application of the computational algorithms. Such author insight would have been extremely valuable. From the standpoint of extending the applicability of the receding horizon optimal control to faster processes, computational complexity represents an especially critical area.

In the text, input constraints are generally emphasized more than state constraints. However, other techniques, such as antiwindup compensation and gain scheduling, exist for dealing with pure input constraints. A discussion of the relative benefits of the techniques described in the text over those prevalent in the literature would have been beneficial.

Overall, a deeper look at links or extensions to nonlinear systems with general state and input constraints as well as at the associated computational issues would have been valuable. To be fair, the book does provide pointers to the literature should the reader desire a thorough look at these and other topics.

In summary, the book provides a self-contained, well-thought out, and accessible introduction to a wide range of topics and fundamental principles underlying receding horizon constrained control and estimation. The developments are presented at a sufficient level of detail and mathematical rigor to accomplish this objective. The book can be used as a textbook for a graduate-level course, for independent reading, or as a reference. Several other books have recently appeared on the subject of receding horizon optimal control for constrained systems, including [2] and [3]. While the present book has some overlap with these two texts in terms of its coverage (namely the consideration of discrete linear systems having input constraints), *Constrained Control and Estimation* stands on its own as a complete work and a rigorous yet accessible introductory text with unique perspectives on the application of convex optimization tools to systems having input constraints.

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Bicycling Science, 3rd ed., by David G. Wilson with J. Papadopoulos, MIT Press, 2004, 477 pp., ISBN 0-262-23237-5, US$22.95. *Reviewed by Dennis S. Bernstein*.

There's something that's simultaneously primitive and high tech about bicycles. For retro folks like myself, the lack of any electrons running around circuits (perish the thought of a handlebar-mounted computer) gives my bike a kind of antique charm. On the other hand, the shiny, precision gears and composite suspension are pretty advanced. In short, my bicycle represents the best of all worlds.

In this age of gas-guzzling SUVs (which are great for transporting bikes around!) and dwindling petroleum reserves, bicycle lovers will not be surprised to learn that the bicycle is an amazingly efficient vehicle. Besides the healthful exercise and fresh air that the rider gets for free, the equivalent energy consumption of the bicycle is 1,350 miles/gallon at a speed of 20 miles/hour.

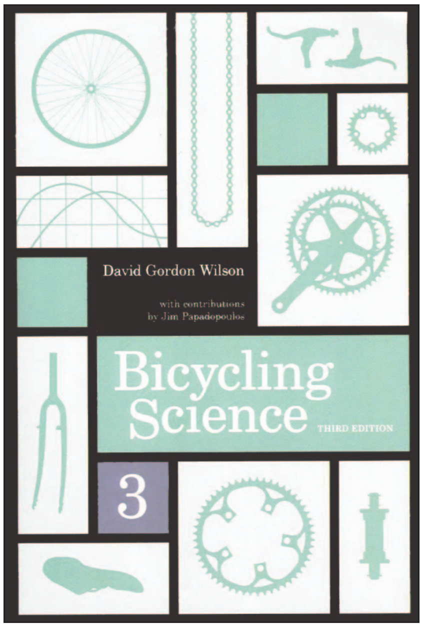
I never thought much about how a bicycle actually works until I read the Åström, Klein, and Lennartsson article [1]. Their delightful article shows us that a bicycle without control principles is like a transfer function without poles. Or maybe I should say zeros, since, as usual, zeros rule and poles drool.

Although I haven't read the earlier editions, the third edition of *Bicycling Science* is apparently a greatly updated version of a book well known to bicycle enthusiasts. A large fraction of these enthusiasts are interested in speed, perhaps for racing or to develop innovative designs for breaking records. For these folks, *Bicycling Science* provides a semitechnical ("semi" for its sparse use of math and equations) compendium of a huge body of research on bicycle design and construction as well as the performance characteristics of the humans who ride them.

The Bike Bible

Bicycling Science begins with a brief but fascinating account of the history of the bicycle. A key point of this history is that it took humanity a long time to harness human leg power. The reasons are far from obvious, since the design of the modern bicycle is so simple that one would expect such a design to have arisen immediately. In fact, the earliest "bicycles" had no foot-driven mechanism (except of the Fred Flintstone sort) and no steering. Later, the lack of gearing led to the classic huge front wheel and tiny trailing wheel. For a much more detailed history, see the elegant [2].

The text devotes the next chapter to a detailed review of the performance characteristics of humans. This material is of great value to engineers working on human-powered vehicles of all kinds, including aircraft and watercraft. What I found interesting about this chapter is not the fact that a particular human managed 2,378 W of power for three seconds but rather the challenge of making accurate and meaningful measurements in tricky situations. Machines can be designed (with great care) to measure human performance characteristics in the lab, but these devices must be supplemented by more challenging road measurements, where the cooling effect of the relative wind can have a significant impact on performance. Thermal effects are considered in the next chapter, followed by a physics-oriented chapter on power and speed.



After chapters on aerodynamic effects (how to reduce drag, explained nicely), tires and bearings (bad friction), and brakes (good friction), we finally reach the "controls" chapter: steering and balancing. This chapter begins with a warning and a teaser:

> Unfortunately, the mathematics purporting to describe bicycle motion and self-stability are difficult and have not been validated experimentally, so design guidance remains highly empirical. The most significant design detail is a geometric quantity called "mechanical trail." (p. 263)

The statement about mathematics is unique since, up to this point, there have been no "show stoppers" ascribed to difficult mathematics. Nevertheless, the chapter wastes no time grappling with control issues. One key point made almost immediately is that the rider's mass is a large fraction of the mass of the system; thus, the rider is able to use body motion in complex ways to control the vehicle. Next, the basic ideas are explained in words rather than equations, as in:

> Balancing a broomstick, or a bicycle, consists in making the small support motions necessary to counter each fall as soon as it starts, by accelerating the base horizontally in the direction in which it is leaning, enough so that the acceleration reaction (the tendency of the center of mass to get left behind) overcomes the tipping effect of unbalance.

This style of exposition and thought process is rare in the control classroom. Our usual approach would be to derive equations of motion and then demonstrate through formulas the actions needed for balancing to occur. But for those who are not experts in control, words have to suffice, and I believe the authors have done a good job.

In [1], the authors focus on countersteering, that is, the need to steer left to turn right, and vice versa. This effect is analyzed in terms of right-half-plane zeros arising from open-loop unstable poles. In *Bicycling Science,* there is no mention of zeros, but the physical effect is explained graphically in multiple ways. First

> To see [countersteering] most clearly, one can ride a bicycle along a painted line on the right edge of a road and watch the front wheel position while making a quick maneuver to change lanes rightward. One will notice a brief leftward deviation of the front wheel's path, caused by briefly steering leftward before settling into a sustained rightward steer angle. (p. 270)

And again:

> That everyone who knows how to ride a bicycle already unconsciously understands [countersteering] becomes clear when we are riding close to the edge of a curb or a slight drop-off. Riding closer than about 125 mm makes us feel nervous and "trapped": we know that it will be necessary to turn *toward* the danger in order to steer *away* from it. If there's no room, we sense that trying to escape will take us over the edge. (p. 271)

Some icing on the cake is the additional explanation that runners lean forward to accelerate and lean back to slow down. If the goal is to get somewhere fast, why not put a foot forward first? Of course, all of these phenomena can be traced to nonminimum phase zeros that arise from feedback stabilization.

The book continues with chapters on power transmission and materials. The penultimate chapter is a fascinating overview of unusual human-powered machines, such as aircraft, watercraft, and lawncraft (lawn mowers), all of which are pedaled. The final chapter focuses on trends that look toward the future. The authors' point seems to be that if engineers invested as much effort in designing human-powered tools and vehicles as they do designing gasoline-powered machines, then the world would be a better place. Amen.

Who Should Buy This Book?

This book is a necessity for anyone involved in a project involving human power. For all other engineers who like bikes (and who doesn't?), this book makes for semitechnical reading with real-world relevance. Even if your goal isn't to optimize the drive train of your bicycle, *Bicycling Science* has a wealth of material for those bored with the usual "isn't the Internet amazing" chatter. The book would also make a great gift for the scientifically inclined younger set who just might catch the engineering bug. Of course, the text will appeal to anyone with an interest in science and technology. Finally, this book is "better together" with not only [2] but also the fascinating [3], which offers many beautiful illustrations and a wealth of mechanical engineering details and ingenious designs.

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Here's what planned for the next issue:

Beyond Doc Ock: Control of Tokomak Plasmas