Cobots

http://cobot.com

Michael Peshkin
J. Edward Colgate
Witaya Wannasuphoprasit (“Wit”)

Northwestern University

Collaborative Motion Control, Inc.
“CoMoCo”

1

“Intelligent Assist Devices”

- IADs use computer control of motion to create functionality greater than that of conventional ergonomic assist devices, such as hoists, overhead rail systems, and manual manipulators.

2

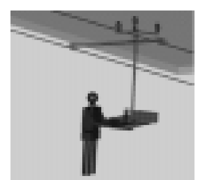
Two forms of intelligent assist

- Power Assist
  - to augment operator-applied forces
  - necessary to counteract gravity
  - improves ergonomics by reducing stress on operator
- Guidance (Virtual Surfaces)
  - virtual surfaces guide the motion of payload/worker
  - allows *physical* interface to computer: *co*-manipulation
  - analogy: straightedge vs. freehand

3

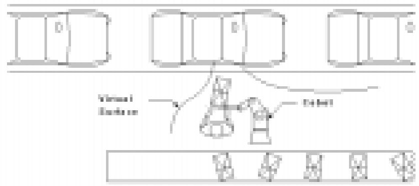
Co-Manipulation with Virtual Surfaces

- In co-manipulation tasks, a human and robot *share* control



4

Example of Virtual Surfaces: the “virtual funnel”



5

Advantages of Virtual Surfaces

- Ergonomics
  - pushing straight is easier than redirecting; virtual surface takes care of redirecting
- Quality/Productivity
  - virtual paths or virtual funnels ensure that collisions do not occur
  - motion along a virtual surface is swift and sure
- Flexibility
  - virtual surfaces are programmable, allowing for worker preferences, product mix, inexpensive retooling…
- Software Driven Material Handling
  - due to programmability, virtual surfaces can be interfaced to larger-scale (e.g., plant-wide) information systems

6

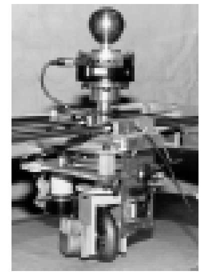
Technologies
for implementing virtual surfaces

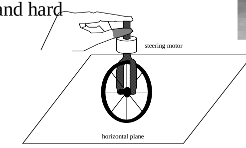
- Powered manipulators
  - servo-actuated joints
  - excellent for power assist
  - poor for virtual surfaces
- Cobotic manipulators
  - servo-steered joints
  - completely passive (no power assist)
  - excellent for virtual surfaces
- Powered cobotic manipulators
  - a single servo-actuated joint; multiple servo-steered joints
  - excellent for both power assist and virtual surfaces

7

Cobots

- Cobots implement virtual surfaces via "servo-steered" joints
- Cobotic surfaces are programmable, passive, smooth and hard



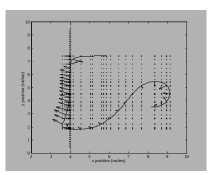


The simplest cobot:
a servo-steered wheel
which rolls on a plane

8

Two basic control modes of cobots

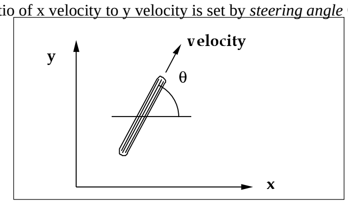
- Free mode
  - cobot is responsive to the operator, steering to allow whatever direction of motion the operator intends
- Path mode
  - cobot is unresponsive to the operator, but instead steers to remain on a virtual surface defined in software



9

Cobots have more generalized coordinates than degrees of freedom

- Wheel is a continuously variable transmission (CVT). The ratio of x velocity to y velocity is set by *steering angle* θ

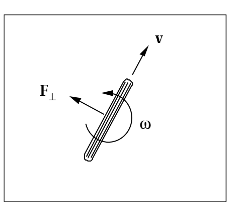


- Unicycle Cobot has *one* degree-of-freedom, but *two* generalized coordinates

10

The "virtual caster" -- adding degrees of freedom

- Feedback control can be used to make the unicycle cobot behave as though it had two degrees-of-freedom
- Lateral force and velocity are measured, and wheel is steered to minimize lateral force



11

Free mode or "virtual caster"

- ω_s is angular velocity of steering: this is under our control
- Use coordinate system aligned with instantaneous rolling direction: $F_{||}$ $v_{||}$ $a_{||}$ $F_\perp$ $v_\perp$ $a_\perp$
- In the rolling direction $F_{||} = m\, a_{||}$ is natural and not under our control
- Match it in the perp direction via active control:
- have $a_\perp = \omega_s\, v_{||}$; want $F_\perp = m\, a_\perp$

  so use control law $\omega_s = F_\perp / m\, v_{||}$

12

Path mode

- ω_s is angular velocity of steering: this is under our control
- $v_{||}$ is rolling velocity, not under our control
- ρ is local curvature of path to be followed
- Use control law $\omega_s = v_{||} / \rho$

  (open loop control; feedback terms are more complicated)

13

Inherently passive

- Although a servo motor is used to steer the wheel of the Unicycle Cobot, none of the power introduced by this motor may be coupled into the plane of motion.

➨ Thus, the cobot is completely passive from the operator's perspective.

14

Beyond unicycles

- Regardless of configuration space dimension *n*, all cobots have one degree-of-freedom
  - under feedback control, the *apparent* dof can vary from 0 to *n*
- Cobot singularities are configurations in which a degree-of-freedom is gained
- All cobots rely upon steerable nonholonomic devices
  - steerable wheels are best suited to low dimensional, parallel cobots
  - a "rotational CVT" has been developed which is well-suited to higher dimensional, serial cobots

15

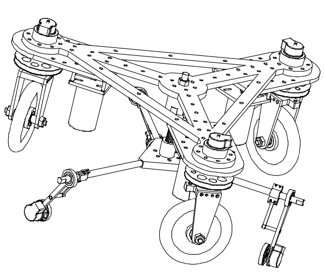
Cobot characteristics

- Steering motors cannot initiate cobot motion; operator pushing cannot affect steering
- No kinetic energy source except human muscle >> safety
- Smooth, hard, frictionless constraint surfaces — so you can slide along them *without loss of energy*
  - important if you want to interact with the constraints (use them for your benefit) rather than just avoid them
  - optimally, a collision with a surface should redirect kinetic energy, not absorb it.
- small actuators control large forces

16

Scooter: a tricycle cobot

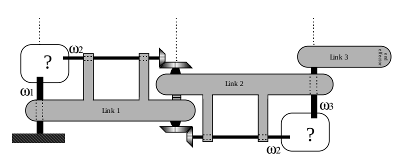
- Floor-based
- Three independently steered wheels
- Three dimensional workspace (x, y, θ)



17

How to Build a Serial, Revolute Cobot

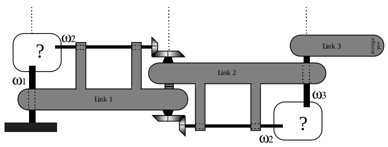
- Remove the actuators from a serial robot
- Couple the n revolute joints using n-1 steerable nonholonomic devices, reducing the degrees-of-freedom to 1
  - e.g. 3 revolute joints coupled by 2 nonholonomic devices:



18

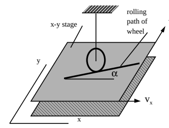
Beyond wheels: the spherical CVT

- Suppose we wanted to build a serial link cobot… what would be the appropriate servo-steered device to couple the joints?
- Key point: the joints are *rotary*



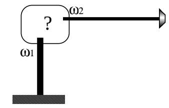
19

A servo-steered device to couple *rotary* motions is...



$V_y / V_x = \tan(\alpha)$

A unicycle wheel relates two *translational* velocities

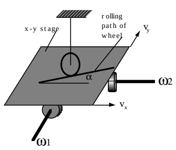


$\omega_2 / \omega_1 = \tan(\alpha)$

The needed device relates two *angular* velocities

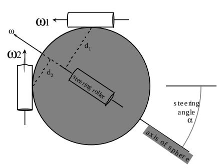
20

…is a continuously variable transmission



$\omega_1 \propto V_x, \omega_2 \propto V_y$

Allow the plane under the unicycle wheel to move, and convert translational velocities to rotational

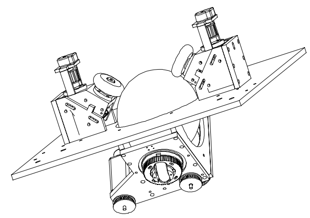


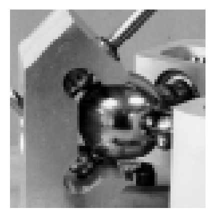
$\omega_2 / \omega_1 = \tan(\alpha)$

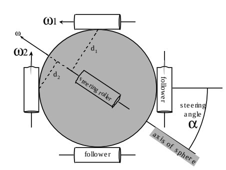
Wrap the plane into a sphere

21

CVT - "the revolute analog of a rolling wheel"



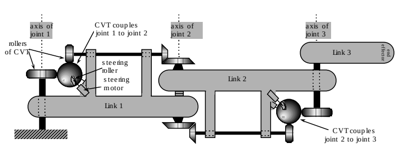




22

A serial link cobot

- This mechanism looks quite different than Scooter… …but has essentially the same capabilities.



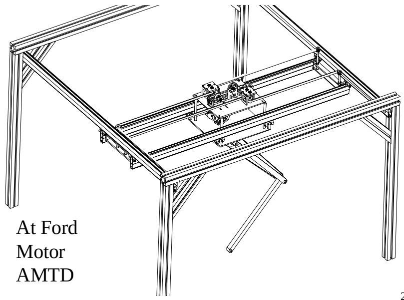
23

Powered cobots

- All power derives from a single actuator, regardless of number of degrees of freedom
- Virtual surfaces are implemented by servo-steered joints, just as with passive cobots
- Power assist and virtual surface functions are completely decoupled

24

An overhead-rail powered cobot



At Ford
Motor
AMTD

Door-unloader wheeled cobot

At GM GAC

Applications

- Software guided materials handling, e.g. in automotive assembly
- Haptic display of CAD models, e.g. in product design
- Rehabilitation and exercise machines
- Guidance in computer assisted surgery
- Others ;)

Research areas

- Path planning: a traditional area, now with a human operator and with guiding surfaces rather than trajectories
- Haptic effects: attractive surfaces, breakthrough strengths, etc.
- Higher dimensions: path tracking becomes quite non-trivial beyond the single wheel
- Control: new control issues arise from the central role played by the human; neither a “disturbance” nor an “input”
- Mechanics of CVTs

Summary

- Materials handling industry moving towards “software driven materials handling”
- Virtual surfaces can form the interface between computers and people, in the control of motion
- Cobots implement smooth hard virtual surfaces, safely

Thanks to...

- General Motors Foundation
- General Motors
- Ford Motor Company
- National Science Foundation

For more information, phone numbers, etc:

http://cobot.com