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Quasi-harmonic Functions Approach to Human-following Robots

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Abstract - In this paper, an approach for human-following robot control is investigated. The approach is based on velocity potential fields that permit to generate velocity vector commands that drive the robot at a safe distance with regard to the human while avoiding obstacles. Velocity potential fields are known for not crating local minima present in the case of artificial potential fields. The approach is first formulated and illustrated for a robot moving toward a fixed goal while avoiding two close-by obstacles without being stopped in a local minimum. For achieving a safe stop at the goal. A quasi-harmonic control law is proposed. Next, for the same environment, the approach is formulated and simulated for a robot following a human.

Keywords**:** Human-following robots, collision avoidance, velocity potential fields, quasi-harmonic functions.

1. Introduction

Human-Following robots have numerous applications: maintenance in outdoor and in-door environments, assisting workers in the field, assisting military personnel, tracking intruders, terrorists or violent people, assisting incapacitated people etc. For achieving these tasks, the robots have to sense the human, track and follow while avoiding accidents and collisions as previously shown (Feng et al., 2012). A suitable candidate for these tasks is the use of harmonic functions as shown by Medio et al. (1991), Bemmporad et al. (1996), Zeng and Bone (2010), Conolly et al. (1990), Akishita et al. (1990), Decuyper and Keymeulen (1990), Kim and Khosla (1992), Masoud (2007), Chanson (2009) and Necsulescu and Nie (2014). These harmonic functions are steady state solutions of Laplace equation, used in hydrodynamics as shown by Conolly et al. (1990), Akishita et al. (1990), Decuyper and Keymeulen (1990), Kim and Khosla (1992), Masoud (2007), Chanson (2009). Harmonic functions and their linear combinations are known having maximum values on the boundary of a finite space and, thus do not lead to local minima as in the case of artificial potential fields. A more efficient control results from adding vortex components in the control law as shown Medio et al. (1991). Human collision avoidance for non-holonomic robots was investigated by Zeng and Bone (2010). In this paper harmonic functions approach is used in the modified form of quasi-harmonic approach, proposed by Necsulescu and Nie (2014), to achieve safe stop at a fixed goal.

2. Velocity Potential Fields for Crowded Environments

2.1 Quasi-harmonic Approach for Obstacle Avoidance

In this paper the focus is on investigating a solution that solves the problem local minimum of potential field approach. The approach is presented for the simple case of a holonomic robot avoiding two close-by obstacles. The model of this environment is shown in Figure 1.There are two obstacles, which are very close to each other, at (-0.1, 0) and (0.1, 0) and the goal is at (0, 1). The robot, has the coordinates (x, y), and starts moving from a position on the other side of the obstacles with regard to the goal.

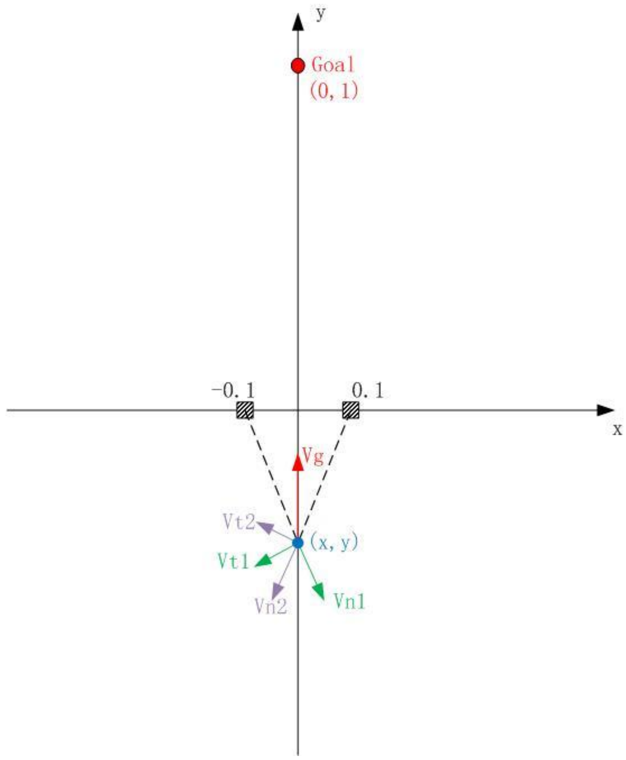

Fig. 1. Position of obstacles and goal and velocity commands of robot.

Uniform flow with velocity U at angle θ and polar distance r, used for going toward the goal, is described by the following velocity potential function ϕ,

$$\phi = Ur\cos\theta \tag{1}$$

The doublet of source and vortex, used for avoiding collision with obstacles at distance r, is described by

$$\phi = \frac{q}{2\pi}\ln r - \frac{K}{2\pi}\theta \tag{2}$$

where q and K are intensities.

The negative gradient of the velocity potential fields result in velocity vector commands is shown in Fig. 1 [11]. Vn1 and Vn2 are normal vectors directing the robot away from the obstacles. The obstacles are positioned very close and the associated velocity potential fields do not allow the robot to pass in-between them. The potential field of this model using harmonic function is shown in Figure 2. The inclusion of vortexes in the velocity potential field approach allow the robot to move around the obstacles as a result of tangent velocity commands, Vt1 and Vt2, as shown in Fig. 1.

The negative gradient equations are partial differential equations with regard to x and y. The solutions of equations 3 and 4 set to zero give the point whose velocity is zero, which means it is either a minimum point or a saddle point. The first two ratios in the right hand side the velocity commands V_{n1} and $V_{n2,}$ inspired by the source in fluid dynamics to achieve collision avoidance [10]. Velocity commands Vn1 and Vn2 are. The third component in Equation 3 and Equation 4, inspired from a sink in hydrodynamics, corresponds to the velocity command V_g and achieves motion toward the goal. When k_t is not zero, the last two components correspond to tangential velocity commands.

$$\frac{\partial\Phi(\mathrm{x,y})}{\partial x} = -\frac{x-0.1}{(x-0.1)^2+y^2} - \frac{(x+0.1)}{(x+0.1)^2+y^2} - \frac{x}{x^2+(y+1)^2} - k_t \frac{y}{(x-0.1) * \sqrt{(1+\frac{y^2}{(x-0.1)^2}) * \sqrt{(x-0.1)^2+y^2}}} + k_t \frac{y}{(x+0.1) * \sqrt{(1+\frac{y^2}{(x+0.1)^2}) * \sqrt{(x+0.1)^2+y^2}}} = 0 \quad (3)$$

$$\frac{\partial\Phi(\mathrm{x,y})}{\partial y} = \frac{y}{(x-0.1)^2+y^2} + \frac{y}{(x+0.1)^2+y^2} - \frac{y+1}{x^2+(y+1)^2} + k_t \frac{1}{\sqrt{(1+\frac{y^2}{(x-0.1)^2}) * \sqrt{(x-0.1)^2+y^2}}} - k_t \frac{1}{\sqrt{(1+\frac{y^2}{(x+0.1)^2}) * \sqrt{(x+0.1)^2+y^2}}} = 0 \quad (4)$$

The coordinates of this point, obtained with MAPLE, were: x=0, y=0.004987562112 .

Figure 2 illustrates that the point is a saddle point instead of a local minimum point.

The saddle point means that the robot is in an unstable equilibrium. To avoid staying in this point for too long a period and to control the robot in a desired direction, tangent velocities were added. Tangent velocity can be changed by changing the value of k_t in Equation (4) and (5).

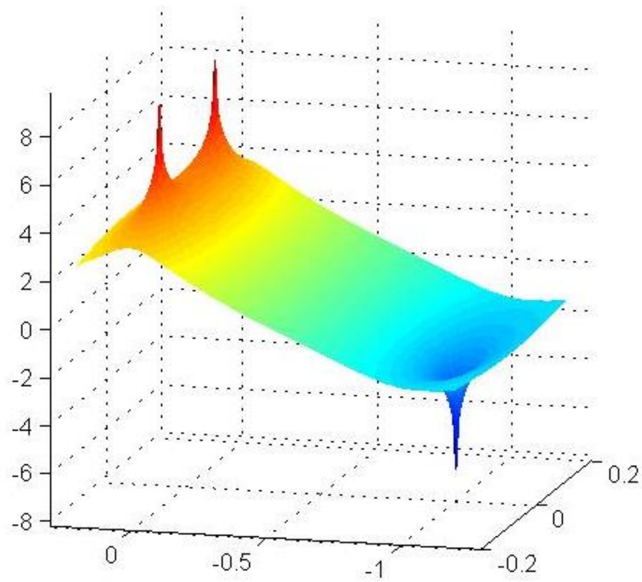

Fig. 2. Plot of the harmonic function for two obstacles.

Figure 3 shows the results when k_t equals to 1.0. This solution is inspired from the spiral vortex in hydrodynamics, [10, 11].

In Figure 3 it appears clearly that there is a saddle point and no minimum except on the boundaries. This is a consequence of using harmonic functions.

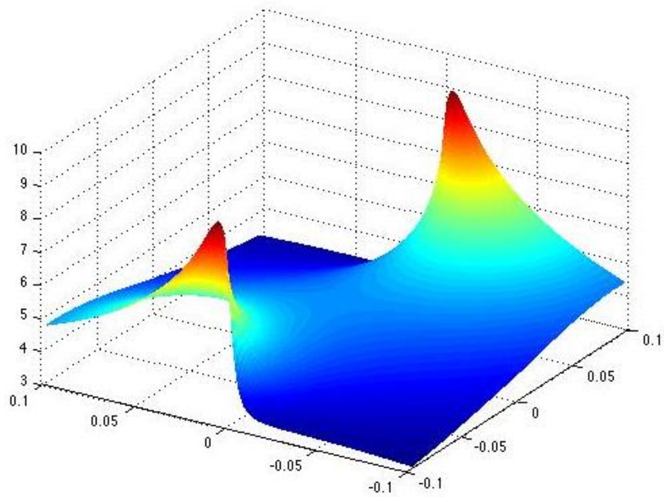

Fig.3. Area near the saddle point when k_t=1.0.

MAPLE solution of the equations 3 and 4 when k_t=1 indicates that there is the real root at (0.00249, 0.00249), where the minimum velocity is almost zero. The fact that it is not exactly zero is explained by the numerical approximations of computation of the solution.

As a result of using velocity potential function corresponding to a uniform flow in hydrodynamics, is that the robot would not have zero velocity command when arriving at the goal [11].

For this reason, the harmonic function with respect to goal is replaced by

$$v_g = k_g(1 - e^{-kr^2})\frac{1}{r} \tag{5}$$

In which k_g and k are constant coefficients and r is the distance between goal and robot in polar coordinates [11]. This function allows the robot to slow down smoothly in the region close to the goal. When the distance r increases, equation 5 tends towards a harmonic function $V_g=k_g/r$, corresponding to a velocity potential field $\Phi = \ln(r)$.

2.2. Simulation Results for a Holonomic Robot

The simulation is based on the proposed quasi-harmonic approach and done with MATLAB. Figure 4 present the results three frames of the simulation with the following symbols [11]:

The diamond represents the position of the goal. The circle around the diamond is the surrounding area of goal. Black rectangles denote the obstacles assumed too close to get through. The arrow points to the current direction of the robot. The circle with radials shows the detection range of robot. The curve is the trajectory of robot.

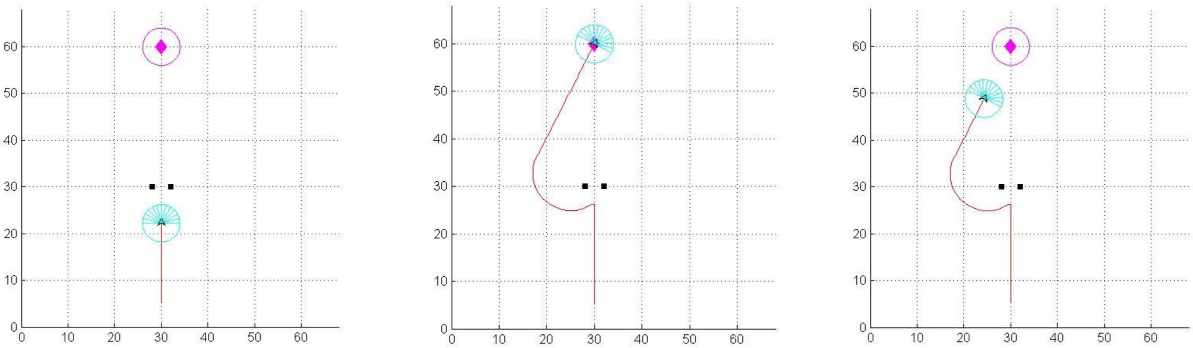

Fig. 4. Three frames of the quasi-harmonic function simulation results for a robot avoiding two obstacles [11].

These results show that the quasi-harmonic function approach, illustrated by Equation 3 and 4, permits to avoid the saddle point issue of the harmonic function approach by including tangent velocity commands which help robot move away faster from unstable equilibrium points.

3. Human-following Approach

In this paper, our objective is to let a car-like robot have the ability to follow a human in environment obstacles.

A human is assumed going to a goal point. The robot's task is to detect and find where the goal is on the map. Simulation results using the quasi-harmonic approach are shown in Fig. 5, where a small circle represents the human, the obstacles by squares and the goal by a diamond.

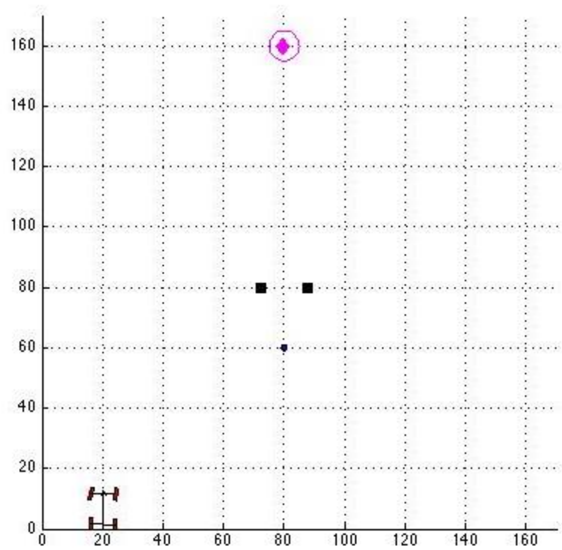

Fig. 5. Description of the task.

To finish this task successfully the robot should first find the human and then catch up with the human rapidly. When the robot gets closed to the human, it has to slow down. And at the same time, the robot needs to avoid obstacles to make sure it can continue following the human without colliding with obstacles.

The human is a goal when the robot finds him and far from him, but becomes t an obstacle when the robot is getting too close.

In this paper precise sensory data will be assumed. The issue of uncatain measurements will be analysed in a separate paper. The car-like robot is actually a non-holonomic robot with the following its kinematic model

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} r \bullet \cos(\theta+\phi) \\ r \bullet \sin(\theta+\phi) \\ \frac{r}{l}\sin\phi \\ 0 \end{bmatrix} w_r + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} w \tag{6}$$

where, x, y define the position of the front wheel, θ is robot body orientation, φ is the steering angle, l is the distance between the centres of front wheels and rear wheels, r is the radius of wheels, w is the velocity of the steering and w_r is velocity of the centre of front wheels.

Here, the “same speed” means that the speed value of front wheels’ centre point equals to human’s speed.

The investigation radius of sensors is set to 18.5 [m] which is also the car-like robot’s Minimum Turning Radius getting from Equation 8. l is the distance between the center of front wheels and the center of rear wheels. $\theta_{\max}$ is the maximum steering angle of robot. d is the distance between front wheels.

$$R_{\min} = R_0 + \frac{d}{2} = \frac{l}{\sin\theta_{\max}} + \frac{d}{2} \tag{7}$$

The simulation is based on quasi-harmonic approach and done with MATLAB for car-like non-holonomic robot. Six frames of Figure 6 shows the results of the simulation.

4. Conclusion

The results presented in this paper show that the quasi-harmonic approach could be used efficiently to control a non-holonomic robot to follow a human and avoid obstacles when they form a concave block that does not permit the robot to pass in-between.

The proposed quasi-harmonic function approach avoids the saddle point difficulties of the harmonic function approach by including tangent velocity commands, which help the non-holonomic robot move fast away from unstable equilibrium saddle points.

Since motion of human can be very complicated, the robot will be designed to adjust more motion condition of human in the future. For instance, when the human turns back and goes towards the robot, the robot should have ability to move backward to avoid to be found by the human. We will try to do some experiments in the following semester and try to realize the theory in practice.

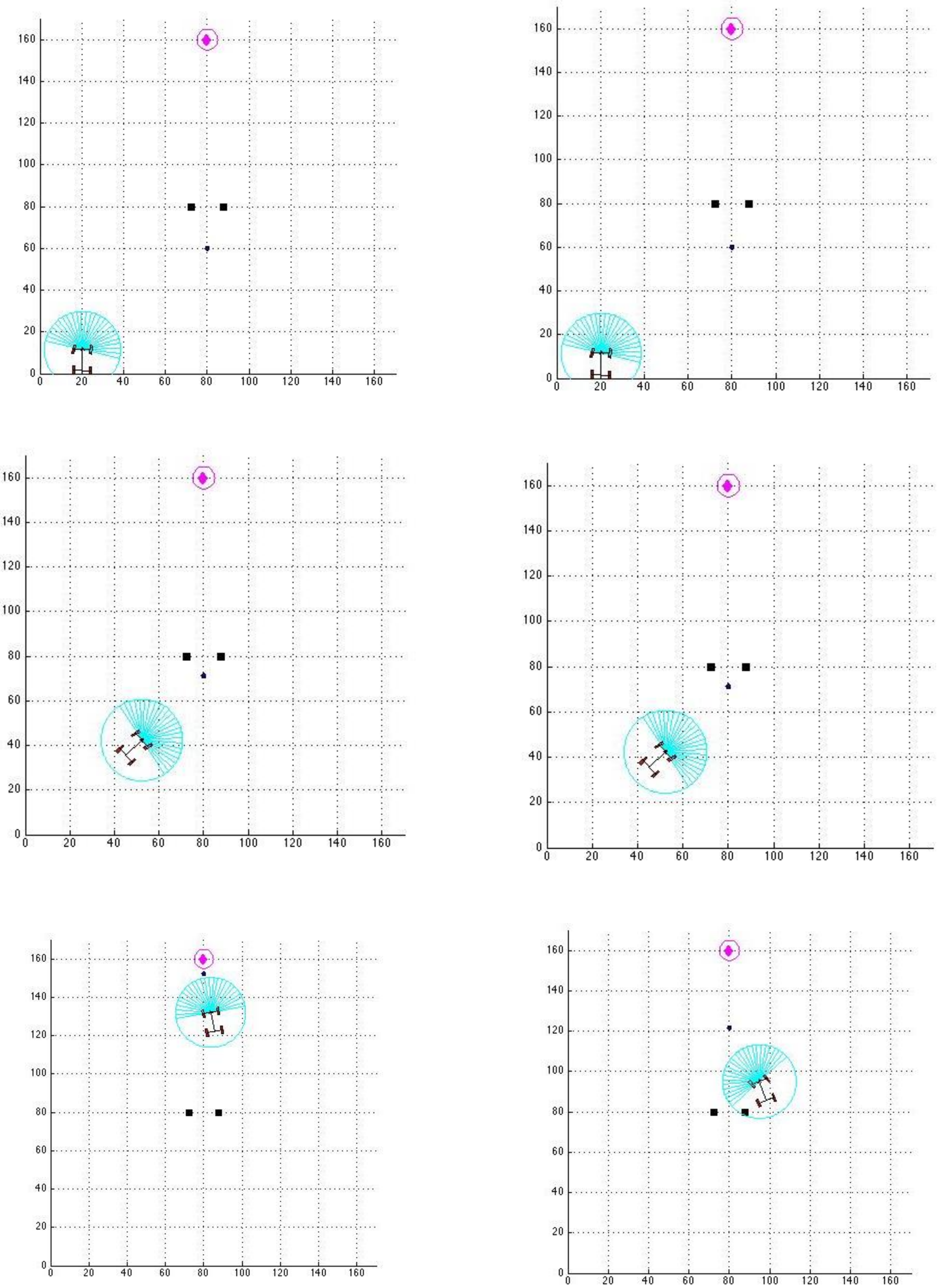

Fig. 6 Six frames of the simulation of a non-holonomic robot following a human while avoiding obstacles.

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