Legged Robots for Last 50 Feet Delivery

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Most parts of the logistics chain are rapidly automating.
The human world *isn’t designed* for robots
New infrastructure can be designed for automation from day one. But most spaces are designed around humans, and are difficult to retrofit.

Our world is designed around us, not robots.
Legged robots provide human-like mobility and do not require new infrastructure.

**Cars** do roads well.
No need to reinvent the wheel. Leverage the efficiency of wheels for long distances, and high cargo capacity for aggregating demand.

**Legs** do sidewalks and stairs well.
Legs are hard to build, but we’ve spent two decades learning how. Use legs to access the customer’s preferred delivery location.

Re-use existing infrastructure wherever possible to increase addressable market.
Why legs + vehicles?

The existing paradigm of package aggregation in a road-legal vehicle is efficient, and a delivery driver is able to place the package in the customer’s preferred location. But this is hard to automate.

Current automation solutions are largely point-to-point (which is inefficient) and can’t deliver to the door (which forces changes to customer behavior).
Human-like mobility is required for many jobs …not just logistics.
Mobile computing provides an app ecosystem for information

Digit provides an app ecosystem for labor
Hardware
Human-like mobility
Rugged design
Long battery life
Integrated computing
20 kg payload capacity
Near + far range sensors

Perception stack
Map the environment
Identify obstacles
Recognize objects and people

Mobility stack
Balance and posture
Movement planning
Handle stairs/obstacles/terrain
Walk from A to B indoors or out

Manipulation stack
Grasp objects
Pick and place

Software Apps
Move + Carry
Carry packages point to point
Manual labor (the robot alone)
Last mile (with vehicle)

Move + Inspect
Monitor infrastructure
Autonomous: security
Local teleop: military / law enf.

Move + Interact
Telepresence, remote interaction
Virtual tourism: hike with family

Common Platform
Software APIs
Software Apps
Core Product
App Ecosystem
OTA app downloads and platform updates

- Updates can apply to the core “mobility operating system” APIs
  - E.g. faster footstep planning
- Or updates can be app-specific
  - E.g. faster box-picking/placing
- The fleet learns as a whole
Outdoor move+carry
Ongoing partnership with Ford

Video link: https://youtu.be/CUhuhleQNos
Indoor move+carry
Ongoing partnership with multinational logistics company

Video link: https://youtu.be/LSk8uCHN5CY
The first autonomous taxi is useful
- Operates with existing infrastructure
- Scales to large fleets

One warehouse robot is not useful
- Requires new infrastructure
- Requires full fleet up front

ROI from first unit deployed
- Works with existing infrastructure
Seeing and mapping the world

Velodyne VLP-16 Lidar

(4) Intel RealSense Stereo Cameras

LIDAR SLAM on Digit
Technology development timeline

- **MABEL**
  - 2004-7

- **ATRIAS 1.0**
  - 2009-13

- **ATRIAS 2.0**
  - 2014-15

- **CASSIE**
  - 2016-17

- **DIGIT V1**
  - 2018-19

- **DIGIT V2/V3**
  - 2019/20
Our core technology: mobility for imperfect worlds

Science: Understand and model the dynamics of a highly capable system.

Engineering: Incorporate these principles into products, and physics ensures that the capabilities will be similar “for free”.

POWERED BY POSSIBILITIES.
Video here of Digit V2 walking over foam and blocks, as well as handling push recoveries.
Our control hierarchy

- **1Hz**: User input, high-level intent, waypoints, task-level decisions
- **30Hz**: Continuously updated plans
- **2 kHz**: Classical control, such as inverse dynamics, PD gains, etc
- **∞ kHz**: Dynamics Foundation

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**Inverse Kinematics**
- Solution for more complex structures:
  - Find best solution (e.g., minimize energy in motion)
  - Non-linear optimization

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POWERED BY POSSIBILITIES.
Machine learning can expand on the base skill “repertoire”
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Kinematic reference motion
Fully Autonomous Operations
Waypoints and “box move” task user-defined
Picking/placing and walking autonomous
Bipedal robots are ready to work in human spaces
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