Locomotion versus Manipulation

Matt Mason

April 2, 2015

NSF Workshop on Locomotion and Manipulation

This talk is very difficult for me.
Alberto and Koushil asked me to reveal my ideas about locomotion, as viewed by a manipulationist. For years I have hidden my true feelings about locomotionists, but I have decided to sacrifice my own comfort for the good of the field. So the theme of the talk is that locomotionists are knuckleheads.

I know that some of you are jealous that your faces are not on this picture. I didn't choose the people honored in this picture. I just asked my artistic friend to pick the three faces that map most easily to the three stooges.

(Thanks to Deb Tobin for artistic assistance.)

History

- Stage 1: (1976 - 1988)
  Pure and innocent
- 1989: expulsion from the garden
- Stage 2: (1993 - today)
  Corrupted

In the beginning was the word, and the word was “manipulation”. When people said robotics, it meant robotic manipulation. This may have been an East Coast thing. Some in California worked on locomotion, but I didn’t know about that. I remained in that innocent state until 1989. So for the first stage of my career, when some poor knucklehead wanted to work on locomotion, my observations were pure and innocent.
Then in 1989, Buhler and Koditschek showed us the tree of knowledge. I partook of the fruit of locomotion. I was expelled from the garden. For the rest of my career, stage 2, my observations are those of a corrupted manipulationist.

Observation 1
Duality

Observed from robot frame,
locomotion is actually manipulation of the globe

- A cute observation,
- of no significance

I don't know when somebody first explained the duality thing to me. Probably grad school in the 70's. I assume everybody here knows this. The idea applies Newtonian relativity. If you watch a mobile robot from the world frame, the robot is moving itself. If you watch it from the robot's frame, the robot is moving the world. Sounds silly for a terrestrial robot, but less silly for a robot on a tiny asteroid, or an ant crawling around on a leaf in the middle of a stream.

Observation 2
Too simple to be interesting

- Manipulation:
  Move a robot to control several other objects
- Locomotion:
  Move a robot

This wasn't something somebody explained to me. This was my own immediate reaction. In 1979 I went to AAAI. There I met a full-blown unabashed locomotionist. He gave a talk on a planetary rover. I was puzzled that anybody could possibly care about such a simple problem.
Imagine: you are knocking yourself out trying to move a robot so as to move other things. And you meet a guy who is trying to move a robot.

Observation 3
Legs? Why not wheels?

- If there isn't a road, what does that tell you?
- Percentage of coverage? Build boats!

Actually, I just made this up for the talk. At the time, when Marc Raibert started pitching legged locomotion, I was hooked. Only now, preparing for this talk, did I realize that Marc had pulled the wool over my eyes.
What was the main element of Marc's pitch? The most persuasive element? Excluding the joy of watching people kick robot dogs? Marc likes to say that most of the Earth's land surface is inaccessible to wheels. Well is that really what we are after? Maximizing percentage of coverage?

Observation 4
Nonholo mumbo jumbo

- Locomotion is simple
- Nonholo mumbo jumbo is not simple
- They must be doing it wrong

As you know, there were some advances in nonlinear differential geometrical control of nonholonomically constrained dynamic systems. For brevity, I will refer to “nonlinear differential geometrical control of nonholonomically constrained dynamic systems” as “nonholo mumbo jumbo”. We can blame Jean Paul Laumond, Zexiang Li, Murry, Sastry, and their ilk for this.

1989: The fall of man(ipulation)
Dynamically stable manipulation

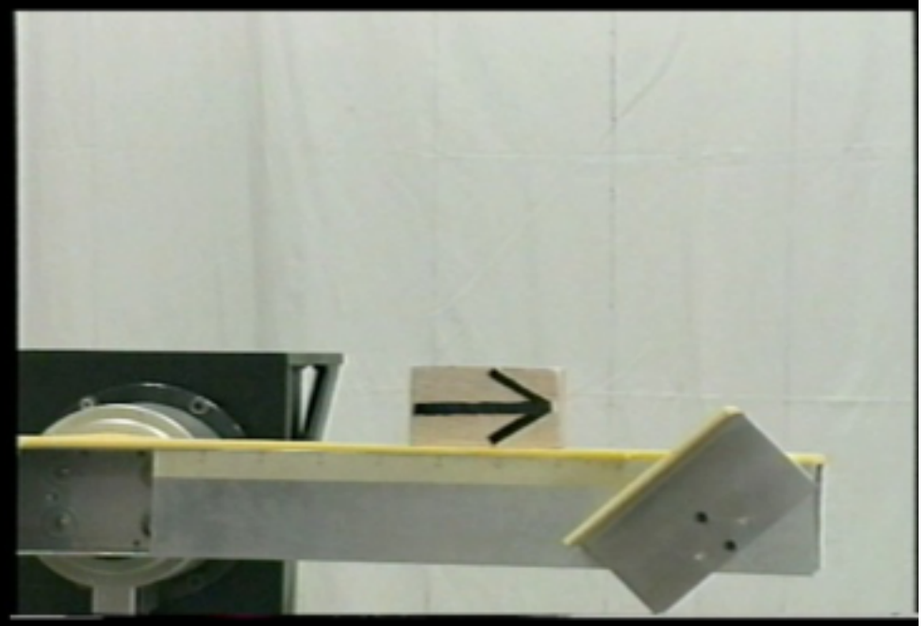
- Manipulation *gaits*!
- *Dynamic* manipulation!
- Where is the boundary between loco and mani?

Rizzi and Kotitschek's later 3D juggler

Then, the fateful event. Around 1989, ISRR in Tokyo, I saw Koditschek give a talk on juggling. A locomotionist's manipulation. Although, Koditschek wasn't a locomotionist, was he? I'm not sure. At any rate, I believe I have heard him say he was inspired by Raibert. Koditschek, Buhler, Rizzi … they were the serpents that beguiled me.
If I had had time, I would have done another Photoshop picture here. Whose face goes on the serpent?

Nonholo mumbo jumbo revisited

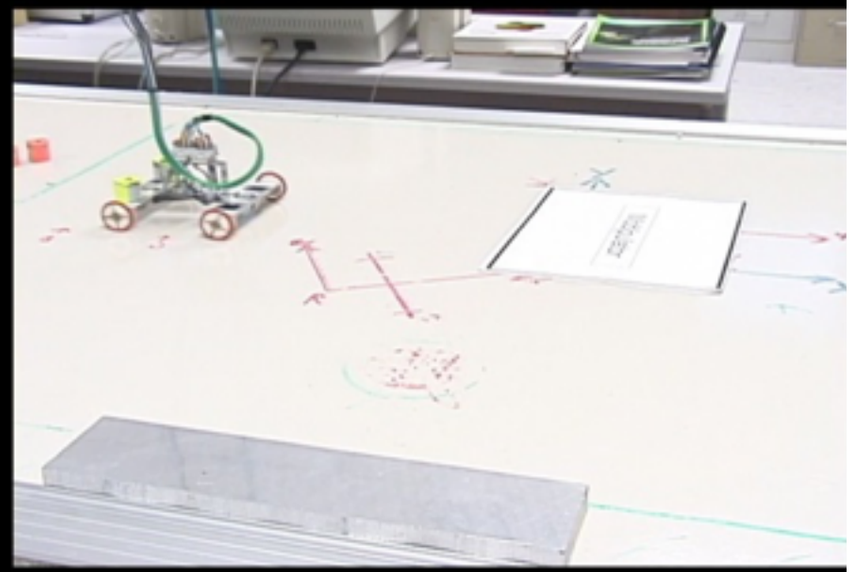
- Manipulation is fundamentally nonholonomic!
- Therefore, nonholo is interesting



Here is my first bite of the apple. Kevin Lynch … pushing … throwing … nonholo. Manipulation is about moving lots of objects around, using just a few actuators. This is accomplished by grasping, or pushing, or other means that attach actuators to object freedoms intermittently using unilateral constraints, which are nonholonomic. Look at Koditschek's bead on a wire. (Robotica 1994)

Duality revisited

- The mobipulator
  - “Feet” on “world”
  - “Hands” on “object”

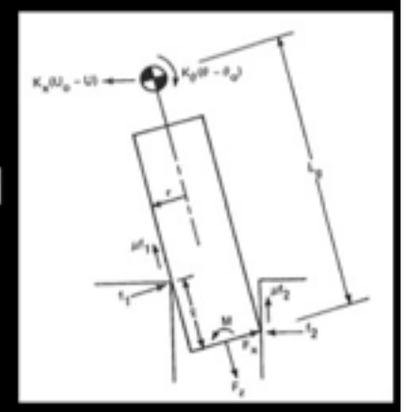


Here is my second bite of the apple. We built the mobipulator. The feet are wheels, and the hands are wheels. The world is an “immobile” plane, and the object is a “mobile” plane. The hands are doing exactly the same things as the feet.
So, what happens when a manipulationist dabbles in locomotion? I think there are some differences, primarily with respect to modeling and control of contact, and the nature of the task, which then affect even the nature of programming and architecture, but my ideas on that are all muddled up.

Too simple to be interesting? Let's look at manipulation.

- Arms:
  - don't fall over
  - no tether problem
  - no weight problem
  - (but weight distribution is a problem)
- Contact
  - Control of contact state is feasible, required
  - Bot on object, *and* object on object
- Task
  - Multiple objects
  - Precision, often defined by contact

Duality?



What about Observation 1, that locomotion is too simple to be interesting? Let's aim that criticism the other direction and see what we come up with.

Evolution from pure skepticism to corrupted interest

- Duality. Curious factoid? —> path to insight
- Too simple? —> Sometimes…
- Legs. Use wheels? —> … bio … stairs … who cares, legs are cool.
- Nonholo. Wrongheaded? —> fundamental
- Knuckleheads —> ?

Many of my first impressions of locomotionists have mellowed over the years. What about the first impression? That they are all knuckleheads?

Thanks to my fellow knuckleheads and good sports (I hope):
Jonathan Hurst, Jerry Pratt, and Marc Raibert

Those of you who are afficionados of the Three Stooges know there was a fourth stooge, Curly Joe, so …

References p1

- Bühler, M., D. E. Koditschek, and P. J. Kindlmann. “Planning and control of a juggling robot.” *International Journal of Robotics Research* 13, no. 2 (1994): 101–118.
- Koditschek, D.E. “An approach to autonomous robot assembly.” *Robotica* 12, no. 02 (1994): 137–155.
- Lynch, Kevin M., and Matthew T. Mason. “Dynamic nonprehensile manipulation: Controllability, planning and experiments.” *International Journal of Robotics Research* 18, no. 1 (January 1999): 64–92.
- Lynch, Kevin M., and Matthew T. Mason. “Stable Pushing: Mechanics, Controllability, and Planning.” *International Journal of Robotics Research* 15, no. 6 (December 1996): 533–556.
- Mason, Matthew, Dinesh Pai, Daniela Rus, Lee Taylor, and Michael Erdmann. “A Mobile Manipulator.” In *IEEE Int. Conf. on Robotics and Automation.* 1999.
- Raibert, Marc H. *Legged Robots That Balance*. Cambridge: MIT Press, 1986.
- Whitney, D. E. “Quasi-static assembly of compliantly supported rigid parts.” *ASME Journal of Dynamic Systems, Measurement, and Control* 104 (March 1983): 65–77.

References p2

- Barraquand, Jérôme, and Jean-Claude Latombe. “On Nonholonomic Mobile Robots and Optimal Maneu- vering.” In *International Symposium on Intelligent Control*, 340–347. 1989.
- Li, Zexiang, and John Canny. *Nonholonomic Motion Planning*. Kluwer Academic, 1993.
- Murray, R.M., and S.S. Sastry. “Steering nonholonomic systems in chained form.” In *Decision and Control, 1991., Proceedings of the 30th IEEE Conference on*, 1121–1126. 1991.