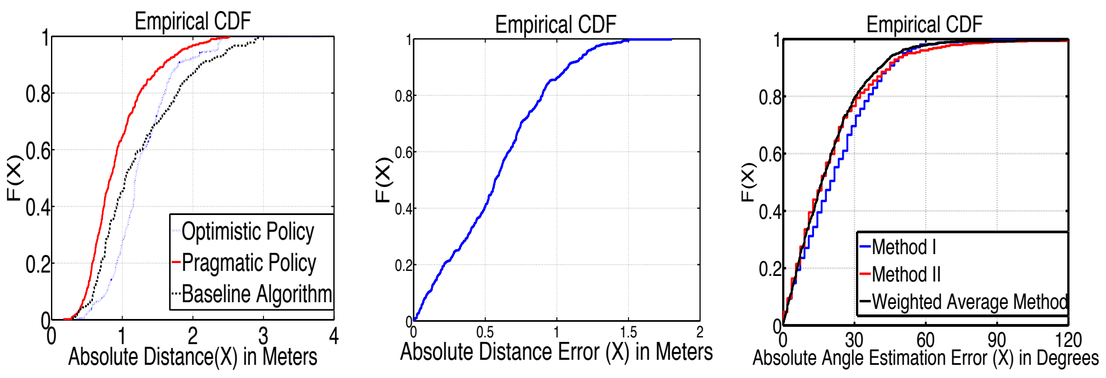
Cost Function: $$J = \lim_{N\to\infty} \frac{1}{N} \mathbb{E}\left(\sum_{t=0}^{N} S(t)^T \mathbf{Q} S(t) + \mathbf{U}(t)^T \mathbf{H} \mathbf{U}(t) \right)$$

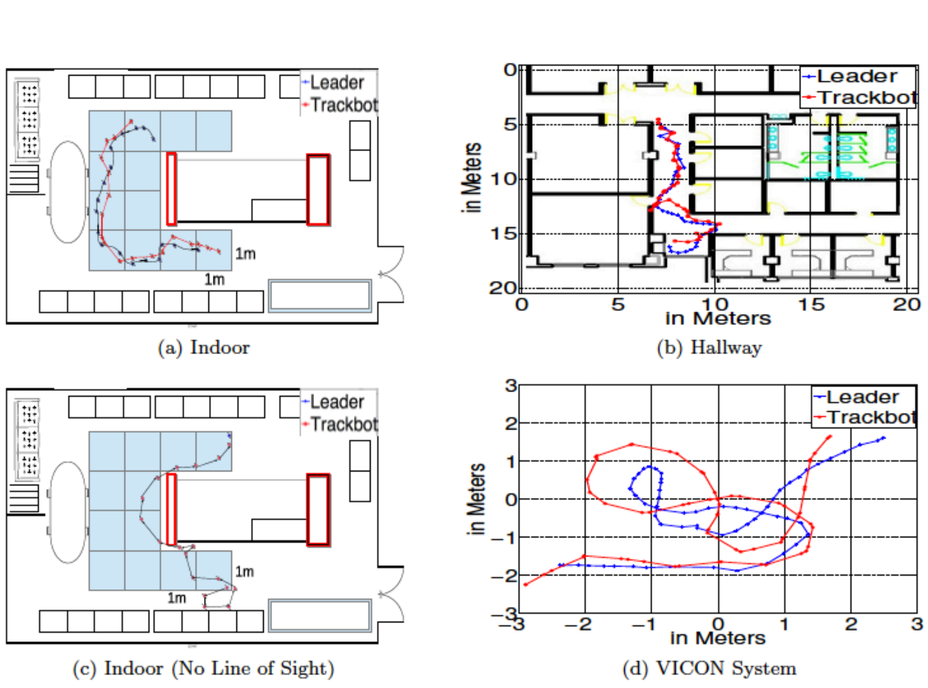
LQG Solution: $$\hat{S}(t+1) = A\hat{S}(t) + B\mathbf{U}(t) + K(\mathbf{O}(t+1) - C\{A\hat{S}(t) + B\mathbf{U}(t)\})$$
$$\mathbf{U}(t) = -L\hat{S}(t) \quad \text{and} \quad \hat{S}(0) = \mathbb{E}(S(0))$$

The TrackBot Prototype



Practical Experiment Results



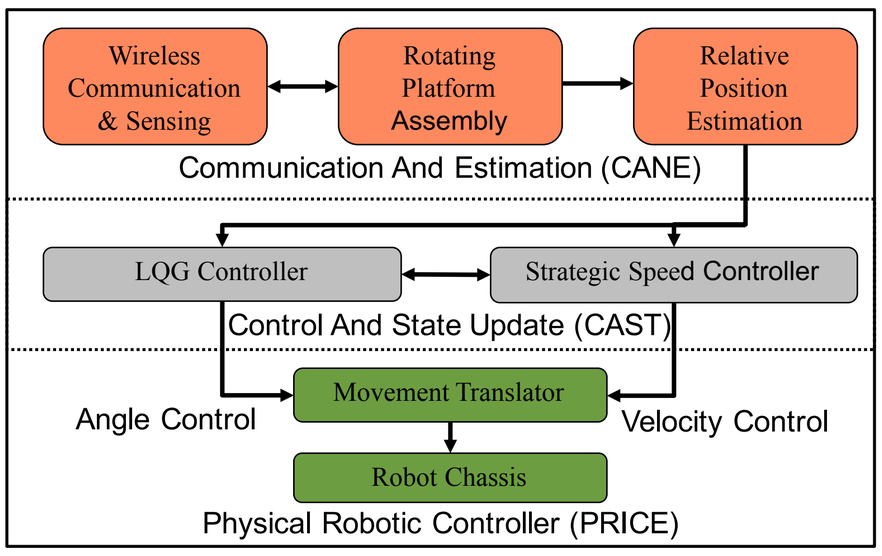


(a) Indoor (b) Hallway

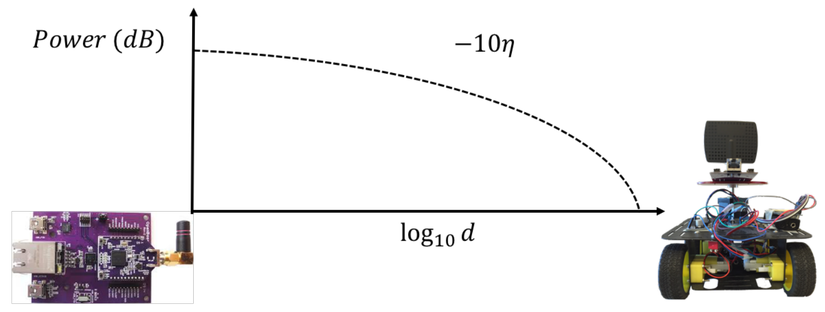
(c) Indoor (No Line of Sight) (d) VICON System

Full Path Traces from Practical Experiments

The Proposed System

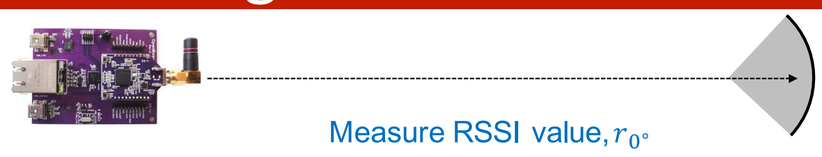


Distance Observation



$$\left.\begin{aligned} P_{r,dBm} &= P_{t,dBm} + G_{dB} - PL_{ref} - 10\eta \log_{10} \tfrac{d^m(t)}{d_{ref}} + \psi \\ P^{ref}_{r,dBm} &= P_{t,dBm} + G_{dB} - PL_{ref} + \psi \end{aligned}\right\} \Longrightarrow \frac{d^m(t)}{d_{ref}} \approx 10^{\frac{(P^{ref}_{r,dBm} - P_{r,dBm})}{10\cdot\eta}}$$

Angle Observation



r_{-180°	$r_{-178.2^\circ}$	⋯	$r_{-1.8^\circ}$	r_{0°	$r_{1.8^\circ}$	⋯	$r_{176.4^\circ}$	$r_{178.2^\circ}$	$rssi_v$
				Normalize					
r'_{-180°	$r'_{-178.2^\circ}$	⋯	$r'_{-1.8^\circ}$	r'_{0°	$r'_{1.8^\circ}$	⋯	$r'_{176.4^\circ}$	$r'_{178.2^\circ}$	$gain_m$
g_{-180°	$g_{-178.2^\circ}$	⋯	$g_{-1.8^\circ}$	g_{0°	$g_{1.8^\circ}$	⋯	$g_{176.4^\circ}$	$g_{178.2^\circ}$	$gain_{abs}$
				Shift by θ					
$g_{-180+\theta}$	$g_{-178.2+\theta}$	⋯	$g_{-1.8+\theta}$	$g_{0+\theta}$	$g_{1.8+\theta}$	⋯	$g_{176.4+\theta}$	$g_{178.2+\theta}$	$gain_{abs}(\theta)$

$\theta \in \Theta = \{-180^\circ, -178.2^\circ, \cdots, 0^\circ, \cdots, 178.2^\circ\}$

- Method I: $\theta^m_{rel} = \arg\min_{\theta\in\Theta} \sum_{k\in\Theta} ||r'_k - g_{(k+\theta)}||_2 \cdot \mathbb{I}_{r'_k}$
- Method II: $\theta^m_{rel} = \arg\min_{\theta\in\Theta} \sum_{k\in\Theta} \omega_k \cdot ||r'_k - g_{(k+\theta)}||_2 \cdot \mathbb{I}_{r'_k}$
- Method III: $\theta^e_m = \begin{cases} \frac{blk_{avg}}{gap_{avg}} \cdot \theta^1_m + (1 - \frac{blk_{avg}}{gap_{avg}}) \cdot \theta^2_m & \text{if } blk_{avg} \leq gap_{avg} \\ \theta^1_m & \text{if } blk_{avg} > gap_{avg} \end{cases}$

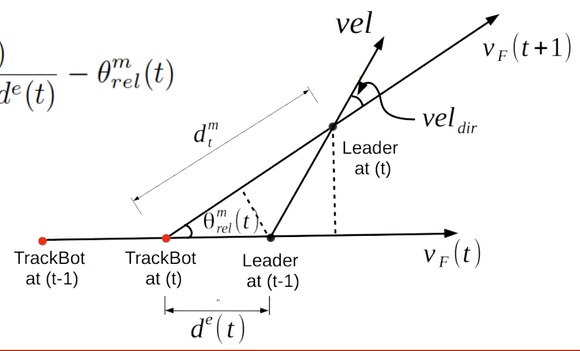
Speed Observation

- Optimistic:

$$v^m_{rel}(t) = v^e_{rel}(t) - \frac{(d^m(t) - d^e(t) \times \cos\theta^m_{rel}(t))}{\delta t} \quad \text{and} \quad v^e_L(t+1) = 0$$

- Pragmatic:

$$vel = \frac{\left((d^e(t) - d^m(t)\cdot\cos\theta^m_{rel}(t))^2 + (d^m(t)\cdot\sin\theta^m_{rel}(t))^2\right)^{1/2}}{\delta t}$$
$$vel_{dir} = \arctan\frac{d^m(t)\cdot\sin\theta^m_{rel}(t)}{d^m(t)\cdot\cos\theta^m_{rel}(t) - d^e(t)} - \theta^m_{rel}(t)$$
$$v^e_L(t+1) = v^m_L(t) = vel\cdot\cos(vel_{dir})$$
$$v^m_{rel}(t) = v_F(t) - v^m_L(t)$$



pradiptg@usc.edu, jasontra@usc.edu, bkrishna@usc.edu

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