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Research Paper

Randomised kinodynamic motion planning for an autonomous vehicle in semi-structured agricultural areas

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A randomised motion planner is presented that operates within a suitable timeframe for constrained mobile robots in agricultural environment. The core of this approach relies on splitting planning into two efficient phases to reduce its computational time. The effectiveness of sampling based planners is combined with the robustness of parametric vector-valued splines. The first phase involves relaxed two-dimensional path planning using rapidly-exploring random trees (RRT). Recent advances in sampling based planning are leveraged to improve the performance of the planner. Detailed implementation of the RRT approach and parameter selection are highlighted using comprehensive analysis and simulations. Feasible continuous paths with bounded curvature for nonholonomic robots are generated using B-spline curves. Curve segment parameters are formulated with respect to vehicle specifications. Manoeuvres satisfying maximum curvature constraints and path continuity are designed based on the segment parameters. Numerical experiments are used to validate the practicality of the proposed two-phase planner in solving kinodynamic motion queries, in real-time and replanning under limited sensing conditions.

1. Introduction

Autonomous robots are capable of performing tasks independent of human intervention. They have properties beneficial for a broad range of applications. Contemporary developments in computing, sensor technology and electronics, have led to widespread robots use in military, industrial and commercial applications. Self-driving passenger cars, fork lifts, medical robots, mining trucks, domestic robots, planetary rovers and rescue robots are amongst the existing applications of autonomous ground vehicles. The agility, size and cost-effectiveness of Micro Aerial Vehicles (MAV) have drawn interest towards their use for commercial purposes such as monitoring, aerial photography, document delivery, mapping and exploration in addition to their military uses. As in the case of any novel technology, autonomous robots will be embraced by industry, as researchers develop more efficient, reliable, safe and intelligent robots.

There is much potential in agriculture for the application of autonomous systems/robots. The ever-growing global demand for food, together with climate change, poses challenges for the farming industry (Bennett, Bending, Chandler, Hilton, & Mills, 2012; Chakraborty & Newton, 2011; Karp &

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Nomenclature

C_{free}	Free configuration space
C_{obs}	Obstacle configuration space
q	Vehicle configuration (pose)
$q.rand$	Random configuration
$q.new$	New configuration
$q.failure$	Node failure rate
d	Extension step distance
x,y	Vehicle position coordinates
θ	Vehicle heading
r	Vehicle turning radius
w	Vehicle wheel base
δ	Vehicle steering angle
v	Vehicle velocity
v_f	Maximum forward vehicle velocity
v_r	Maximum reverse vehicle velocity
a	Vehicle acceleration
ω	Vehicle angular velocity
$d(i,j)$	RRT node distance metric between nodes (i) and (j)
$h(i,j)$	RRT node heading metric between nodes (i) and (j)
$m(i,j)$	RRT metric between nodes (i) and (j)
g_d	RRT distance metric weight
g_h	RRT heading metric weight
g_f	RRT node failure rate metric weight
n	B-spline number of control point
p	B-spline curve degree
m	B-spline number of knots
$\hat{u}$	B-spline knot vector
u	B-spline parametric length
k	B-spline curvature
K_{max}	Maximum B-spline Curvature
u	B-spline normalized length parameter
$N(u)$	B-spline basis function
Px, Py	B-spline control polygon coordinates
$c(u)$	B-spline curve
$x(u)$	B-spline curve x-coordinates
$y(u)$	B-spline curve y-coordinates
L	B-spline segment length
α	B-spline segment angle
L_{min}	B-spline minimum segment length
α_{min}	B-spline minimum segment angle

Abbreviations

RRT	Rapidly-exploring random trees
PRM	Probabilistic roadmap method
UAV	Unmanned aerial vehicle
MAV	Micro aerial vehicle
CAD	Computer-aided design
FCFS	First come first serve
CLOOK	Circular Look
SSTF	Shortest seek time first
C-space	Configuration space
RC-RRT	Resolution complete rapidly-exploring random tree
ERRT	Execution extended rapidly-exploring random tree

Richter, 2011; Mueller et al., 2012). The deployment of autonomous robots is an opportunity for enhancing tasks such as weeding, spraying, harvesting and mowing (Bakker, van Asselt, Bontsema, Müller, & van Straten, 2011; De-An, Jidong, Wei, Ying, & Yu, 2011; McPhee & Aird, 2013; Van Henten, Hemming, Van Tuijl, Kornet, & Bontsema, 2003; Van Henten et al., 2006). Monitoring and sampling are also important to improve crop yields and pest control (Slaughter, Giles, & Downey, 2008). Autonomous mobile robots have the potential to ultimately revolutionise agriculture. Small, cost-effective robot swarms, which can operate in various conditions and are easily maintained, can eventually replace heavy expensive machinery.

Operations of autonomous robots can be categorised into four main procedures, which are perception, localisation, planning and execution (Siegwart, Nourbakhsh, & Scaramuzza, 2011). Multisensory, vision-guided, perception systems are well studied and commonly used for different robotic platforms (Atanacio-Jiménez et al., 2011; Corke, Lobo, & Dias, 2007; Geiger, Lenz, Stiller, & Urtasun, 2013; Pandey, McBride, & Eustice, 2011). Data gathered by perception systems is further analysed to extract localization, mapping and obstacle information (Durrant-Whyte & Bailey, 2006; Endres, Hess, Sturm, Cremers, & Burgard, 2014; Rone & Ben-Tzvi, 2013). Planning is the process of computing a feasible, collision-free route towards the goal, given the current knowledge of the environment. Feedback control loops are commonly used for plan execution (Antonelli, Chiaverini, & Fusco, 2007; Wallace et al., 1985).

1.1. *Path planning*

Path planning is a primary task for a robot to achieve mobility. Arguably, it is considered to be the most widely researched topic in robotics. Planning has extended well beyond robotics into computer animation, games and biology (Latombe, 1999). Planning in a fully observable, deterministic environment for an unrestrained robot is referred to as the *piano movers problem* in three dimensions or *sofa movers* in two dimensions. Deterministic solutions for, the aforementioned, simplified problems have proven to be computationally extensive (Reif, 1979). Path planning algorithms produce simple paths consisting of subsequent waypoints linked by straight lines. Agile robots, such as omnidirectional robots and multi-rover aerial vehicles, are capable executing similar paths. This strategy involves performing stationary turns at all waypoints to change heading towards the subsequent waypoint. Following such paths will lead to increased traversal time. Nonholonomic robots, similar to car-like robots and fixed wing UAVs, are incapable of performing stationary turns, as their turning radius is bounded.

Roadmaps algorithms attempt to capture the connectivity of the environment (Asano, Asano, Guibas, Hershberger, & Imai, 1985; Brooks & Lozano-Perez, 1985; Canny, 1985; Keil & Sack, 1985). Graph search algorithms such as A* (Hart, Nilsson, & Raphael, 1968) and AD* (Likhachev, Ferguson, Gordon, Stentz, & Thrun, 2008) rely on the search space discretisation. It is undesirable, as coarse cell size can fail to capture the search space and lead to loss of completeness. High fidelity discretization will cause a surge in computation especially in