Mobile Robot Navigation Amidst Humans with Intents and Uncertainties:A Time Scaled Collision cone Approach

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Outline

Motivation

Human Intention prediction

Proactive collision avoidance in intent space

Motivation

- Robots and humans are beginning to occupy the same work spaces
- Account for human intent in robot's navigation and avoidance Maneuver
- Uncertain and Haphazard local movements of human

Outline

Motivation

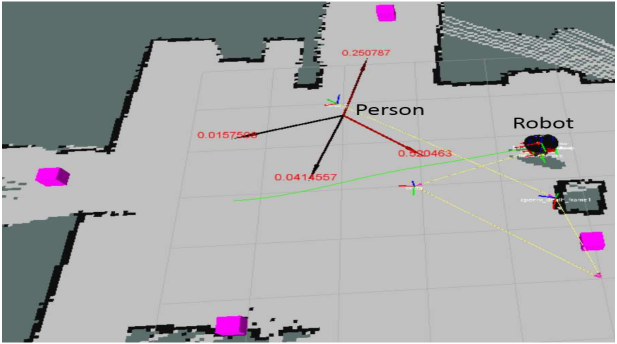
Human Intention prediction

Proactive collision avoidance in intent space

Human Intention prediction

- Characterize intents as the final destinations a person might reach
- Let $D = \{\mathbf{d^1}, \mathbf{d^2}, ..., \mathbf{d^m}\}$ be the set of final destinations a person can go to in a given environment
- compute the probability of each of these intents Using Hidden Markov Model.
- Characterize local Haphazard movements as a gaussian $\mathcal{N}(\mu_i(\mathbf{x}^t), \sigma_t)$

Human Intention prediction

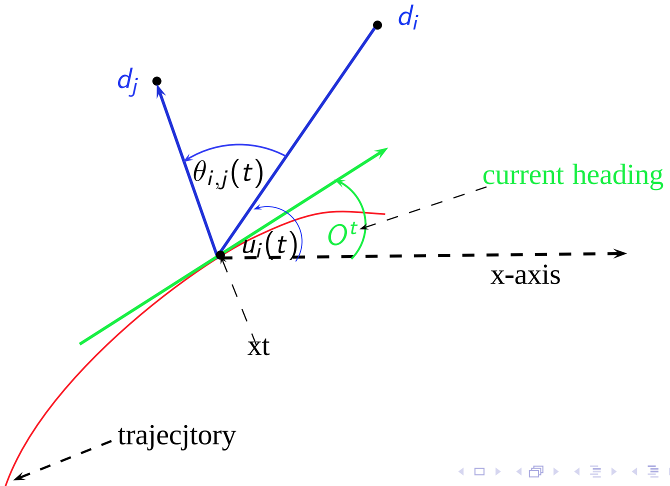


HMM for Intention prediction

- Let $S^t \in D$ represent the intent of a person to reach destination S^t at time t.
- D represents set of states in HMM.
- Human trajectories are represented as $X(T) = \{\mathbf{x^1}, \mathbf{x^2}, ..., \mathbf{x^T}\}$

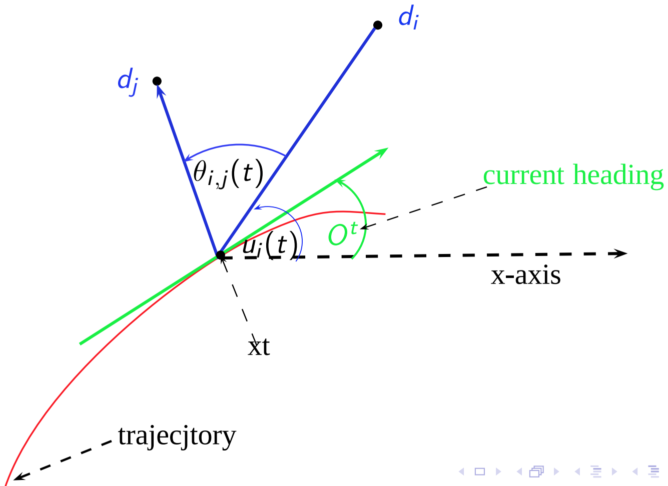
HMM for Intention prediction

- O^t is the angle defined by the first derivative of the trajectory at point $\mathbf{x^t}$
- Given the current position and orientation we compute the probability of reaching each of the destination $d^i \in D$



HMM for Intention prediction

- $\mu_i(t)$ is the measure relative to the destination $\mathbf{d^i}$
- O^t is the global measure of the target orientation
- $\theta_{ij}(t)$ is the measure between final destinations $\mathbf{d^i}$ and $\mathbf{d^j}$ relative to the current position $\mathbf{x^t}$



HMM for Intention prediction

- $b_i(O^t)$ is the probability of observing heading O^t given that the person is following the intent $\mathbf{d^i}$ at time t.

$$b_i(O^t) = p(O^t | S^t = \mathbf{d^i}) = \mathcal{N}(O^t | \mu_i(t), \sigma_o)$$

- $a_{ij}(t)$ is the probability that the human changes his intent from $\mathbf{d^i}$ to $\mathbf{d^j}$ at any discrete instant t

$$a_{ij}(t) = p(S^{t+1} = \mathbf{d^j} | S^t = \mathbf{d^i}) = \eta\mathcal{N}(\theta_{ij}(t) | 0, \sigma_a)$$

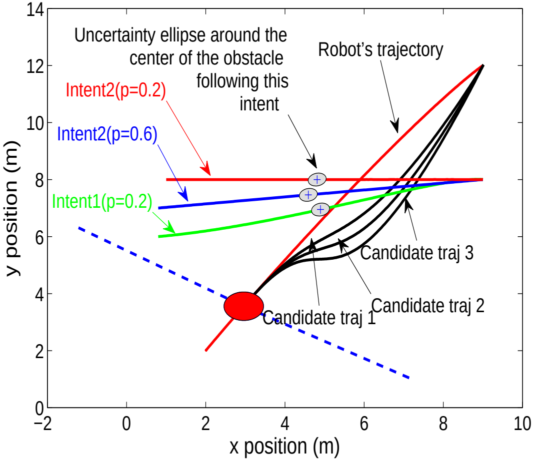
HMM for Intention prediction

- Let $O^{1:T} = \{O^1, O^1, ..., O^T\}$ is the set of measurements obtained till time T.
- Our task is to calculate $p(S^t = \mathbf{d^i} | O^{1:T}, \lambda)$
- In HMM this term is usually referred to as $\gamma_t(i)$ To find this we use standard forward and backward algorithms.

Proactive collision avoidance in intent space

- To propose an optimization framework, That achieves an elegant balance between minimizing risk and ease of collision avoidance maneuver.
- Ease of Collision avoidance maneuver directly relates to factors like deviation from current path and acceleration and deceleration capabilities of robot.
- Minimizing risk boils down to biasing the maneuver towards avoiding the most likely intent with higher confidence.

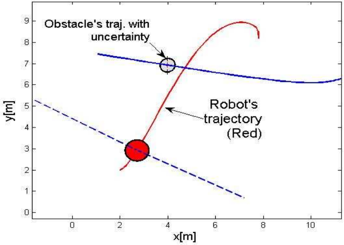
Proactive collision avoidance in intent space



Proactive collision avoidance in intent space

Formulation steps

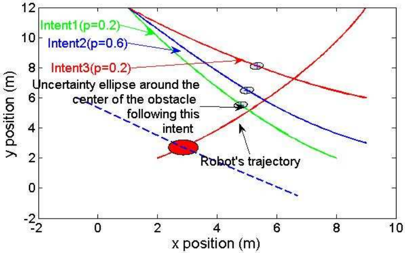
- Formulation for finding a relation between a particular collision avoidance maneuver and its confidence of safety, for a particular obstacle/intent.



Proactive collision avoidance in intent space

Formulation steps

- Formulation extending it to multiple intent space



Proactive collision avoidance in intent space

Explanation of Formulation one

- Finding a relation between a particular collision avoidance maneuver and its confidence of safety, for a particular obstacle/intent [1]

[1]: Bharath Gopalakrishnan*, Arun Kumar Singh*, K.Madhava Krishna, Closed form characterization of Collison free velocities and confidence boinds for Non- holonomic robots in uncertain dynamic environments- To appear in IEEE Proc of IROS 2015

Proactive collision avoidance in intent space

Recap of time scaled collision cone:

- Time scaled collision cone constraint takes the following from

$$f_i^s \geq 0$$

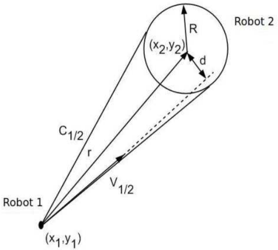
- where f_i^s is given by

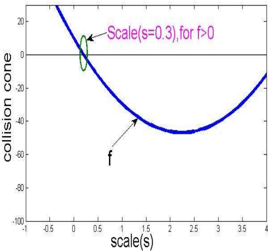
$$f_i = (x^{t_c} - x_i^{t_c})^2 + (y^{t_c} - y_i^{t_c})^2 - R^2 \quad (1)$$
$$- \frac{(s\dot{x}^{t_c} - \dot{x}_i^{t_c})(x^{t_c} - x_i^{t_c}) + (s\dot{y}^{t_c} - \dot{y}_i^{t_c})(y^{t_c} - y_i^{t_c})^2}{(s\dot{x}^{t_c} - \dot{x}_i^{t_c})^2 + (s\dot{y}^{t_c} - \dot{y}_i^{t_c})^2}$$
$$, \forall i = 1, 2 \ldots n$$

- f_i^s denotes the collision cone constraint for the i^{th} obstacle as a function of scale s. which depends on the state of the robot and obstacle at time $t = t^c$ which gets reduced to

$$a_i s^2 + b_i s + c_i \geq 0$$

Proactive collision avoidance in intent space





Proactive collision avoidance in intent space

Probabilistic version of time scaled collision cone

- if at time $t = t_c$ the obstacles state are given by

$$x_i^{t_c} = \mathcal{N}(\mu_i^x, \sigma_i^x), \dot{x}_i^{t_c} = \mathcal{N}(\mu_i^{\dot{x}}, \sigma_i^{\dot{x}})$$

$$y_i^{t_c} = \mathcal{N}(\mu_i^y, \sigma_i^y), \dot{y}_i^{t_c} = \mathcal{N}(\mu_i^{\dot{y}}, \sigma_i^{\dot{y}})$$

- Then the objective would be to find the scale that maximizes

$$P(f_i^s \geq 0)$$

Proactive collision avoidance in intent space

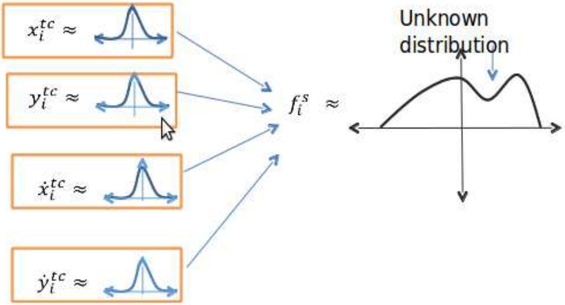
Objective

$$\underset{s}{\operatorname{argmax}}\{P(f_i^s \geq 0)\}$$

Challenge

- f_i^s *is* a random variable with unknown analytical expression for its probability distribution.

Proactive collision avoidance in intent space



Proactive collision avoidance in intent space

Solution

- Though the pdf of $f_i^s is$ does not have an analytical expression we can get its mean and standard deviation in closed form as a function of s
- By the law of unconscious statistician

$$E[f_i^s] = \mu_{f_i^s} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_i^s(.)P_i(.)dx_i^{t_c}dy_it_c d\dot{x_i}^{t_c}d\dot{y_i}^{t_c}$$

- Which evaluates as

$$\mu_{f_i^2} = A_is^2 + B_is + C_i$$

Where A_i, B_i and C_i are the function of robot states and obstacle distribution parameters , $\mu_i^1, \mu_i^2, \sigma_i^1, \sigma_i^2$

Proactive collision avoidance in intent space

Solution

- Similarly

$$\sigma_{f_i^s} = \sqrt{E[(f_i^s - E[f_i^s])^2} = \sqrt{D_i s^4 + E_i^3 + F_i^2 + G_i s + H}$$

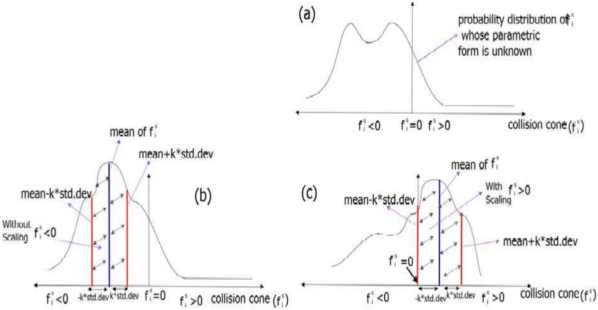
Where D_i, E_i, F_i, G_i, and H_i are the function of robot states and obstacle distribution parameters , $\mu_i^1, \mu_i^2, \sigma_i^1, \sigma_i^2$

Proactive collision avoidance in intent space

Solution

$$\underset{s}{\operatorname{argmax}}\{P(f_i^s \geq 0)\} \Longrightarrow \mu_{f_i^s} \pm k * \sigma_{f_i^s}$$

This can be suitably achieved by suitably changing the value of k



Summary

- The first main message of your talk in one or two lines.
- The second main message of your talk in one or two lines.
- Perhaps a third message, but not more than that.

- Outlook
  - Something you haven't solved.
  - Something else you haven't solved.

For Further Reading I

A. Author.
Handbook of Everything.
Some Press, 1990.

S. Someone.
On this and that.
Journal of This and That, 2(1):50–100, 2000.