Razvan Solea

Sliding-Mode Control Applied in Mobile Robots and Autonomous Vehicles

Trajectory-Tracking Control Problem

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Contents

Acknowledgment **1**

1 Introduction **13**

1.1 Motivation and Background 13

1.2 Contributions 15

1.3 Outline of the Work 16

2 Trajectory Tracking Problems **17**

2.1 Related Works 17

2.2 Motivation 19

3 Kinematic and Dynamic Models for Differential-drive and Car-like Mobile Robots **21**

3.1 Kinematic and Dynamic Modeling for Differential-drive Robots 21

3.2 Motion Control for WMR 24

3.2.1 Point Stabilization 27

3.2.2 Trajectory Tracking 27

3.2.3 Path Following 28

3.3 Kinematic and Dynamic Modeling for Car-like Vehicle 31

3.3.1 Dynamics of the Nonlinear Single-Track Model 33

3.3.2 Linearized Single-Track Model 37

3.4 Motion Control for Car-like Vehicle 38

3.4.1 Longitudinal Control 38

3.4.2 Lateral Control 39

3.4.3 Integration of Lateral and Longitudinal Controls 39

4 Path Planning **41**

4.1 Introduction 41

4.2 Quintic Equations 43

4.3 Velocity Planning 46

5 Sliding Mode Control Design **55**

5.1 Definitions and Preliminaries 55

5.2 Sliding Surface Design . . . 57
5.3 Control Law Design . . . 60
5.4 Chattering Problem and its Reduction . . . 65
5.5 Sliding Mode Trajectory-Tracking Control for WMR . . . 67
5.5.1 Simulation Results . . . 68
5.6 Sliding Mode Trajectory-Tracking Control for Car-like Vehicle . . . 70
5.6.1 Simulation Results . . . 74
5.7 Sliding-Mode Path-Following Control for WMR . . . 75
5.7.1 Simulation Results . . . 78

6 Human Body Comfort **83**
6.1 Introduction . . . 83
6.2 Model of Human Head-Neck Complex . . . 87
6.3 Experimental Data From Inertial Sensor . . . 89

7 Implementation in Real Wheelchair - RobChair **93**
7.1 Introduction . . . 93
7.2 Architecture of RobChair . . . 94
7.2.1 Hardware and Software Architecture . . . 95
7.3 Robot Constraints . . . 99
7.3.1 Velocity Limits . . . 99
7.3.2 Acceleration and Deceleration Limits . . . 99
7.3.3 Maximum Velocity to Avoid Sliding Out . . . 100
7.3.4 Wheel-Ground Interaction to Avoid Slippage . . . 102
7.3.5 Calculation of the Coefficient of Friction . . . 103
7.3.6 Bounded Wheel Speed Commands . . . 104
7.3.7 Dynamic Constraints . . . 106
7.3.8 Feasible Constraints . . . 107
7.4 Experimental Results . . . 108
7.4.1 Experimental Results Under Odometry Navigation . . . 108
7.4.2 Experimental Results Under Magnetic-markers Navigation . . . 109

8 Conclusions **115**

A Appendix **117**

Bibliography **119**

List of Tables

3.1 Parameters of the car model 34
3.2 Vehicle model summary 38

4.1 Length, time and r.m.s. acceleration values for each curve 52
4.2 Length, time and r.m.s. acceleration values for each curve (Fig. 4.9) 54

6.1 Most relevant parameters 85
6.2 ISO 2631-1 STANDARD. 87
6.3 Characteristics of user's elements 89
6.4 Experimental results. 90

7.1 Fusion algorithm. 98
7.2 Experimental results for SM-TT controller under odometry navigation. 109
7.3 Experimental results for SM-TT controller under odometry navigation. 109
7.4 Experimental results for SM-TT controller under magnetic-markers navigation. . 112
7.5 Experimental results for SM-TT controller under magnetic-markers navigation. . 112
7.6 Experimental results for SM-PF controller under magnetic-markers navigation. . 112

List of Figures

3.1 WMR model and symbols. 22
3.2 Motion control using the kinematic model. 25
3.3 Two-stage model of a real mobile robot. 25
3.4 Inner loop control of a mobile robot (dynamic-level control). 25
3.5 Control of a real mobile robot. 26
3.6 Description of the Trajectory Tracking Problem. 28
3.7 Description of the Path Following Problem. 29
3.8 Description of the Path Following problem with look-ahead distance. 30
3.9 Kinematics model of A) 4 wheel vehicle; B) Bicycle model. 31
3.10 The one-track bicycle model. 35
3.11 The one-track bicycle model. 36

4.1 Path planning example using quintic polynomial curves. 43
4.2 Lane change ($\eta_1 = \eta_2 = 1, 2, 3, 4, 5, \eta_3 = \eta_4 = 0$). 45
4.3 Lane change ($\eta_1 = \eta_2 = 5, \eta_3 = \eta_4 = -50, -25, 0, 25, 50$). 45
4.4 An example of a longitudinal velocity profile. 47
4.5 Restrictive cases of a_w. 50
4.6 Linear and angular velocity for path example depicted in Fig. 4.1. 51
4.7 Lateral and longitudinal accelerations for path example depicted in Fig. 4.1. . . . 51
4.8 R.m.s. acceleration values for path example depicted in Fig. 4.1. 52
4.9 Path planning example 53
4.10 Linear and angular velocity for path example (Figure 4.9); case A and B. 53
4.11 Lateral and longitudinal accelerations for path example (Figure 4.9); case A and B. 53
4.12 R.m.s. acceleration values for path example (Figure 4.9); case A and B 54

5.1 Geometric interpretation of two intersecting switching surfaces. 56
5.2 Block diagram of observer based sliding mode control. 66
5.3 Disturbance compensation with sliding mode disturbance observer. 66
5.4 Simulation model block diagram (Simulink scheme). 69
5.5 Simulink model for RobChair. 69
5.6 Path examples calculated by the trajectory planner (see Chapter 4). 69
5.7 Velocities and accelerations for the path depicted in Fig. 5.6. 70

5.8 R.M.S. acceleration values for each path-segment (AB, BC,...) of the paths depicted in Fig. 5.6. 70
5.9 Desired v_d, command v_c and real v_r linear velocities for SM-TT control - Path 1 and Path 2. 70
5.10 Desired ω_d, command ω_c and real ω_r angular velocities for SM-TT control - Path1 and Path 2. 71
5.11 Desired av_d, command av_c and real av_r longitudinal accelerations for SM-TT control - Path 1 and Path 2. 71
5.12 Desired $a\omega_d$, command $a\omega_c$ and real $a\omega_r$ angular accelerations for SM-TT control - Path1 and Path 2. 71
5.13 Longitudinal, lateral and angular errors of SM-TT control - Path 1 and Path 2. 71
5.14 Simulation SM-TT control starting from an initial error state ($x_e(0) = -0.5$, $y_e(0) = -0.5$, $\phi_e(0) = 0$). 72
5.15 Bicycle model (5.62) 72
5.16 Lateral, longitudinal and orientation error (trajectory-tracking) 73
5.17 Simulation model block diagram (Simulink scheme). 74
5.18 Simulink model for car-like vehicle. 75
5.19 Desired (v_d, δ_d), command (v_c, δ_d) and real (v_r, δ_r) linear velocities and steering angles for SM-TT controller without initial pose error - Path Fig. 4.1 75
5.20 Desired $(av_d, a\delta_d)$, command $(av_c, a\delta_c)$ and real $(av_r, a\delta_r)$ longitudinal and lateral accelerations for SM-TT controller without initial pose error - Path Fig. 4.1 . . 75
5.21 Longitudinal (x_e), lateral (y_e) and orientation (ϕ_e) errors for SM-TT controller without initial pose error - Path Fig. 4.1 76
5.22 Simulation SM-TT control starting from an initial error state ($x_e(0) = -2.5$, $y_e(0) = -2.5$, $\phi_e(0) = \pi/4$). 76
5.23 Simulation model block diagram for TT-PF control - Simulink scheme. 79
5.24 Simulation of TT-PF controller with a given longitudinal velocity profile. 79
5.25 Desired $a\omega_d$, command $a\omega_c$ and real $a\omega_r$ longitudinal and angular velocity for SM-PF control. 80
5.26 Lateral and angular errors of SM-PF control. 80
5.27 Simulation of TT-PF controller with a constant longitudinal velocity ($v_d = 0.5m/s$). 80
5.28 Desired $a\omega_d$, command $a\omega_c$ and real $a\omega_r$ longitudinal and angular velocity for SM-PF control. 81
5.29 Lateral and angular errors of SM-PF control. 81

6.1 The human response (ride quality) involves human variables as well as dynamic motion and other physical variables, but the ride comfort response and technical evaluation of ride (dis-)comfort involves dynamic motion variables only. Modified from Forstberg [120]. 85
6.2 Human head-neck model 89

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6.3 Experimental sliding-mode trajectory-tracking control using an EKF-based fusion in the on-line pose estimation. 90
6.4 Cross-spectal density functions for all experiments. 91
6.5 Longitudinal and lateral accelerations from IMU and from encoders. 91

7.1 RobChair platform. 95
7.2 Levels and modules of the motion control system. 96
7.3 RobChair CAN-based hardware architecture. 97
7.4 Robotic wheelchair model and symbols. 99
7.5 Surfaces used in the determination of acceleration limits. 100
7.6 Experimental (green and red) and desired (blue) wheels speed values used to determine the maximum acceleration and deceleration of the RobChair. 101
7.7 Free body diagram showing the RobChair mobile robot (in plane yz). 102
7.8 Free body diagram to find the maximum acceleration before wheel slippage. . . 103
7.9 Schematic showing the forces acting on RobChair to cause it to move. 104
7.10 Feasible WMR velocities. 105
7.11 Differential drive curvature as function of the wheels speeds. 106
7.12 Linear velocity as function of wheels' speed. 107
7.13 Experimental SM-TT control starting from an initial error state ($x_e(0) = -1$, $y_e(0) = -1$, $\phi_e(0) = 0$), under odometry navigation. 108
7.14 Experimental SM-TT control under magnetic-markers navigation: Left) $Path-1$; Right) $Path-2$. In both paths, the circles represent the positions of the seven magnetic markers used in the experiment. 110
7.15 Experimental SM-PF control under magnetic-markers navigation: Left) $Path-1$; Right) $Path-2$. In both paths, the circles represent the positions of the seven magnetic markers used in the experiment. 110
7.16 RobChair pictures at different positions in a real experiment. 110
7.17 Desired (v_d, ω_d), command (v_c, ω_c) and real (v_r, ω_r) linear and angular velocities for SM-TT control using an EKF-based fusion in the on-line pose estimation - $Path-1$. 111
7.18 Desired (v_d, ω_d), command (v_c, ω_c) and real (v_r, ω_r) linear and angular velocities for SM-TT control using an EKF-based fusion in the on-line pose estimation - $Path-2$. 111
7.19 Longitudinal and lateral errors of SM-TT control under magnetic-markers navigation: Left) $Path-1$; Right) $Path-2$. 111
7.20 Longitudinal and lateral accelerations from IMU and from encoders in case of SM-TT control, Left) $Path-1$; Right) $Path-2$. 113

List of Abbreviations

CAN .... Controller-Area Network
CSD .... Cross Spectral Density
DOF .... Degree Of Freedom
EKF .... Extended Kalman Filter
eVDV .... Estimated Vibration Dose Value
FFT .... Fast Fourier Transformation
HNC .... Head-Neck Complex
IMU .... Inertial Measurement Unit
ISO .... International Organization for Standardization
ISR .... Institute of Systems and Robotics
MCL .... Motion Control Level
MPL .... Motion Planning Level
MTL .... Motion Tracking Level
PSD .... Power Spectral Density
rmq .... Root Mean Quad
rms .... Root Mean Square
SM-PF .... Sliding-Mode Path-Following
SM-TT .... Sliding-Mode Trajectory-Tracking
SMC .... Sliding Mode Control
Tr .... Transmissibility
VDV .... Vibration Dose Value
VSC .... Variable Structure Control
VSS .... Variable Structure Systems
WMR .... Wheeled Mobile Robot

Chapter 1

Introduction

1.1 Motivation and Background

Everyday more and more robotic vehicles are entering the real world. They are put to work just about everywhere manual vehicles have been used in the past. From agriculture, and mining operations, to inside factories and hospitals, they are increasing safety, efficiency, and performance in all tasks otherwise considered to be too dull, dirty or dangerous for manual labor.

Autonomous vehicles pose a number of unique problems in their design and implementation. There is no longer a human-in-the-loop control scheme for the vehicle. The system itself must close the loop from environment feedback to low-level vehicle control. Where a human operator would normally analyze data feedback from telemetry, remote video, etc. and then decide the best course of action, designers must now instrument the vehicle so that it can automate these tasks. This requires the inclusion of internal state and environmental sensors, along with onboard computers and software capable of processing the sensed information and planning the vehicle's action accordingly.

The first design step is the inclusion of different types of sensors onto the vehicle platform. These sensors serve two general purposes. The first is to measure the state of the vehicle itself, such as its position, orientation, speed, and perhaps also health monitoring information such as comfort, temperature, pressure, etc (proprioception).

The second general purpose is the system's ability to sense information originating outside of itself (exteroception). It is the ability to sense one's environment. Sensors such as cameras and range detectors provide this information. The job of the system designer is to outfit the autonomous vehicle with those sensors necessary and appropriate to provide the correct environment feedback, thus allowing the system to decide how to act within it.

The second design step is giving the autonomous vehicle the ability to calculate how to react to sensed internal and external information. This step requires the vehicle to have the necessary processing and computational power along with the algorithms and software capable of providing robust and stable control laws that guide the navigation of the robot.

Autonomous vehicles generate their own decisions, at the planning level, that govern how to drive the vehicle actuators, and cause the platform to move.

The problem of motion planning and control is that there must be consideration for the motion constraints of any actuators involved or the vehicle platform itself. This is especially an important issue for car-like vehicles and WMRs because they are subject to nonholonomic constraints. This means that a vehicle driving on a surface may have three degrees of freedom: translation in two dimensions and rotation in one. Consequently, the equations of motion describing the vehicle dynamics are non-integrable, which makes the problem much more difficult to solve. This also means that car-like vehicles and WMRs are under actuated. In other words, the number of control inputs to the system is less than the number of degrees of freedom in the system's configuration space.

Many people nowadays spend a significant proportion of their time travelling and there is an increasing demand for comfort, in private and public transportation. Three classes of factors are considered in the analysis of travelling comfort: organizational, local and riding. The riding comfort can be analysed in three different respects: dynamic factors - related to vibration, shocks and acceleration; ambient factors - thermal comfort, air quality, noise, pressure gradients, etc; spatial factors - dealing with the ergonomics of the passenger's position.

Comfort is a complex definition that contains both physiological and psychological components; this includes the subjective feeling of well being with the absence of discomfort, stress and pain. Comfort not only consists of the absence of negative effects; it is also the experience of positive aspects of comfort. Therefore, comfort includes a form of evaluation, i.e. *it feels well* and has as its opposite, negative sensations. From interviews of vehicle passengers it is obvious that ride comfort is dependent not only on the magnitude but also on the occurrence of occasional shocks or transients.

Ride quality is a person's reaction to a set of physical conditions in a vehicle environment, such as dynamic, ambient and spatial variables. Dynamic variables consist of motions, measured as accelerations and changes (jerk) in accelerations in all three axes (lateral, longitudinal and vertical), angular motions about these axes (roll, pitch and yaw) and sudden motions, such as shocks and jolts. Normally, the axes are fixed to the vehicle body. The ambient variables may include temperature, pressure, air quality and ventilation, as well as noise and high frequency vibrations, while the spatial variables may include workspace, leg room and other seating variables. However, many use the term passenger comfort, ride comfort or average ride comfort for ratings on a ride quality scale regarding the influence of dynamic variables. Normally, higher rating on a ride quality scale means better comfort, whereas higher rating on a ride (dis-)comfort scale means less comfort.

This is the nature of the problem undertaken in this work.

The theory of variable structure systems (VSS) opened up a wide new area of development for control designers. Variable structure control (VSC), which is frequently known as sliding mode control (SMC), is characterized by a discontinuous control action which changes structure upon reaching a set of predetermined switching surfaces. This kind of control may result in a very robust system and thus provides a possibility for achieving our goals. Some promising

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