Initialisation and Decentralised Control for Robotic Formation

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

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Anh Duy Nguyen

To my mother and my father

To my wife and my son

Abstract

This thesis addresses the problem of coordination of a group of mobile robots to get into and maintain a formation with a desired shape. Two issues of particular importance in the coordination problem are formation initialisation and maintenance. Inter-robot collision and communication bandwidth limitations raise certain difficulties and require a thorough treatment. This thesis presents original contributions towards a solution to the formation initialisation and maintenance for multiple mobile robots in an obstacle-free environment.

In the context of robotic formation control, the commonly-used virtual robot tracking combined with *l-l* control has limitations in the establishment of a line formation, the possibility of collision between robots, and the singularity cases involved. A new approach called the *Virtual Head Robot Tracking* (VHRT) and *Three Point l-l* (3PLL) control incorporated with reactive control schemes is presented. The approach represents an appropriate solution to formation control for a group of three mobile robots with singularities alleviated and inter-robot collision completely avoided.

For a group of more than three robots, a step-by-step procedure is proposed allowing the robots in turn to participate in the process of formation initialisation, that is based on a predefined control graph, while ensuring inter-robot collision avoidance.

An observed-based decentralised control approach is proposed to establish and maintain a desired formation in the condition of a limited information exchange among robots in the group. This suggests the capability of enlarging the size of the platoon of vehicles in practice.

The theoretical work of the thesis is evaluated by extensive simulations of multiple mobile robots based on their kinematic models. The results obtained are also experimentally tested, in part, on a group of two Amigo mobile robots.

List of symbols

Symbol	Description	Unit
b	The half distance between two wheels of a robot	m
$-b_h, b_h$	Hardware bound on the steering angle in car-like vehicle model	rad
$Card(S,N)$	The number of elements of a set S of control graphs of N robots	-
D	Distance between the castor and the centre of axis of the wheels of a robot	m
D_{max}	Largest distance from one of three head points of a robot to its centre	m
d	Distance between two centre points of head robot and its host	m
e_x	Horizontal coordinate error between a virtual robot of robot j and robot i in *virtual robot tracking* control	m
$e_x(0)$	Initial horizontal coordinate error between a virtual robot of robot j and robot i in *virtual robot tracking* control	m
e_y	Vertical coordinate error between a virtual robot of robot j and robot i in *virtual robot tracking* control	m
$e_y(0)$	Initial vertical coordinate error between a virtual robot of robot j and robot i in *virtual robot tracking* control	m
e_{xji}	Horizontal coordinate error between a head robot of robot j and a virtual robot of robot i in *virtual head robot tracking* control	m
$e_{xji}(0)$	Initial horizontal coordinate error between a head robot of robot j and a virtual robot of robot i in *virtual head robot tracking* control	m
e_{yji}	Vertical coordinate error between a head robot of robot j and a virtual robot of robot i in *virtual head robot tracking* control	m

Symbol	Description	Unit
$e_{yji}(0)$	Initial vertical coordinate error between a head robot of robot j and a virtual robot of robot i in *virtual head robot tracking* control	m
F	Input force of a robot	N
h	Platoon level function	-
i, j	Index of a robot	-
I_{r_i}	An identity matrix of dimension r_i.	-
J	Moment of inertia of a robot.	kg.m^2
k, l	Index of a step in initialisation process	-
l	Longitudinal clearance from a virtual robot to its host in *virtual robot tracking* control	m
L	Longitudinal clearance from a virtual robot to its host in *virtual head robot tracking* control	m
l_K	Longitudinal clearance from point K to the centre point of a robot	m
l_{ij}	Distance between the centre of robot i and the reference point of the robot j	m
$l_{ij}(0)$	Initial distance between the centre of robot i and the reference point of the robot j	m
l_{ij}^d	Desired length between robot i and robot j	m
l_{ijK}^d	Desired length between robot i and robot j with respect to virtual point K	m
m	Mass of a robot	kg
m_i	The number of input signals of ith control agent	-
m_Σ	The number of input signals of a platoon	-
N	The number of robots in a group	-
n_k	The number of steps of the formation initialisation process	-
n_Σ	The number of state variables of a platoon	-
p_i	The observer order for ith control agent	-

Symbol	Description	Unit
p, q	Control parameter – positive constant	-
r	Clearance along rear wheel axis from a virtual robot to its host in *virtual robot tracking* control	m
R	Clearance along rear wheel axis from a virtual robot to its host in *virtual head robot tracking* control	m
r_i	The number of output signals of ith control agent	-
r_Σ	The number of output signals of a platoon	-
r_K	Clearance along rear wheel axis from point K to the centre point of a robot	m
r_{safe}	Radius of a virtual safe circle covering a robot	m
r_w	Radius of the wheel of a robot	m
$S_1(N)$	The set of allowable control graphs of N robots in which at the final step there is one robot to become active	-
$S_2(N)$	The set of allowable control graphs of N robots in which at the final step there is two robots to become active	-
T_r	Finite reaching time for *l-l* control using terminal attractor	s
u_1, u_2	Input signal of a robot	-
u_i	The velocity vector of robot i	-
$u_i(t)$	The input vector of the i-th agent	-
v	Translational velocity of a robot	m/s
v_1, v_2	Horizontal and vertical velocity of a robot respectively	m/s
v_i	Translational velocity of robot i	m/s
v_{vi}	Translational velocity of a virtual robot of robot i	m/s
x	Horizontal coordinate of the centre point of a robot	m
x_i	Horizontal coordinate of the centre point of robot i	m
$x_i(0)$	Initial horizontal coordinate of the centre point of robot i	m
x_{ci}	Horizontal coordinate of the castor of robot i	m
x_{hj}	Horizontal coordinate of the centre point of a head robot of robot j	m

Symbol	Description	Unit
x_{vi}	Horizontal coordinate of the centre point of a virtual robot of robot i	m
y	Vertical coordinate of the centre point of a robot	m
y_i	Vertical coordinate of the centre point of robot i	m
$y_i(0)$	Initial vertical coordinate of the centre point of robot i	m
$y_i(t)$	The output vector of the i-th agent	-
y_{ci}	Vertical coordinate of the castor of robot i	m
y_{hj}	Vertical coordinate of the centre point of a head robot of robot j	m
y_{vi}	Vertical coordinate of the centre point of a virtual robot of robot i	m
w_{ij}	Weight of edge ij of a weighted digraph	-
α_1, α_2	Control parameter, positive constant	s^{-1}
α_1^*, α_2^*	Control parameter in modified l-l control	$m^{(1-p/q)}s^{-1}$
$\alpha_{1K}^*, \alpha_{2K}^*$	Control parameter in *three point l-l* control with respect to virtual point K	$m^{(1-p/q)}s^{-1}$
δ_1, δ_2	Control parameter for collision avoidance	m
Δx_{ij}	Horizontal coordinate error between the castor of robot j and the centre of robot i	m
Δy_{ij}	Vertical coordinate error between the castor of robot j and the centre of robot i	m
θ	Orientation of a robot	rad
θ_i	Orientation of robot i	rad
$\theta_i(0)$	Initial orientation of robot i	rad
$\theta_i(t)$	Orientation of robot i at time point t	rad
θ_{hj}	Orientation of a head robot of robot j	rad
θ_{vi}	Orientation of a virtual robot of robot i	rad
λ_1, λ_2	Control parameter – positive constant	s^{-1}

Symbol	Description	Unit
$\lambda_{j1}, \lambda_{j2}$	Control parameter for robot j – positive constant	s^{-1}
ρ	Distance between two robots	m
τ	Input torque of a robot	N.m
ϕ	Rolling angle of the wheel in Roller unicycle model	rad
ϕ_{st}	Steering angle in car-like vehicle model	rad
ψ_{ij}	Relative angle between robot i and robot j	rad
ψ_{ijK}	Relative angle between robot i and robot j with respect to virtual point K of robot j	rad
$\psi_{ij}(t)$	Relative angle between robot i and robot j at time point t	rad
$\psi_{ij}(0)$	Initial relative angle between robot i and robot j	rad
ψ_{ij}^d	Desired relative angle between robot i and robot j	rad
ω	Angular velocity of a robot	rad/s
ω_1, ω_2	Left and right wheel rotational velocity respectively	rad/s
ω_i	Angular velocity of robot i	rad/s
ω_{vi}	Angular velocity of a virtual robot of robot i	rad/s
$\Im_i(t)$	Information available to the ith control station	-

Abbreviations

3PLL	Three Point *l-l*
ARIA	Advanced Robotics Interface Application
AUV	Autonomous Unmanned Vehicle
DOF	Degree of Freedom
GA	Genetic Algorithm
HR	Head Robot
ID	Identification
LAS	Linear Autonomous System
LFS	Leader-to-Formation Stability
MDLe	extended Motion Description Language
MPC	Model Predictive Control
PC	Personal Computer
PTZ	Pan Tilt Zoom
RFP	Formation Reference Point
RL	Reinforcement Learning
SIP	Server Information Packet
TCP	Transmission Control Protocol
V-GPS	Vision-based Global Positioning System
VHRT	Virtual Head Robot Tracking
VR	Virtual Robot
VRT	Virtual Robot Tracking
VS	Virtual Structure
WMR	Wheeled Mobile Robot

Contents

List of figures