Mobile Robot Mechanism

Howie Choset
CLASSIFICATIONS

Outdoor

Indoor
CLASSIFICATIONS

Wheeled

Non-Wheeled
CLASSIFICATIONS

Wheeled

Legged

Whole body

Hybrid
ALREADY NOT A GOOD CLASSIFICATION

Wheeled

Legged

Whole body

Hybrid
TYPES OF WHEELED SYSTEMS (AGVS)

Carrier (Savant)  
Tow (Seegrid)  
Transport (Kiva)
Wheels: Steer and Drive (Aim and Go)

**Fixed Axle: Differential Drive**
- Two wheels and a caster
  - Skid Steer
  - Omni-wheels
  - Mechanum wheels

**Steerable Axle**
- Ackerman
- Synchrodive
- Multi-body
- Indirect
Wheels: Steer and Drive (Aim and Go)

**Fixed Axle: Differential Drive**
- Two wheels and a caster
- Skid Steer
- Omni-wheels
- Mechanum wheels

**Steerable Axle**
- Ackerman
- Synchrodrive
- Multi-body
- Indirect
TWO WHEELS AND A CASTER

Advantages:
• Simple drive system
• Larger wheels handle bumps

Disadvantages:
• Slippage and poor odometry results
• Caster cause undesirable motion
• Careful calibration for good control
• Takes a larger wheel to handle bumps
CALIBRATION

Changing diameter makes for uncertainty in dead-reckoning error

Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.
Dragon runner
(Schempf; NREC, Automatika)
A view from the Robot
SKID STEERING

Advantages:
• Simple drive system

Disadvantages:
• Slippage and poor odometry results
• Requires a large amount of power to turn
IRobot, Packbot
Rescue Robot Quince（IRS、furo、Tadokoro）
TEPCO Using QUINCE
Wheels: Steer and Drive (Aim and Go)

Fixed Axle: Differential Drive
- Two wheels and a caster
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- Omni-wheels
- Mechanum wheels

Steerable Axle
- Ackerman
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- Multi-body
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Wheels: Steer and Drive (Aim and Go)

(a) Two wheel steer
(b) Four wheel steer
(c) Crab steer
(d) Zero turn

Steerable Axle

- Ackerman
- Synchrodrive
- Multi-body
- Indirect
TRICYCLE STEERING

- Advantages:
  - No sliding

- Disadvantages:
  - Non-holonomic planning required

Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.
ACKERMAN STEERING

- Advantages:
  - Simple to implement
  - Simple 4 bar linkage controls front wheels
  - No slipping

- Disadvantages:
  - Non-holonomic planning required

\[ \cot \theta_i - \cot \theta_o = \frac{d}{l} \]

where:
\( \theta_i \) = relative steering angle of inner wheel
\( \theta_o \) = relative steering angle of outer wheel
\( l \) = longitudinal wheel separation
\( d \) = lateral wheel separation
SYNCHRODRIVE

Advantages:
• Separate motors for translation and rotation makes control easier
• Straight-line motion is guaranteed mechanically

Disadvantages:
• Complex design and implementation

Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.
SYNCHRODRIVE (BOTTOM VIEW)
Something where Axle Can move

Advantages:
• Simple to implement except for turning mechanism

Disadvantages:
• Non-holonomic planning is required

Nomad: Red Whitaker

Internal Body Averaging Motors in the wheels
Wheels: Steer and Drive (Aim and Go)

Fixed Axle: Differential Drive
- Two wheels and a caster
  - Skid Steer
    - Omni-wheels
    - Mechanum wheels

Steerable Axle
- Ackerman
- Synchrodrive
- Multi-body
- Indirect
Advantages:
• Allows complicated motions

Disadvantages:
• No mechanical constraints to require straight-line motion
• Complicated implementation
• Does not handle bumps well

Manuela Veloso and Cobot
VIRTUAL VEHICLE
MECANUM WHEELS

Advantages:
• Allows complicated motions

Disadvantages:
• No mechanical constraints to require straight-line motion
• Complicated implementation
• Does not handle bumps well
X’S AND O’S

“O” Configuration

“X” Configuration

Bottom View
OMNI VS MECANUM WHEELS

Climbs ramps easier
More power efficient
Fit in a normal frame

Cheaper
More finicky
True omidirectional motion
Point of contact change is greater
CLASSIFICATIONS

Wheeled

Legged

Whole body

Hybrid
Asimo
Early Raibert robots

Quadruped, 1984-1987

Planar Quadruped (Hodgins, 1985-1990)
Boston Dynamics Big Dog
Cheetah Robot runs 28.3 mph; a bit faster than Usain Bolt
Wildcat

Galloping

Boston Dynamics
BDI Petman
RHex
Running Animals (and RHhex) Anchor A Pogo Stick

Biomechanics Literature:
- all animal runners studied to date
- have ground force reaction patterns
- that resemble a pogo stick

RHhex Literature:
- Well tuned robot
- With large aerial phases
- exhibits ground reaction force patterns
- that resemble a pogo stick


Thanks to Dan Kodischek
Sprawlita
Bowleg Hopper
(Brown, Zeglin, Mason)
Bow Leg Climber
(Degani, Brown, Lynch, Mason, Choset)
Benefits of Compliance: Robustness

- Handle unmodeled phenomena
- Regulate friction (e.g. on textured surfaces)
- Minimize large forces due to position errors
- Overcome stiction
- Increase grasp stability
- Extra passive degree of freedom for rolling
- Locally average out normal forces (provides uniform pressure, no precise location)
- Lower reflected inertia on joints [Pratt]
- Energy efficiency (probably not for snakes)
Wheels vs. Legs

- Are legs better than wheels?
Wheels vs. Legs

• Are legs better than wheels?
• Are legs optimal?
With respect to what?

• Are legs better than wheels?
• Are legs optimal?
Are wheels good?

- Power efficient
- Constant contact with (flat) ground (no impacts)
- Easy and inexpensive to construct
- Easy and inexpensive to maintain
- Easy to understand
- Minimal steady-state inertial effects

Can only go on flat terrains?
Design Tradeoffs with Mobility Configurations

- Maneuverability
- Controllability
- Traction
- Climbing ability
- Stability
- Efficiency
- Maintenance
- Environmental impact
- Navigational considerations
- Cost
- Simplicity in implementation and deployment
- Versatility
- Robustness
- Accuracy
- Elegance? (if we are selling robots)
- Speed
- Manufacturability
- Safety
ALREADY NOT A GOOD CLASSIFICATION

Wheeled

Legged

Whole body

Hybrid
What’s a wheel?

• Single wheel
• Ball
• Gait (think Rhex and Snake)
• And of course, tank treads
Gyrover (Brown)
Ballbot, Ralph Hollis

“A Dynamically stable Single-Wheeled Mobile Robot with Inverse Mouse-Ball Drive.”
NXT Ballbot
Horizontal and Vertical Motion
UGCV (Crusher)
[Bares/Stentz, REC]
Recon Scout
Rocker Bogie

Taken from Hervé Hacot, Steven Dubowsky, Philippe Bidaud

Rocker Bogie
Lunakod: Were we first?

- 1969 Lunokhod 1A was destroyed at launch
- 1970 Lunokhod 1 landed on the moon
- 1973 Lunokhod 2 landed on the moon

In 322 days, L1 traveled 10.5km
Both operated 414 days, traveled 50km
In 5 years, Spirit and Opportunity 21km

1969 Lunokhod 1A was destroyed at launch
1970 Lunokhod 1 landed on the moon
1973 Lunokhod 2 landed on the moon
Lunakod
Marsakhod
Marsokhod unskillful operator control
From Biology to Robotics and Back
Gaits

\[ Q = G \times M \]

\[ \phi : \mathbb{R} \to M, \quad t \mapsto r, \]

\[ \phi(t) = \phi(t + \tau) \quad \tau \in \mathbb{R} \]
\[ \alpha(n, t) = \beta + A \sin(\theta) \]
\[ \theta = \Omega n + \omega t \]

\[ \alpha(n,t) = \begin{cases} 
\beta_{\text{odd}} + A_{\text{odd}} \sin(\theta_{\text{odd}}) \\
\beta_{\text{even}} + A_{\text{even}} \sin(\theta_{\text{even}} + \delta) 
\end{cases} \]

\[ \theta_{\text{odd,even}} = (\Omega_{\text{odd,even}} n + \omega_{\text{odd,even}} t), \]
SAIC/CMU Snake
Are snakes better than legs?
ALREADY NOT A GOOD CLASSIFICATION

Wheeled

Legged

Whole body

Hybrid
Mobile Manipulators

- Romeo and Juliet
- HERB
- Boeing
Themes

- Drive and Steer
- Horiz and vert
Metrics

Standard metrics here

Lisa Slide here
Original email 12-24-2014

I was looking for something general and not specific to the Foxybots.

I thought there were other criteria than the ones you listed in Part 5.

We should also just create a list of all types of wheeled mobile bases

Wheel configurations
1. differential drive
2. skid steer
3. synchrodrive
4. omni-wheel based
5. mechanum wheel based

Suspension
1. none / soft wheels
2. springs, shock absorbers
3. kinematic - rocker bogie, Nomad, other mechanisms

What other classes should we consider??
Howie
END
<table>
<thead>
<tr>
<th>Robot</th>
<th>Purpose</th>
<th>Size</th>
<th>Weight</th>
<th>Payload</th>
<th>Speed</th>
<th>Tech</th>
<th>Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMT Robotics</td>
<td>Transport</td>
<td>40” Diameter 20” Height</td>
<td></td>
<td>Trays &amp; Crates. Shelf or motorized rollers</td>
<td>1.5m/s</td>
<td>LIDAR, SLAM, path replanning, remote “call buttons”</td>
<td>2 Diff</td>
</tr>
<tr>
<td>Seegrid</td>
<td>Forklift/pulling</td>
<td>Large</td>
<td></td>
<td>Pallets</td>
<td></td>
<td>Stereo cameras, SLAM, LIDAR/SICK 15cm virtual bumper</td>
<td></td>
</tr>
<tr>
<td>Robotiq</td>
<td>Lifting Box</td>
<td>Small</td>
<td></td>
<td>&gt;2kg</td>
<td>1m/s</td>
<td>QR Codes, arm on base</td>
<td>2 Diff</td>
</tr>
<tr>
<td>Adept Tech.</td>
<td></td>
<td></td>
<td>132lb</td>
<td></td>
<td>1.8m/s</td>
<td>Batteries=19hrs, traversable gap=15mm, multiple payload platforms, LIDAR, contact</td>
<td>2 Diff</td>
</tr>
<tr>
<td>Vehicle Tech. (various models)</td>
<td>Platform</td>
<td>42x28” 86-48”</td>
<td>500-5500lb</td>
<td>1000-20000lb</td>
<td>1-2m/s</td>
<td>Wireless controller, no high level functions provided</td>
<td>4 wheel Omni</td>
</tr>
<tr>
<td>Kuka</td>
<td>Transport/arm</td>
<td>Large</td>
<td></td>
<td></td>
<td></td>
<td>LIDAR/SICK, dockable</td>
<td>Many omni wheel</td>
</tr>
<tr>
<td>Kuka 2 OmniRob</td>
<td>Platform/arm</td>
<td>1.2x0.7x0.6m</td>
<td>250kg</td>
<td>400kg</td>
<td>1m/s</td>
<td>LIDAR/SICK, SLAM</td>
<td>4 wheel omni</td>
</tr>
<tr>
<td>Clearpath Husky</td>
<td>Rugged Platform</td>
<td>0.99x0.67m</td>
<td>50kg</td>
<td>75kg</td>
<td>1m/s</td>
<td>Outdoors</td>
<td>4 diff</td>
</tr>
<tr>
<td>Hannover Messe</td>
<td>Platform</td>
<td>0.58x0.7x0.6m</td>
<td>60kg</td>
<td>50kg</td>
<td>1.4m/s</td>
<td>15mm max step, 24 ultrasonic range, contact</td>
<td>diff</td>
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<tr>
<td>iRobot</td>
<td>Tele-Presence</td>
<td>Human</td>
<td></td>
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</tr>
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<td>Robot</td>
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<tr>
<td>Neobotix</td>
<td>Transport</td>
<td>Small-medium</td>
<td></td>
<td>Crates 100-500kg</td>
<td></td>
<td>LIDAR/SICK</td>
<td></td>
</tr>
<tr>
<td>Eagle</td>
<td>Transport</td>
<td>Small-medium</td>
<td></td>
<td>Crates</td>
<td></td>
<td>Ultrasonic??</td>
<td></td>
</tr>
<tr>
<td>Aethon (Tug)</td>
<td>Transport</td>
<td>Medium</td>
<td></td>
<td>1000lb</td>
<td></td>
<td>LIDAR &amp; 27 sonar+IR, Auto charge/dock, wifi talks to elevators, etc..</td>
<td></td>
</tr>
<tr>
<td>Blue Ocean (Tug Clone)</td>
<td>Transport</td>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
<td>LIDAR</td>
<td></td>
</tr>
<tr>
<td>Serva</td>
<td>Transport</td>
<td>Large</td>
<td></td>
<td>Cars (3.31ton)</td>
<td></td>
<td>LIDAR</td>
<td></td>
</tr>
<tr>
<td>Kiva Systems (maybe not for sale)</td>
<td>Transport</td>
<td>1. 2x2.5x1 2. Medium</td>
<td>1. 1000lb 2. 3000lb</td>
<td>1.3m/s</td>
<td>Recharge every hour for 5 minutes, barcodes on the floor with downward camera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspector Bots</td>
<td>Transport</td>
<td>1. 31x26x14” 2. 33x33x16”</td>
<td>1.200lb 2. 240lb</td>
<td>1. 150lb 2. 250lb</td>
<td>1. 3.3 m/s 2. 6.7 m/s</td>
<td>Outdoor, rugged (just a platform)</td>
<td>4 wheel diff</td>
</tr>
</tbody>
</table>