

# Bicycle Dynamics and Control

By Karl J. Åström,  
Richard E. Klein, and  
Anders Lennartsson

Adapted bicycles for  
education and research



**T**his article analyzes the dynamics of bicycles from the perspective of control. Models of different complexity are presented, starting with simple ones and ending with more realistic models generated from multibody software. We consider models that capture essential behavior such as self-stabilization as well as models that demonstrate difficulties with rear wheel steering. We relate our experiences using bicycles in control education along with suggestions for fun and thought-provoking experiments with proven student attraction. Finally, we describe bicycles and clinical programs designed for children with disabilities.

## The Bicycle

Bicycles are used everywhere—for transportation, exercise, and recreation. The bicycle's evolution over time has been a product of necessity, ingenuity, materials, and industrialization. While efficient and highly maneuverable, the bicycle represents a tantalizing enigma. Learning to ride a bicycle is an acquired skill, often obtained with some difficulty; once mastered, the skill becomes subconscious and second nature, literally just “as easy as riding a bike.”

Bicycles display interesting dynamic behavior. For example, bicycles are statically unstable like the inverted pendulum, but can, under certain conditions, be stable in forward motion. Bicycles also exhibit nonminimum phase steering behavior.

Bicycles have intrigued scientists ever since they appeared in the middle of the 19th century. A thorough presentation of the history of the bicycle is given in the recent book [1]. The papers [2]–[6] and the classic book by Sharp from 1896, which has recently been reprinted [7], are good sources for early work. Notable contributions include Whipple [4] and Carvallo [5], [6], who derived equations of motion, linearized around the

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**J. I. Woodfill**



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**16th International Symposium on Advanced Vehicle Control** Giampiero Mastinu, Francesco Braghin, Federico Cheli, Matteo Corno, Sergio M. Savaresi, 2024-10-03 This open access book highlights the latest advances innovations and applications in the field of vehicle systems dynamics and control as presented by leading international researchers at the 16th JSAE International Symposium on Advanced Vehicle Control AVEC held at Politecnico di Milano Milan Italy on September 2 6 2024 It covers a diverse range of topics such as vehicle dynamics theory steering brake tire suspension chassis control powertrain electrified vehicles stability enhancement systems driver vehicle systems advanced driver assistance systems and automated driving systems driving simulator dynamics and control The contributions which were selected by means of a rigorous international peer review process present a wealth of exciting ideas that will open novel research directions and foster multidisciplinary collaboration among different specialists

*Advances in Nonlinear Dynamics* Walter Lacarbonara, Balakumar Balachandran, Michael J. Leamy, Jun Ma, J. A. Tenreiro Machado, Gabor Stepan, 2022-03-01 This second of three volumes includes papers from the second series of NODYCON which was held virtually in February of 2021 The conference papers reflect a broad coverage of topics in nonlinear dynamics ranging from traditional topics from established streams of research to those from relatively unexplored and emerging venues of research These include Nonlinear vibration control Control of nonlinear systems and synchronization Experimental dynamics System identification and SHM Multibody dynamics

[Evolutionary Computation in Combinatorial Optimization](#) Christian Blum, Gabriela Ochoa, 2014-08-21 This book constitutes the refereed proceedings of the 14th European Conference on Evolutionary Computation in Combinatorial Optimization Evo COP 2014 held in Granada Spain in April 2014 co located with the Evo 2014 events Euro GP Evo BIO Evo MUSART and Evo Applications The 20 revised full papers presented were

carefully reviewed and selected from 42 submissions The papers cover the following topics swarm intelligence algorithms fitness landscapes and adaptive algorithms real world and routing problems and cooperative and metaheuristic search

Proceedings of the Second International Conference on Intelligent Transportation Huapu Lu,2016-11-24 These proceedings present the latest information on intelligent transportation technologies and their applications in real world cases The Second International Conference on Intelligent Transportation was held in Chengdu China on November 25 27 2015 to present the latest research in the field including intelligent transportation management intelligent vehicles rail transportation systems traffic transportation networks as well as road traffic element simulations and their industrial development The aim of conference was to bring together academics researchers engineers and students from across the world to discuss state of the art technologies related to intelligent transportation Proceedings ,2007 Proceedings A publishes refereed research papers in the mathematical physical and engineering sciences The emphasis is on new emerging areas of interdisciplinary and multidisciplinary research Continues Proceedings Mathematical and physical sciences

**Dynamics of Continuous, Discrete & Impulsive Systems** ,2001 *Highway Safety Literature* ,1974

**Proceedings of the ... International Modal Analysis Conference & Exhibit** ,1991 Memoirs of the Faculty of Engineering, Kyushu University ,2000 *Mobile Robot Technology* Jurek Sasiadek,2001 This Proceedings contains the papers presented at the IFAC Workshop on Mobile Robot Technology held in Jejudo Island Korea on 20 23 May 2001 This is an important and interesting topic and this Proceedings contains approximately 50 papers featuring some of the very best work being undertaken by research groups from all around the world The papers deal with both the theoretical and practical aspects of mobile robot technology covering important problems and issues related to the subject Estimation of Specific Vehicle Dynamic Outputs Using the Controller Output Observer Jeremy Vane Cornwall,2006 Journal of Dynamic Systems, Measurement, and Control ,2004 Publishes theoretical and applied original papers in dynamic systems Theoretical papers present new theoretical developments and knowledge for controls of dynamical systems together with clear engineering motivation for the new theory Applied papers include modeling simulation and corroboration of theory with emphasis on demonstrated practicality *A Dynamic Analysis and Simulation of Bicycling* Marvin Glenn Wong,1981 *Motion Vision and Tracking for Robots in Dynamic, Unstructured Environments* J. I. Woodfill,1992 Whenever a large object moves into view the object is picked out and tracked while the robot pans the camera to keep the object centered in the field of view The robots have successfully tracked people walking around for long periods These functioning robots demonstrate both the utility of the tracking vision service itself and the manner in which such vision services can be integrated into complete systems *Mobile Robots XV* Howie M. Choset,Douglas Whitney Gage,Matthew R. Stein,2001 Optomechatronic Systems Control Farrokh Janabi-Sharifi,2005 Proceedings of SPIE present the original research papers presented at SPIE conferences and other high quality conferences in the broad ranging fields of optics and photonics These books provide prompt access to

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