Side by Side Motion Planning for a Humanoid Robot

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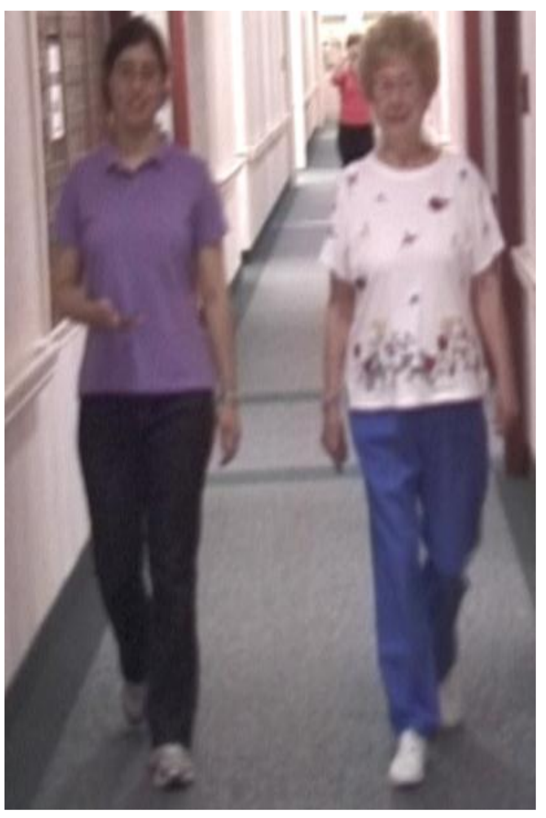
Problem

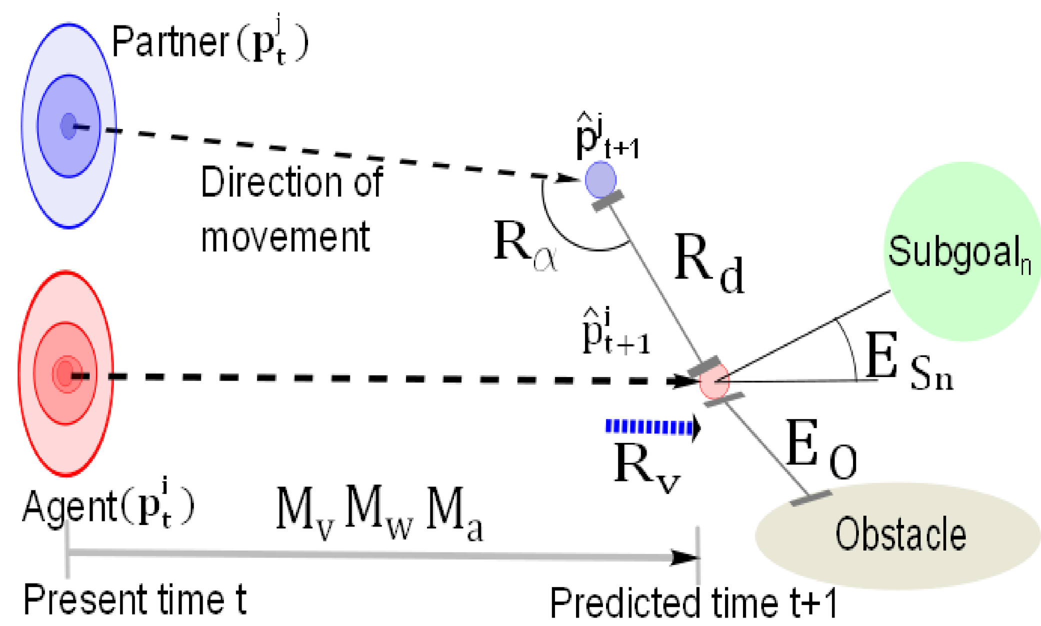
Robots designed to navigate in dynamic environments with humans must be able to adhere to certain social norms especially when walking side by side.



Objective

- Design a planning algorithm for a robot which takes into account social norms as the robot walks side by side with a person

Previous work



There are three factors and 8 utilities that determine the motion of a robot and human when walking next to each other

1. Motion factors
   - Velocity, angular velocity and acceleration
2. Relative factors
   - Social relative distance, relative angle and relative velocity
3. Environment factors
   - Distance to obstacles and moving towards sub-goals

Limitation of previous work

- Doesn't work in situations where one partner must walk in front of the other. such as situations where the human and robot must navigate through a door
- Doesn't take global orientation into consideration when progressing towards sub goal

Navigating through Doors

Used a state machine design approach to address the problem of walking through a door. The robot was in one of three states:

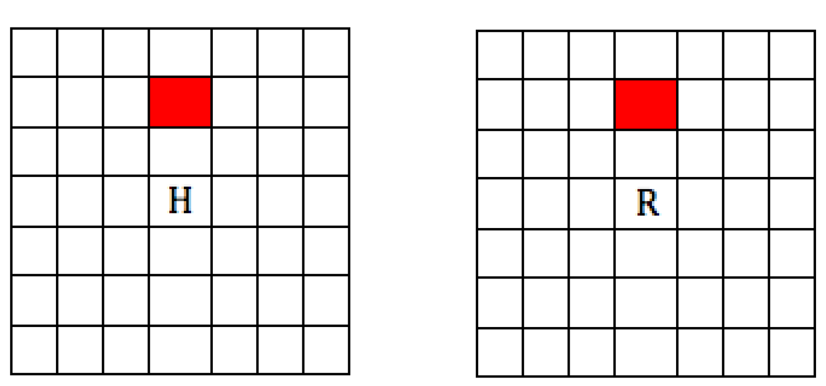
1)Side by Side -used Partner and Self-anticipation utility function
2) Before Door-Used standard predication where the robot allowed the human to walk through the door first and the robot followed. Each utility function was calculated and future path determined individually
3) After Door -Used standard predication and the human slowed down allowing the robot to catch up to the human.

Utility Calculation

- The robot and human potential future positions are illustrated by a 7X7 grid(anticipation grid) with each of their current position at the center of their respective grids. Each grid position is assigned a utility value.
- These values are calculated by summing the eight utilities using the utility modeling equation and a gains value
- The future position of the human or robot is calculated by determining the utility values for each entity, summing them together and determining which grid position has the highest value

$$f_x = \frac{1}{1+\left|\left(\frac{x-c}{a}\right)^{2b}\right|} - 1 \qquad f_o = -\left|\left(\frac{x}{a}\right)^{-2b}\right|$$

Function modeling equations



Anticipation grid for the robot and human

Utility Function

$$U(p^i, p^j) = k_O \cdot f_O + k_S \cdot f_S + k_{R_d} \cdot f_{R_d} + k_{R_\alpha} \cdot f_{R_\alpha} + k_{R_v} \cdot f_{R_v} + k_{M_a} \cdot f_{M_a} + k_{M_v} \cdot f_{M_v} + k_{M_w} \cdot f_{M_w}$$

Standard Prediction

$$\hat{p}^i_{t+1} = \operatorname{argmax}_{\{p^i|P^i\}} U(p^i, \hat{p}^j_{t+1})$$

Self Anticipation

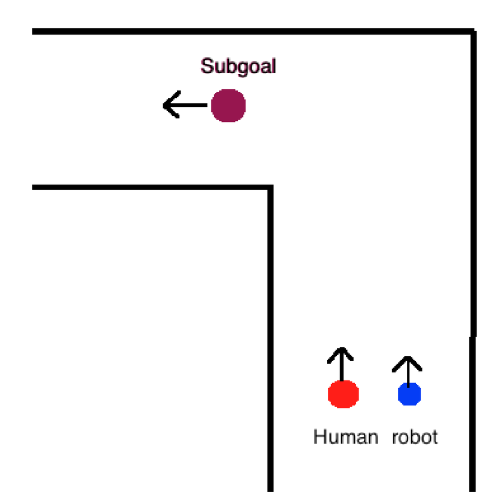
$$\hat{p}^i_{t+1} = \operatorname{argmax}_{\{p^i|P^i\}} U(p^i, \hat{p}^j_{t+1})$$

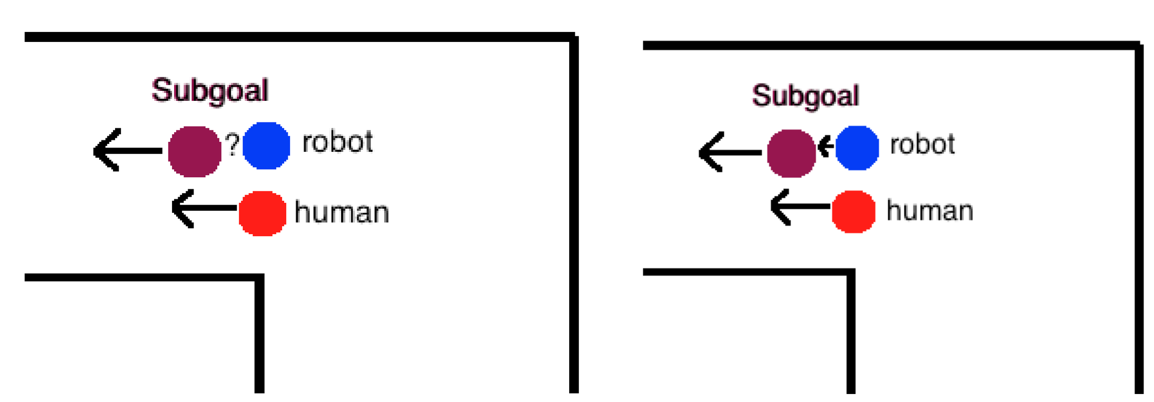
Partner and self-anticipation

$$\hat{p}^i_{t+1} = \operatorname{argmax}_{\{p^i|P^i\},\{p^j|P^j\}} \{U(p^i, p^j) + U(p^j, p^i)\}$$

Orientation

The robot is able to determine its orientation as it approaches the sub goal better now then it did before. This is done by keeping track of the robot's orientation relative to the sub goal and updating the robot orientation as it gets closer to the sub goal





Previous method New method

Reference

1. Prassler, E., Bank, D., & Kluge, B. (2002). Key technologies in robot assistants: Motion coordination between a human and a mobile robot. *Transactions on Control, Automation and Systems Engineering, 4*(1), 56–61
2. Morales, Y., Satoru S., Huq R., Glas D., Kanda T., Hagita N(2012). How Do People Walk Side-by-Side? - Using a Computational Model of Human Behavior for a Social Robot _–. Paper presented at the ACM/IEEE Int. Conf. on Human Robot Interaction (HRI2012).

Conclusions/Future work

- The algorithm works well in the various test cases.
- The next step is to implement it on an actual robot and run it in real time