Plan Recognition for Behavior Estimation in a Robotic Soccer Player

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Plan Recognition

The final objective in [Kaminka et al., 2018] is to recognize the path of a robot in one ambient of free collision.
The problem can be formulated as:

$$\pi_R = \operatorname*{argmax}_{\pi \in W} P(\pi|O) \tag{1}$$

With Bayes Rules we can compute the $P(\pi|O)$

$$\begin{aligned} P(\pi|O) =& \beta P(O|\pi)P(\pi) \\ =& \beta P(O|\pi)P(\pi|g)P(g), \end{aligned} \tag{2}$$

- where $P(g)$ is an uniform distribution probability that robot is pursuing the goal g

Plan Recognition

The common approach in literature:

- Search a linear path between two points, in other words, a straight line. (shortest distance)
- Any consideration about time.
- Any restriction about robot velocity

Problem of this approach

Linear trajectories are problematic because they imply constant velocity and consequently discontinuous accelerations in the initial and final instants [Niku, 2020].

Proposal

The proposal

Use cubic trajectories because they have a smoother velocity profile.

- The cubic function can generate any trajectory for this problem.

$$T_x(t) = A_3^x t^3 + A_2^x t^2 + A_1^x t + A_0^x \tag{3}$$
$$T_y(t) = A_3^y t^3 + A_2^y t^2 + A_1^y t + A_0^y \tag{4}$$
$$T_\theta(t) = A_3^\theta t^3 + A_2^\theta t^2 + A_1^\theta t + A_0^\theta \tag{5}$$

where t is the real time and A_i^η, $i \in \{0, 1, 2, 3\}$, $\eta \in \{x, y, \theta\}$ are unknown coefficients.

Proposal

How the initial and final positions are known, the equations (3-5) can be calculated from analytic way as:

$$A_0^\eta = T_\eta(t_0) \tag{6}$$
$$A_1^\eta = \dot{T}_\eta(t_0) \tag{7}$$
$$A_2^\eta = \frac{3}{{t_f}^3}(T_\eta(t_f) - T_\eta(t_0)) - \frac{2}{t_f}\dot{T}_\eta(t_0) - \frac{1}{t_f}\dot{T}_\eta(t_f) \tag{8}$$
$$A_3^\eta = -\frac{2}{{t_f}^3}(T_\eta(t_f) - T_\eta(t_0)) + \frac{1}{{t_f}^2}(\dot{T}_\eta(t_f) + \dot{T}_\eta(t_0)), \tag{9}$$
$$\eta \in \{x, y, \theta\}$$

where t_0 and t_f are respectively the initial and final time.

- The Final time is the last variable that can be uncovered to calculated the coefficients A_i^η.

Proposal

To finding the final time, we can use the planning domain formulations as

$$W_t := \langle T,\, A_t,\, cost,\, I,\, G \rangle, \tag{10}$$

- T is an infinite set of fluents composed: $T = \{T_x(t), T_y(t), T_\theta(t)\}$
- $A_t \in \{t_0, \ldots, t_f\}$ is an infinite set of actions.
- cost is the metric to guide the search (min t_f).
- $I \in T$ is an initial state at time t_0.
- G $\in$ T a set of goals at final time t_f.

Proposal

The optimal cubic trajectory for each goal can be calculated as

$$
\begin{aligned}
T_\eta^g(t)^* = & A_3^\eta t^3 + A_2^\eta t^2 + A_1^\eta t + A_0^\eta \\
& t \in \{t_0, \ldots, {t_f}^*\} \\
& \forall g \in G \\
& \forall \eta \in \{x, y, \theta\}
\end{aligned} \tag{11}
$$

Proposal

Example of optimal cubic trajectory

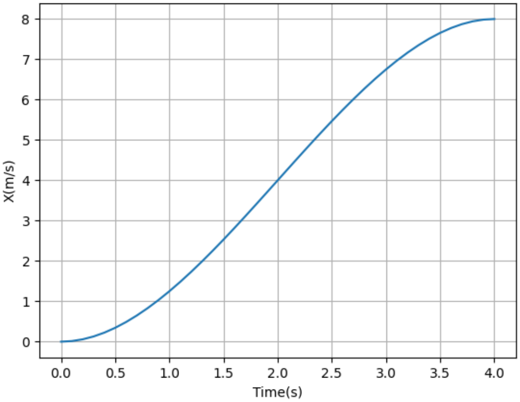

Figure: $T_x(t)^*$.

- $I = \{0\}$
- $g = \{8\}$
- $t_f = 4.02$

Proposal

Example of optimal cubic velocity

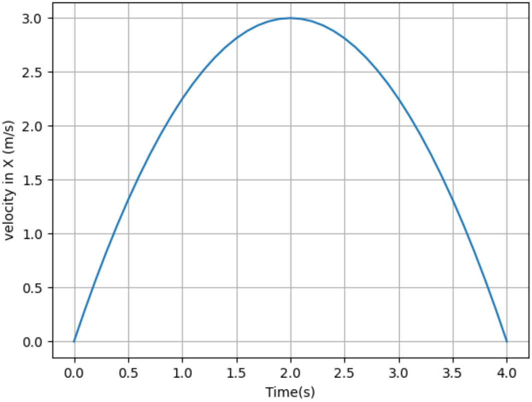

Figure: $\dot{T}_x(t)^*$.

- $I = \{0\}$
- $g = \{8\}$
- $t_f = 4.02$
- $U_{max} = 3$

Online Recognition Problem

Algorithm Outline

At each observations arrived, the recognition algorithm find the trajectory that best fits the sequence of observations and predict the trajectory to each goal.

The online recognition problem is a tuple

$$R_t := \langle W_t, O_t, I, G \rangle \tag{12}$$

- W_t is the domain theory defined in previously slides.
- O_t is a sequence of observations.
- I the initial states.
- G the set of hypothesis goals.

Online Recognition Problem

The recognition objective is now defined as

$$
{T_\eta}^R = \underset{T_\eta \in W_t}{\operatorname{argmax}} P(T_\eta | O_t) \tag{13}
$$

With Bayes Rules we can compute the joint probability defined as

$$
\begin{aligned}
P(T_\eta | O_t) &= \beta P(O_t | T_\eta) P(T_\eta) \\
&= \beta P(O_t | T_\eta^g) P(T_\eta^g | g) P(g),
\end{aligned} \tag{14}
$$

Online Recognition Problem

The $T^g_\eta(t)$ is the trajectory that passes through the observations and continues for each $g \in G$.

$$
\begin{aligned}
&\textit{From } t_0 \textit{ to } t: \\
&T^g_\eta(t) = o(t) \\
&\textit{From } t \textit{ to } {t_f}^*: \\
&A^\eta_0 = T_\eta(t) \\
&A^\eta_1 = \dot{T}_\eta(t) \\
&A^\eta_2 = \frac{3}{{t_f}^{*2}}(T_\eta({t_f}^*) - T_\eta(t)) - \frac{2}{{t_f}^*}\dot{T}_\eta(t) - \frac{1}{{t_f}^*}\dot{T}_\eta({t_f}^*) \\
&A^\eta_3 = -\frac{2}{{t_f}^{*3}}(T_\eta({t_f}^*) - T_\eta(t)) + \frac{1}{{t_f}^{*2}}(\dot{T}_\eta({t_f}^*) + \dot{T}_\eta(t)) \\
&T^g_\eta(t) = A^\eta_3 t^3 + A^\eta_2 t^2 + A^\eta_1 t + A^\eta_0 \\
&\eta \in \{x, y, \theta\} \\
&\forall g \in G.
\end{aligned}
\tag{15}
$$

Online Recognition Problem

Example of $T^g_\eta(t)$ generation

The robot is pursuing a fake goal in $\{8, 1, 0\}$

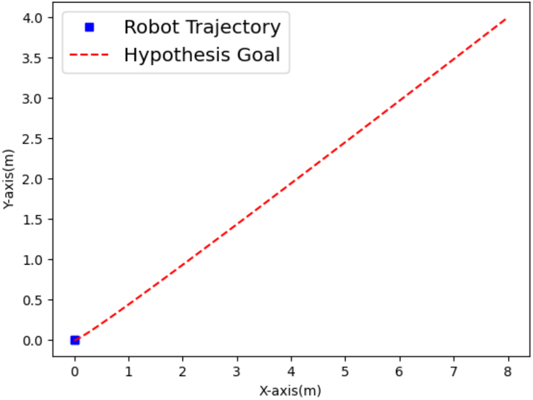

Figure: $T^g_\eta(t)$.

- $I = \{0, 0, 0\}$
- $t^*_f = 4.02$
- $U_{max} = 3$
- $g_1 = \{8, 4, 0\}$

Online Recognition Problem

Example of $T_{\eta}^{g}(t)$ generation

The robot is pursuing a fake goal in $\{8, 1, 0\}$

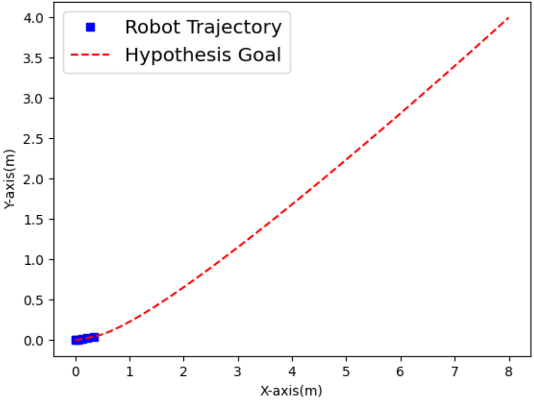

Figure: $T_{\eta}^{g}(t)$.

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Online Recognition Problem

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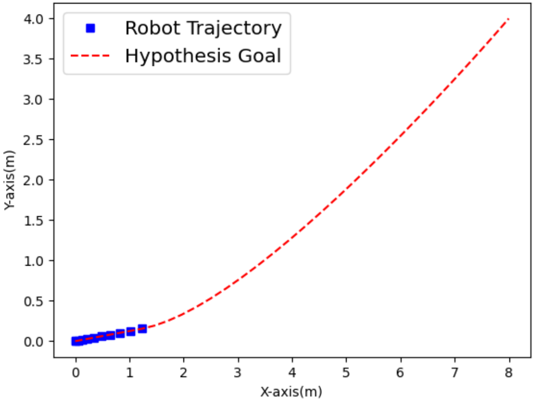

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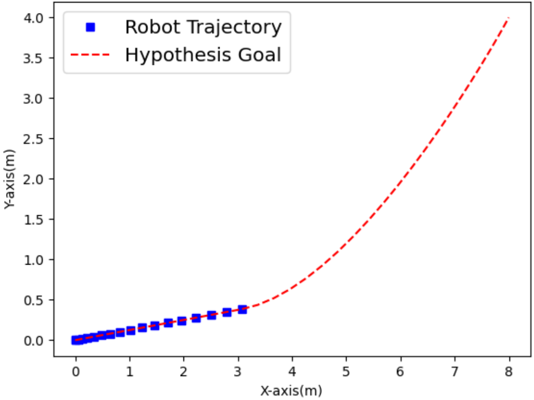

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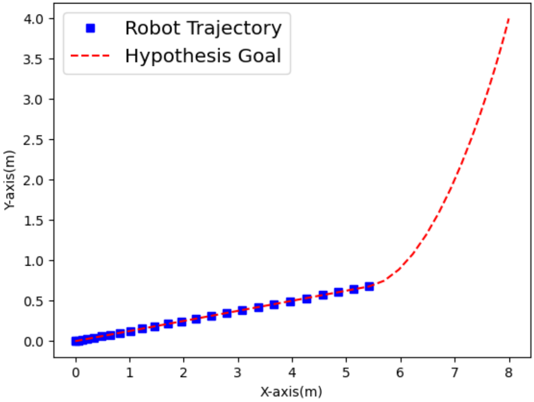

Figure: $T^g_\eta(t)$.

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Online Recognition Problem

Example of $T_\eta^g(t)$ generation
The robot is pursuing a fake goal in $\{8, 1, 0\}$

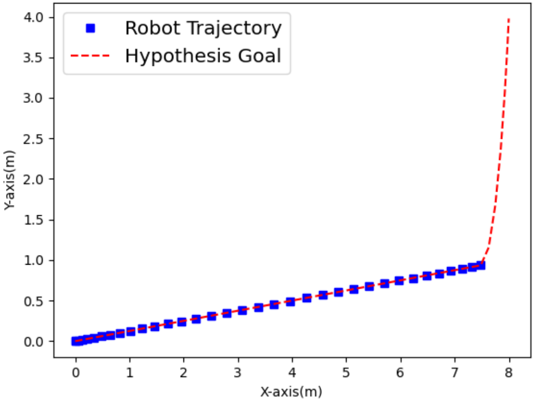

Figure: $T_\eta^g(t)$.

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Online Recognition Problem

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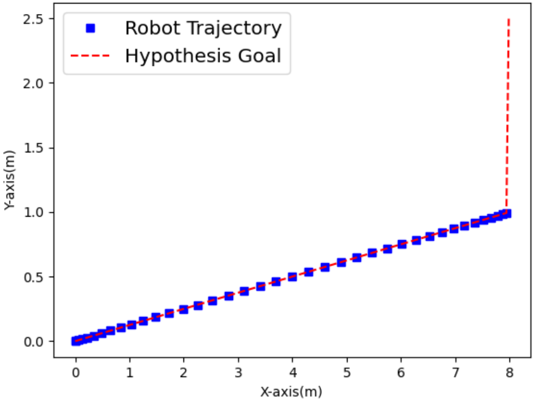

Figure: $T^g_\eta(t)$.

- $I = \{0, 0, 0\}$
- $t^*_f = 4.02$
- $U_{max} = 3$
- $g_1 = \{8, 4, 0\}$

Online Recognition Problem

Finally, we could use the following function to approximate the joint probability of $P(T_\eta^g|g)$

$$\forall g \in G, P(T_\eta^g|g) := \frac{cost(T_\eta^{g*})}{cost(T_\eta^g)}. \tag{16}$$

where $cost(\cdot)$ is a cost function that measure the trajectory length from t_0 to $t_f{}^*$.

Simulated Experiment

Simulated experiment of navigation
The robot is pursuing the goal 1

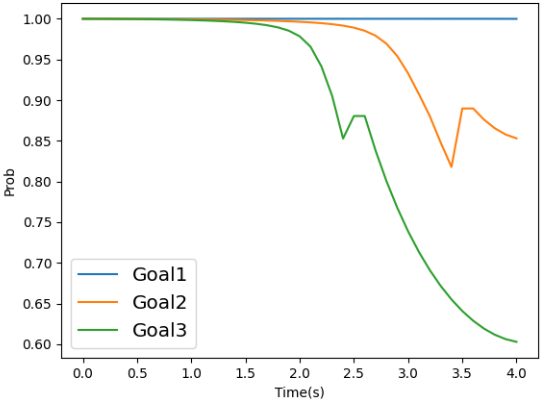

Figure: $P(T_\eta^g|g)$ by the time.

- $I = \{0, 0, 0\}$
- $g = \{8, 4, 0\}$
- $t_f = 4.02$
- $U_{max} = 3$
- $g_1 = \{8, 4, 0\}$
  $g_2 = \{7, 3, 0\}$
  $g_3 = \{5, 2, 0\}$

Future Works

- To insert collisions in the formulation.
- To add multi robots iterations.

References

Kaminka, G., Vered, M., and Agmon, N. (2018).
Plan recognition in continuous domains.
In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 32.

Niku, S. B. (2020).
Introduction to robotics: analysis, control, applications.
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