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Constraint Optimised Path Tracking for Social Robots

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Abstract - The paper gives a mathematical model to efficiently implement social constraints in mobile robots and accordingly control its' tracking. A generalized constraint set including minimizing distance, obstacle avoidance, social avoidance, personal space and their applications such as real time planning, person detection and tracking are demonstrated hereby. Social conventions are implemented using weighted constraint method resulting in human-like behavior. Related simulation-based experiments, performed for verification of the conclusions drawn, are suitably described.

Keywords - Human robot interaction, tracking, social robot, mapping, motion planning, obstacle detection

I. INTRODUCTION

Most traditional robots consider all the obstacles alike for their path planning. With this paper we give a methodology to distinctively identify any person based on algorithms as mentioned further for social robots. Also traditional robots have been considered insensitive to social conventions which points towards a considerable scope for research and development to instill human like behavior in robots. e.g. - a robot might be conventionally expected to move being towards the left side of the path when in an environment where it works along with humans [1]. The algorithms previously developed for producing conventional behavior generally did not result in a precise social behavior [2]. Also they are typically not extensible to further constraints. Some common errors in traditional robots include halting amidst its path, processing delay leading to path blockage and colliding with people in unanticipated situations.

In our method we represent social constraints as mathematical cost functions [3] which are appropriately weighted to produce a balanced response set by the robot. An important aspect of our work is combination of path planning with social convention [4]. E.g. if there is a crowded path full of obstacles then the robot looks for alternative paths to reach its destination. This behavior can be attributed as human-like. The robots reacting in accordance to the defined cost functions are considered to be socially correct. Hence we have simulated and implemented basic human behavior which is globally recognized into mobile robots.

A proper emphasis on efficiency constraints is laid with respect to generic parameters as well as social parameters. The rest of the paper demonstrates modeling

for individual constraints. Following it are our experiments with conclusive observations in accordance with the methodology followed. The applications and future works are thereafter mentioned encouraging further research in this area.

II. ORIGIN AND APPROACH

The main aim of this research is to give socially acceptable behavior to robots while interacting with people. The normal navigation of the robot change by providing specific constrains to make it a social robot. These constrains are derived from different field including social psychology [4], path planning, obstacle avoidance [5] and human-robot collaboration.

We are interested in our robot working in human environment with humans, for this we need to know how humans behave. The robot's behavior is drawn from human sociology. Humans follow many social conventions such as keeping fixed distance while walking, walking left in a pathway [6].

Types of distances	Distances (in cm)	
	Close phase	Far Phase
Intimate distance	0-15	15-46
Personal distance	46-76	76-120
Social distance	120-210	210-370
Public distance	370-760	760 or more

Table 1 : Proxemic distance data

The concept of proxemics (the study of measurable distances between people as they interact) [7] can be implemented in social robots. The proxemics distances can be observed from the TABLE I. The shape and size of personal space changes with changed situation.

A person-tracking [8] system was designed and two people were analyzed and studied how people walk in pairs.

Person tracking is important for a social robot to distinguish between normal obstacles and persons. Our tracker is similar to that of Topp and Christensen (2005) [9].

The algorithm used for tracking person is that the scanned image is divided into segments; if the distance between points is less than 10 cm then it is considered as same segment. Similarly if the points are more than 3 m apart they are discarded. The potential legs are the segments with width greater than 20 cm and less than 60 cm. If two such leg segments are separated less than 40 cm then they are classified as a person else potential leg is classified as potential person. Potential persons are tracked with standard particle filter algorithm [10]. This algorithm is robust and can track person coming toward or away from the robot. The robot sensors must be reliable enough for tracking a person in order to remain useful and keep safety of people. The robot must ensure the person's safety at all the times and maintain distance from person. The scanning laser range-finder was used to track people.

III. STRUCTURE

Social behavior is a mindset and it is not absolute or rule that must be followed. Instead social conventions are flexible. We are using cost functions to model social convention similar to the way as humans do unknowingly.

A. Approximate path tracker

For the social robot to navigate like people it must have an approximate path plan to the destination. This plan neglects smaller obstacles and moving persons. It takes into account larger obstacle e.g. If there is crowd in the pathway, the robot has two paths either it can trace its shortest part dogging through the crowd which is difficult and my lead to mission failure else it can follow a different new path without the hallway. To produce human like path navigation heuristic planner A* [11] with cost functions is used for task and social convention implementation.

B. Constraints and cost functions

Constraints may be hard with absolute limits or soft with variable limits which may be neglected. A cost function is a mathematical function whose value can be

optimized to a lower value. Soft constrains can be mathematically collected into cost function. The constrains have two aspects task and social. The minimizing distance and obstacle avoidance are tasks of travelling to goal. The remaining ones are related to social aspect of travelling like person avoidance, default velocity, inertia.

1) *Optimizing Distance* : To save time and energy people take short cuts and often take the shortest path possible. Thus, one part of robots objective should be to minimize overall path length.

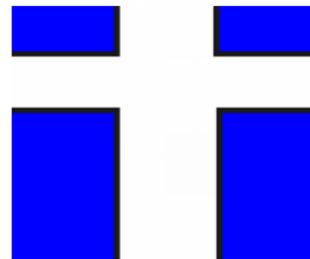
Distance used as heuristic function for the A* planner is :

$$h_{\text{distance}}(s) = \sqrt{(s_{\text{goat}} \cdot x - s \cdot x)^2 + (s_{\text{goat}} \cdot y - s \cdot y)^2}$$

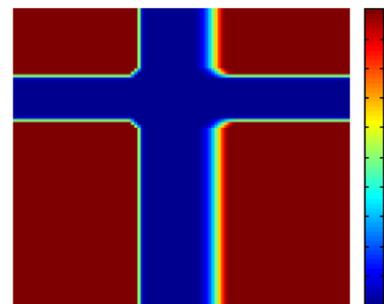
2) *Obstacle Avoidance* : Obstacle avoidance technique involves two aspects: a hard constraint against colliding with obstacles and a function to avoid coming too close to things.

a) *Hard Constraint* : The robot is constrained not to collide with stationary objects and walls.

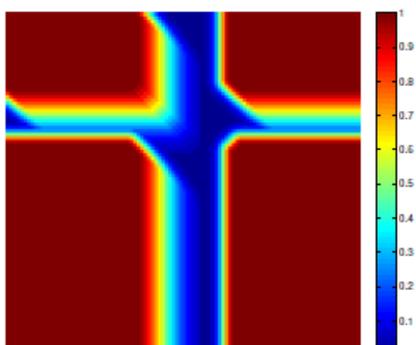
b) *Buffer Constraint* : The robot should keep a safe distance from the obstacles. The cost for this varies in accordance with the speed and angle of approach. This creates a buffer around the obstacle for the robots safety.



(a) Map of simple environment, composed of intersecting pathways



(b) Obstacle buffer cost for the simple map shown in (a), for the robot travelling at a velocity of 0.3 m/s at $\alpha = 0$ (i.e., to the right).



(c) Obstacle buffer cost region for the simple map shown in (a), for the robot travelling at 1 m/s at $\alpha = 3\pi/4$ (i.e., towards the upper left-hand corner).

Figure 1. Shows how the obstacle buffer changes with angle of robot's velocity, obstacle buffer cost region for two robot velocities and directions, where the shading corresponds to the cost of encountering that spot on the map. Furthermore, the robot's direction of travel influences the width of the cost region, so that the robot incurs a higher cost when driving directly toward an obstacle rather than alongside one

3) *Human Avoidance* : With obstacle avoidance, robot also has to avoid person. These are different category of obstacle having hard constrains and other cost functions.

a) *Absolute Avoidance* : The robot must never plan a path through a person. The robot should reject the paths intersecting with people's path.

b) *Personal Space* : Proxemics is the space around the person. It is not constant and differs across cultures and changes with situations and speed of walking.

The personal space can be modelled as two halves of 2D Gaussian functions [12]: an elliptical from the front and symmetrical from the behind. Figure 2 shows the cost function for a person moving along the positive Y-axis, either a relative velocity of 1 m/s toward the robot.

c) *Pass on Left* : When approaching a person travelling in the opposite direction, according to Indian conventions, people typically avoid collision by moving left. This can be modelled by increasing the cost to the left. As with personal space, the convention to pass the left can be modelled as a mixture of Gaussian functions, as shown in Figure 3.

4) *Default Velocity* : The robot should keep constant velocity. Changes to the default velocity should result in cost to the robot; it should have to trade between slowing and travelling greater distances around a person or obstacle. This cost is proportional to the absolute

difference between the chosen velocity and default velocity.

5) *Inertia* : The robot should prefer to move in a straight line.

IV. IMPLEMENTATION

In implementation, we used many methods for path tracker, person-tracking and robot navigation. The following will through some light on the methods used:

1) *Path Tracking*: The reaction time of the robot should be very fast. A plan to the goal should be generated as soon as the environment conditions change in order to ensure a safe, low cost path plan.

We use the heuristic planner A* to produce paths.

a) *Variable Grid* : Rather than planning on single resolution grid, our approach uses variable grids of decreasing resolution. The plan needs to be of high resolution near the robot and less resolution away from the robot.

b) *Objective Function* : All the constrains must be put in a single function for the A* planner to work. We combine each cost function with linear waiting for each constraint. The total cost can be defined as:

$$y = \sum p_i \cdot f_i(y)$$

Where $f_i(y)$ is the action cost of constraint I and p_i is the weight associated with that constraint. Additional constraints can be added in a similar fashion.

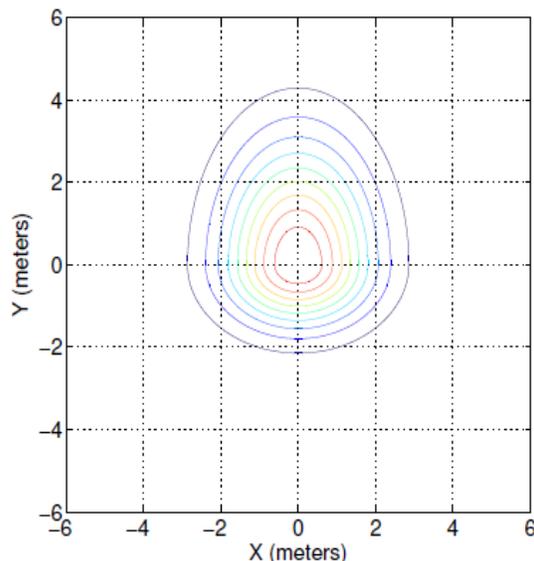


Fig. 2(a) : Personal space cost for a person moving at 1.0m/s along the positive Y axis.

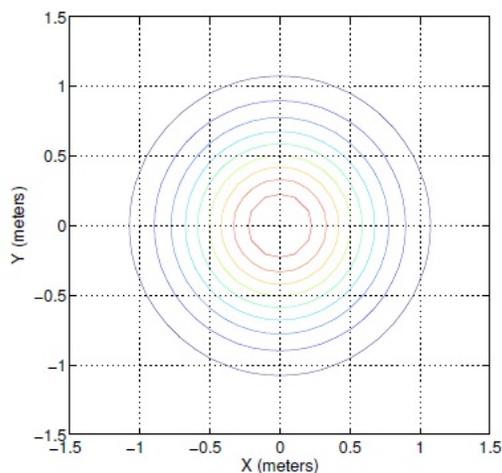


Fig. 2(b) : Personal space cost for a stationary person. The cost function is symmetrical because the robot cannot reliably detect person's orientation.

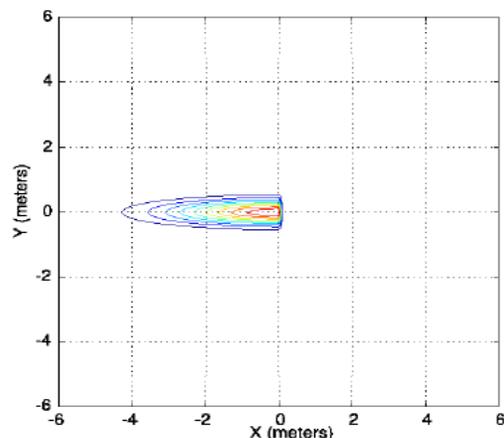


Fig. 3 : Contour map. Tends to the left cost for a person moving along the positive y axis (up). The person is centred at (0, 0). The robot can freely pass on the person's right. But incurs a cost for travelling on the person's left.

2) *Person tracking*: We use laser-based person-tracking method similar to that of Topp and Christensen (2005). The tracker is modified to use map of the environment and better smooth the tracked velocities.

a) *Map-based tracking*: It is assumed that the robot has an earlier map of the environment. The robot scans to find the changes as obstacles or persons.

b) *Velocity smoothing*: Because several of the social constraints in our framework depend on the person's direction of travel. For the robot to know persons velocity we use a linear least-squares regression on the person's tracked positions over time.

3) *Tracking*: Paths are framed continuously, and the robot is expected to update its navigation map accordingly. The Pure Pursuit path-following algorithm [13] is used along with mapping, to redirect the robot in case it travels off in stray directions or new path is framed.

V. RESULT

Carmen simulator has been used to simulate all our works. We simulate a round robot that uses scanning laser range finder. Virtual people are created by adding pair of legs. Real world environment is generated by the simulator as noise added to the readings of the scanner.

Experiments were conducted to verify the implementation of the algorithm.

Experiment: The experiment is performed to observe the path tracking of the social robot influenced by the destination and the obstacles, obstacles may be human or non human and maybe stationary or moving. The moving obstacle may or may not follow the social convention of moving towards the left when crossing. The pathway is broad enough for the robot to pass on either side of the obstacle.

In most of the cases the robot moved to the left when it faced people in its path which is socially correct in accordance with the Indian convention. 70 percent of the time robot behaved in this correct manner. When the person was travelling on the wrong side i.e. the right side, the robot should have turned to its right to avoid the person. Unexpected behaviour was observed when a person was standing towards the left of the robot, and the robot in forward motion.

VI. INFERENCE

From the above experiments, the robot is observed to follow social conventions as expected such as left alignment along the path, maintenance of buffer distance from obstacles including humans. It conforms to optimum speed with respect to human and non human obstacles accordingly. In order to reduce overall costs, the robot may choose different paths even when minor changes are made to the robot's speed or person's position.

Constant weights were used for the different cost functions. In case we want to considerably increase the cost of *pass on left*, the robot mostly moves towards the left and may not choose the shortest path. Thus by varying the weights, different constraints can exemplified accordingly. Further studies are under progress with exceptions being added by varying the number of person and their speed.

VII. CONCLUSION

Human social conventions are hereby successfully represented by mathematical cost functions and the robot traces its path accordingly and so they are recognized by the people as social. We have hence emphasized on technology to distinguish humans from other obstacles and suitably work the robot according to social conventions. This research developed a method for socially acceptable and preferred path tracking for robots. This can be further utilized for more effective human environment interactions.

We believe this adaptation of robots to human environment can be a boon to robot's flexibility and efficiency in future applications. This work will be beneficial for futuristic robots working more closely to human sensitivities.

VIII. FUTURE PROSPECTS

There is a need for improving search speed and person tracking. These limitations arise during implementation and are not fundamental to the overall framework. We believe that a wide variety of other social tasks can be implemented using this method. Robots with different behaviour can be developed using definite constraint weights.

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