Budapest University of Technology and Economics

Department of Mechatronics, Optics and Mechanical Engineering Informatics

Thesis booklet

Path Planning of Autonomous Service Robots

Bence Kovács

Supervisor:

Professor Péter Korondi, DSc

Budapest, 2017.

Introduction

Robots are mainly used in the industry sector by qualified operators in a known environment. However, robots will be suitable to be used more widely, for performing more complex tasks – even in an unknown environment – by the evolution of computer science and artificial intelligence. According to robotics trends, it is predicted that mobile robots will appear in average households in the following decades. A new research topic in this exponentially growing field is path planning in human living areas.

Robots in households should be operated easily and intuitively, and they have to fit in the human social environment. Earlier studies developed human-robot interaction based on human-to-human communication, but robotics is not advanced enough to reach the physical and cognitive capabilities of humans. Therefore human-animal interaction can serve as a better model for designing service robots. The human-dog relationship is a good example for this paradigm as dogs developed social cognitive skills during their domestication that helps humans conclude the dog's intent and target. Therefore humans may interpret dog-like motion attributes similarly in case of mobile robots. Consequently, the movement of a service robot has not only the function of reaching a position, but it is also an element of social integration, which has a significant communication meaning. Therefore ethorobotics has become an emphatic research area of the path planning of autonomous service robots.

State of the art

Several research studies targeted mobile robot path planning, which led to such achievements as path planning based on Genetic algorithms [1], Neural networks [2], Fuzzy logic [3], Machine Learning [4], and Artificial Potential Field (APF) [5].

Global path-planning techniques require knowledge about the environment, therefore they are often studied by including map building [6]. They are guaranteed to find a path if one exists; however, their computational complexity limits their use for real-time path planning in unknown, dynamic environments. Local algorithms are usually based on a Dynamic Window Approach [7] or APF due to simple implementation and low processing needs. Both can get input data directly from range sensors without the need for processor-consuming map calculations and estimations. APF is suitable for underlying real-time control with the lack of global information, but it has a problem of local minima [8] which needs to be handled by global algorithms at a higher layer.

All these studies were focused on finding the optimal path from the point of view of target distance, obstacle avoidance distance, travelling time, or energy. Many research works address the path planning implications of human-robot interaction but mainly focus on collision-free paths. This research is new in terms of describing mobile robot trajectory planning by focusing on human-robot interaction.

Methodology

Natural or animal-like motion attributes are not engineering notions, therefore I cooperated with ethological scientists.

Ethorobotics studies are based on the observation of human-animal interactionto highlight and quantify vitals and create motion models. Models are implemented to real robots. The observation of human-robot interaction serves as feedback for earlier observation, model creation and implementation processes, as shown in Figure 1.

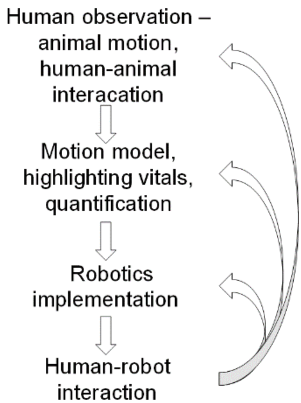


Figure 1. Motion research methology of ethorobotics

My research in ethorobotics focuses on the mathematical description and robotics implementation of motion attributes. I examined the literature of path planning, in particular the methods which can also be used in an unknown, dynamically changing environment. I worked out the mathematical description of motion attributes described by ethological studies. I implemented simulations according to different parameters and dynamic scenarios. Figure 2 shows the holonomic mobile robot which was used for experimentation for my research and for many other ethorobotics studies. The real robotics evaluation confirmed simulation results.

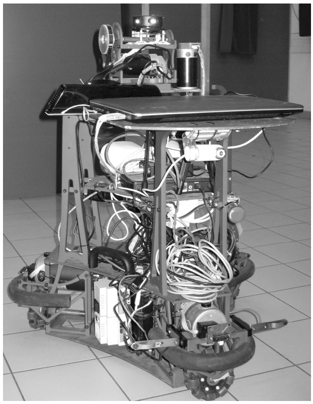


Figure 2. Experimental holonomic mobile robot

Overview and summary of the dissertation

APF is based on the idea that the target attracts the robot, while the obstacles generate repulsive force fields in order to avoid collision. The sum of the attractive and repulsive forces control the robot according to Newton's Second Law. I described potential functions and an application method that is applicable in unknown, dynamically changing environments while adapting animal-like motion attributes.

Thesis 1

Animal-like motion attributes can be described mathematically using artificial potential field based motion planning by applying a repulsive potential function according to Equation (1).

$$\boldsymbol{U_{rep}(x_o, \underline{v}_R, \underline{v}_{OBS})=} \\ \begin{cases} \delta\frac{1}{4}x_o^4 - \delta\left(\frac{d_0+2d_1}{3}\right)x_o^3 + \delta\left(\frac{d_1^2}{2}+d_0d_1\right)x_o^2 - \delta d_0 d_1^2 x_o + \\ +\delta\left(d_0 d_1^3\frac{1}{3} - d_1^4\frac{1}{12}\right) + \zeta\frac{\left\|\underline{v}_R-\underline{v}_{OBS}\right\|^2}{2a_{MAX}} & \text{, if } x_o \le d_1 \\ \zeta\frac{\left\|\underline{v}_R-\underline{v}_{OBS}\right\|^2}{2a_{MAX}} & \text{, if } x_o > d_1 \end{cases} \quad (1)$$

where x_o is the distance between the robot and the obstacle; $\underline{v}_R$ and $\underline{v}_{OBS}$ denote the robot and obstacle velocity vector, respectively; d_0 defines the rate of obstacle approximation; d_1 characterizes the action radius and gradient of the function; δ *and* ζ are non-negative constants; and the maximum acceleration of the robot is a_{max}.

Related publications: [P1,P3,P5,P13-P15]

Background explanation

Equation (1) parametrically defines animal-like motion attributes such as the approximation of obstacles and the velocity along the path depending on the position of the robot and the target. A local, online path planning method is suggested, which describes animal-like motion attributes and can be used in an unknown, dynamically changing environment. Contrary to conventional potential functions, our proposed repulsive potential function is not monotonic. This means that an obstacle can attract the robot depending on the distance and parameter range, therefore the function can describe the object proximity seeking motion characteristics of small mammals as illustrated in Figure 3.

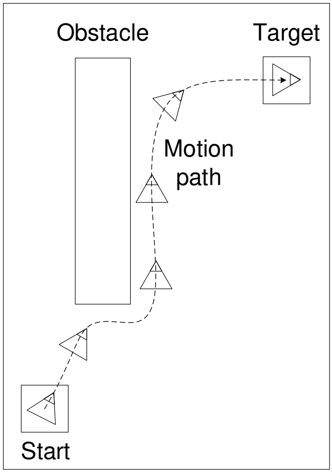


Figure 3. Object proximity seeking motion characteristics, specific to small mammals

The artificial force vector function can be described by deriving the potential function of Equation (1) for distance:

$$F_{rep}\left(x_o, \underline{v}_R, \underline{v}_{OBS}\right) = -\nabla U_{rep}\left(x_o, \underline{v}_R, \underline{v}_{OBS}\right) =$$

$$= \begin{cases} -\delta(x_o - d_0)(x_o - d_1)^2 \underline{n}_{OR} + \zeta \frac{\|\underline{v}_R - \underline{v}_{OBS}\|}{a_{MAX}} \underline{\mathrm{n}}_{VOR} & , if\ x_o \leq d_1 \\ \zeta \frac{\|\underline{v}_R - \underline{v}_{OBS}\|}{a_{MAX}} \underline{\mathrm{n}}_{VOR}, & , if\ x_o > d_1 \end{cases} \qquad (2)$$

where $\underline{n}_{OR}$ is the unit vector pointing from an obstacle to the robot center and $\underline{n}_{VOR}$ denotes the unit vector pointing in the direction of the relative velocity of the obstacle with respect to the robot.

Practical application

Figure 4 shows the simulation results of the proposed algorithm for describing a path similar to Figure 3. Simulation calculations are based on Equation (1) with the following parameters: $\delta = 15$, $\zeta = 0.5$, $d_0 = 0.9\,m$, $d_1 = 1.9\,m$, $v_{max} = 1.5\ m/s$, $a_{max} = 3\,m/s^2$, $m = 20\,kg$.

Simulation was also verified by real robotics evaluation using the robot shown on Figure 2. This simulation scenario does not contain local minimums, but for more general usability, robotics implementation includes an overlaying BUG algorithm based method, which detects trap situations and steers the robot out of the local minimum.

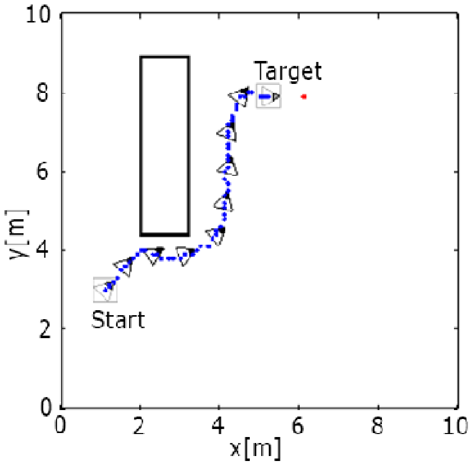


Figure 4. Simulation of object proximity seeking motion characteristics, specific to small mammals

Thesis 2

Path planning algorithm with social adaptability (differentiating between animate, inanimate, known and unknown obstacles) is feasible according to Figure 5.

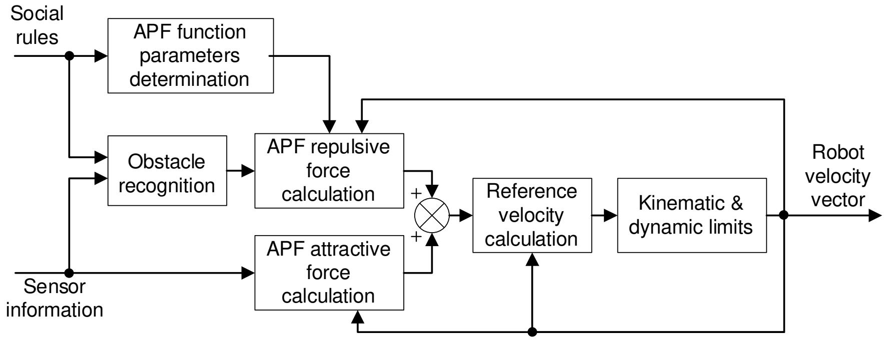


Figure 5. Realization of social adaptability by artificial potential field based path planning methods

Related publications: [P1,P2,P6-P8,P16]

Background explanation

According to ethological studies, dogs approximate differently their owner, a known person, an unknown person, and inanimate obstacles, which behaviour has also a communication meaning. In case of artificial potential field based path planning, social adaptability can be realized by applying different virtual repulsive potential functions to obstacles depending on their social role. This means that two similar sized obstacles with different social significance will generate different virtual forces. According to Figure 5, the force vector field calculation is influenced not only by distance sensor information, but also by social rules defining the different velocity required and distance of approximation near different obstacles.

This way of realization allows path planning in a dynamically changing environment, so as to approximate obstacles differently based on their social role.

Practical application

Figure 6 shows an APF force vector field and path simulation including social adaptation. The robot travels from one corner to the opposite corner of a ten meter by ten meter area. The two similar sized obstacles have different social roles (eg. unknown and known person), and they are located symmetrically.

The effect of the different social roles can be achieved by different potential functions. Equation (2) was used to calculate force vector fields with the following parameters:

$\delta = 3,\ \zeta = 0.5,$

$v_{max} = 1.5\,\frac{m}{s},$

$a_{max} = 3\ m/s^2,$

$d_{0(LEFT)} = 1.78\,m,$

$d_{0(RIGHT)} = 3.3\,m,$

$d_1 = 2\,m\,,\, m = 20\,kg.$

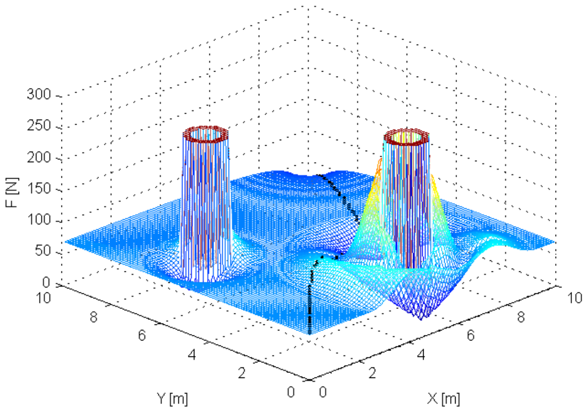


Figure 6. Artificial force vector field and path of APF method based path planning simulation in case of different potential functions per obstacles

Thesis 3

Animal-like orientation along a path, which differs from the direction of movement, can be adapted to the path planning of holonomic mobile robots using the artificial potential field method based orientation potential function as per Equation (3).

$$\boldsymbol{U_{ang}(\varphi_v, \varphi_{rob}, \varphi_T) = \sigma\left(a\,\varphi_v\,\varphi_{rob} + b\,\varphi_T\,\varphi_{rob} - \frac{\varphi_{rob}^2}{2}\right)} \qquad \textbf{(3)}$$

where $\boldsymbol{\varphi_v}$ denotes the direction of robot velocity vector, $\boldsymbol{\varphi_{rob}}$ is the orientation of the robot with respect to the positive x-axis, $\boldsymbol{\varphi_T}$ defines the direction of the vector pointing from the robot actual position to the robot working envelope at the target position, $\boldsymbol{\sigma}$ is a positive constant, $\boldsymbol{a}$ and $\boldsymbol{b}$ are non-negative constants.

Related publications: [P1,P4,P9-P12]

Background explanation

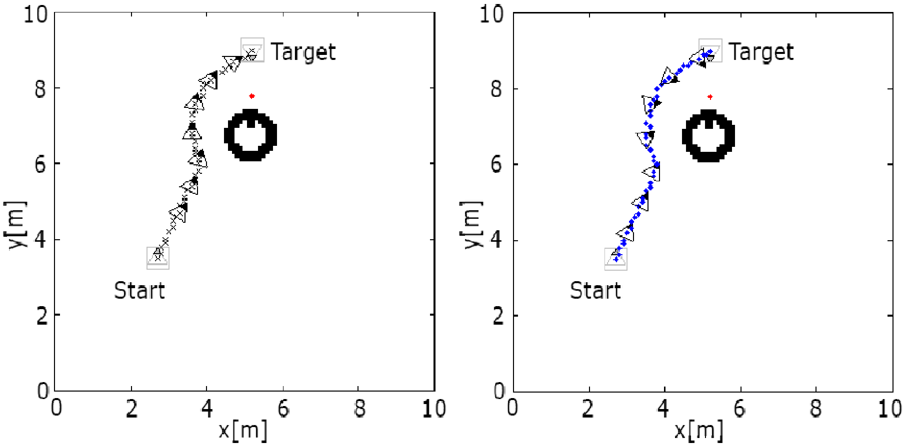
The movement of animals is holonomic, therefore they are capable to move aside, in a different direction from their orientation. According to ethological studies, orientation and moving direction differences often indicate the target position or the intention of the animal. Similar motion attributes may make the movements of mobile robots more predictable to humans. Orientation along the path can be described by orientation potential function as per Equation (3). The artificial torque vector function can be calculated by taking the derivative of Equation (3):

$$\underline{\tau}(\varphi_v, \varphi_{rob}, \varphi_T) = -\nabla U_{ang}(\varphi_v, \varphi_{rob}, \varphi_T) =$$
$$= \frac{\partial U_{ang}(\varphi_v, \varphi_{rob}, \varphi_T)}{\partial \varphi_{rob}}\underline{n_z} = \sigma(a\,\varphi_v + b\,\varphi_T - \varphi_{rob})\underline{n_z} \qquad (4)$$

where $\underline{n_z}$ is the unit vector of rotation, which is perpendicular to the x-y plane, pointing outside. In case of the proposed method, the orientation of the robot is not only a function of velocity direction, but also a function of target direction, similarly to animal motion.

Practical application

Figure 7 shows a simulation arrangement where the robot departs from the starting position, goes around an obstacle and stops in a position in front of its target. In case (a) the orientation of the robot corresponds to the direction of velocity, while in case (b), orientation is a function of velocity direction and also a function of target position according to Equation (3).



(a) ***(b)***

Figure 7. Simulation of holonomic mobile robot path planning
(a) Orientation corresponds to the direction of velocity
(b) Orientation is a function of velocity direction and also a function of target position

The simulation of Figure 7 (b) was calculated by Equation (3) using the following parameters: $\alpha = 100$, $\beta = 1.2$, $\gamma = 4$, $\delta = 15$, $\zeta = 0.5$, $d_0 = 1.4\,m, d_1 = 2\,m$ $v_{max} = 1.5\,m/s$, $a_{max} = 3\ m/s^2$, $m = 20\,kg$, $\sigma = 1$, $a = 0.02, b = 0.98$.

Bibliography / References

[1] P.S. Xuan Zou, Bin Ge, Improved Genetic Algorithm for Dynamic Path Planning, Int. J. Inf. Comput. Sci. IJICS. 1 (2012) 16–20.

[2] J. Ni, X. Li, X. Fan, A Dynamic Risk Level Based Bioinspired Neural Network Approach for Robot Path Planning, in: World Aut. Congr., 2014: pp. 829–833. doi:10.1109/WAC.2014.6936167.

[3] N.A. Mai, K. Janschek, Generic system architecture for behavior-based mobile robot control using fuzzy logic, 2012 Int. Conf. Control. Autom. Inf. Sci. (2012) 253–258. doi:10.1109/ICCAIS.2012.6466598.

[4] K. Charalampous, I. Kostavelis, A. Gasteratos, Thorough robot navigation based on SVM local planning, Rob. Auton. Syst. 70 (2015) 166–180. doi:10.1016/j.robot.2015.02.010.

[5] S. Ge, Y. Cui, Dynamic motion planning for mobile robots using potential field method, IEEE M. Conf. Control Autom. (2002) 207–222. http://www.springerlink.com/index/J6148PQ6724Q7871.pdf.

[6] I. Nagy, From Exploring to Optimal Path Planning : Considering Error of Navigation in Multi-Agent Mobile Robot Domain The Multi-Agent System Used for Potential Field- based Map Building, Acta Polytech. Hungarica. 11 (2014) 39–55.

[7] D. Kiss, G. Tevesz, A Receding Horizon Control Approach to Navigation in Virtual Corridors, Appl. Comput. Intell. Informatics SACI 2011. 1 (2012) 356.

[8] Y. Zhu, T. Zhang, J. Song, An Improved Wall-Following Method for Escaping from Local Minimum in Artificial Potential Field Based Path Planning, Control. (2009) 6017–6022.

[9] A. Cherubini, R. Passama, P. Fraisse, A. Crosnier, A unified multimodal control framework for human-robot interaction, Rob. Auton. Syst. 70 (2015) 106–115. doi:10.1016/j.robot.2015.03.002.

Author's publications related to the theses

[P1] B. Kovács, G. Szayer, F. Tajti, M. Burdelis, P. Korondi, A Novel Potential Field Method for Path Planning of Mobile Robots by Adapting Animal Motion Attributes, Elsevier Robotics and Autonomous Systems. DOI: 10.1016/j.robot.2016.04.007. IF: 1.95 (2016)

[P2] G. Szayer, B. Kovács, F. Tajti, P. Korondi, Feasible utilization of the inherent characteristics of holonomic mobile robots, Rob. Auton. Syst. (2017). doi:10.1016/j.robot.2017.04.002. IF: 1.95 (2016)

[P3] F. Tajti, B. Kovács, G. Szayer, P. Korondi, Variable Robot Geometry Optimization Method to Avoid Tip Over Situations During Slow Motion on Unknown Terrains, Acad. Appl. Res. Mil. PUBLIC Manag. Sci. 15 (2016) 301–323.

[P4] F. Tajti, G. Szayer, B. Kovács, P. Barna, Optical flow based odometry for mobile robots supported by multiple sensors and sensor fusion, Automatika. 57 (2016) 201–211. doi:10.7305/automatika.2016.07.886. IF: 0.38

[P5] F. Tajti, G. Szayer, B. Kovács, M.A.P. Burdelis, Mobile Robot Performance Analysis for Indoor Robotics, Period. Polytech. Civ. Eng.(2015) 123–131.IF:0.271

[P6] B. Kovács, G. Szayer, F. Tajti, Design of a universal robot controller, Periodica Polytechnica-Mechanical Engineering 55:(2) pp. 95-100. (2011)

[P7] F. Tajti, G. Szayer, B. Kovács, P. Korondi, Shop-floor controller based on RT-middleware technology, Journal Of Mechanics Engineering And Automation 3:(11) pp. 686-694. Paper 3-JMEA-E20130808-1. (2013)

[P8] F. Tajti, G. Szayer, B. Kovács, P. Korondi, Industrial robotics for ERP controlled smart factories, Recent Innovations in Mechatronics (RIiM) Vol. 2. (2015). No. 1-2. pp. 1-9. (2015) doi:10.17667/riim.2015.1-2/6.source.

[P9] G. Szayer, B. Kovács, B. Varga, Etho-robot, Workshop on Cognitive and Eto-Robotics in iSpace CERiS'10. Budapest, Magyarország, 2010.03.09-2010.03.10. Budapest

[P10] B. Kovács, G. Szayer, F. Tajti, P. Korondi, I. Nagy, Robot with Dog Type Behavior, International Conference on Electrical Drives and Power Electronics. High Tatras, Szlovákia, 2011.09.28. *pp. 347-352.*

[P11] F. Tajti, G. Szayer, B. Kovács, P. Korondi, Holonomic based robot for behavioral research, Workshop on Cognitive and Eto-Robotics in iSpace 2013, Budapest, Magyarország, 2013.03.19-20.

[P12] F. Tajti, G. Szayer, B. Kovács, P. Korondi, Robot base with holonomic drive, The 19th World Congress of the International Federation of Automatic Control, 2014. Augusztus, 24-29.

[P13] B. Kovács, G. Szayer, F. Tajti, V. Devecseri, P. Korondi, Szociális robotok a 21. században: MOGI Robi a hűséges társ, Erdélyi Magyar Műszaki Tudományos Társaság. Kolozsvár, Románia, 2012.04.19. Kolozsvár: pp. 238-241.

[P14] Kovács Bence, Tajti Ferenc, Szayer Géza, Mobil robotok pályatervezése ismeretlen környezetben, in: Robot. 2014, Budapest, 2014. http://robothadviseles.hu/program_rw14.html.

[P15] Tajti Ferenc, Kovács Bence, Szayer Géza, Változó geometriájú mobilrobotok irányítása terepviszonyok között, in: Robothadviselés, Budapest, 2014. http://robothadviseles.hu/program_rw14.html.

[P16] Szayer Géza, Tajti Ferenc, Kovács Bence, Holonomikus hajtások hatékony alkalmazása beltéri vagyonvédelmi robotoknál, in: Robothadviselés, Budapset, 2014. http://robothadviseles.hu/program_rw14.html.