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THE LOGIC OF LOGISTICS: ROBOTS DELIVER VALUE

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Up to 95% Efficiency

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Easy Mounting to a Wide Variety of Servomotors

Quick Connect® motor adaptation system includes a clamshell style servo coupling and piloted adapter flange.

Flange Output Standard

Flanged output is standard for convenient, stable wheel mounting.

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CONTENTS

THINKING INSIDE THE BOX

Bob Vavra,
Senior Content Manager

Modern logistics is all about computer science—with a healthy bit of art tossed in for good measure. The logistics centers that continue to sprout up along every interstate and near every airport deliver a lesson in robotics that shouldn't be overlooked. In an impatient world, speed is the expectation of consumers and manufacturers. If you can't deliver the product quickly, perhaps there's someone down the road who can.

As a result, logistics centers have turned to robotic pick-and-pack systems that provide the speed and absolute accuracy needed by consumers of all types. Whether it is the ubiquitous box on your front porch or the palletized parts required to keep your plant operation functioning, the suppliers are under tremendous pressure to keep pace with customer requirements.

They also have to keep pace with technology, and as this eBook notes, that is no easy feat. That technology investment, according to Ryan Gariepy, CEO and co-founder of Otto Motors, is moving toward an autonomous robotic order fulfillment process. "The reliability, robustness, and flexibility of robot manipulators continues to increase, as does the willingness of warehouse operators to commit to larger investments," Gariepy says.

Part of the issue is the difficulty in finding skilled human workers to augment the surge in logistics and distribution centers. At this year's ProMat trade show, exhibitors talked at length about the severe worker shortage and demonstrated a range of automation and robotics solutions to address this shortfall.

The overriding message was clear: The world is reliant on rapid delivery, and technology will be the driver to overcome any obstacles to that goal. In other words, it may require outside-the-box thinking to master the challenges of modern distribution, but all that matters to the customer is what's inside the box.

CHAPTER 1:

Robots Will Reshape Distribution Centers

HOWARD COLEMAN, Principal, *MCA Associates*

The author believes the day when robotics become commonplace in the distribution industry is not far away.

This past summer while visiting a wholesale distributor's distribution center, I watched receiving personnel spend an afternoon unloading boxes from a tractor-trailer in near 100-degree heat. This is even before the "stuff" is put away on the shelf. From the looks on their faces they were not happy, and you had to feel some empathy for the difficulty of the task and what was still to be done.

It suddenly occurred to me that instead of just thinking about how to design DC/warehouse space around robots, robots are now being built that are able to operate more on our terms, in our spaces and in our environments.

The situation I was observing just amplified how robotics are now being designed to handle the tough, often menial and accident-prone tasks at warehouses.

Robotics and particularly other forms of automation are not new to logistics. We have conveyor belts, scanners and other innovations that have helped automate and accelerate, for some decades now, the obsession for speed — characteristic of the distribution industry. But the pace of investment and change — fueled by the pandemic-era e-commerce boom, a tight labor market and a fragile supply chain — has really taken off in recent years. Most experts say robotics will change how warehouses are operated and designed. Some say we're entering a golden era.

Actually, the seeds of the surge in warehouse robotics were planted during the 2008 recession, when carmakers, which depend heavily on robotics, dealt with a significant and prolonged downturn. But unlike repetitive assembly line manufacturing, warehouses demand a significant degree of flexibility.

Only recently have systems like visioning and artificial intelligence become cheaper and powerful enough to sort the tens of thousands of different products streaming through a DC or warehouse. This technological leap is part of a larger embrace of robotics. In fact, the robotics industry saw a +28% jump in purchases from 2020 to 2021, according to

the Association for Advancing Automation. The technology is becoming more affordable and filtering down through the distribution industry, beyond the big players like Walmart and Amazon. It's predicted that there will be a +25% increase in robotics and automation investment in 2022.

Although seemingly fueled by the distribution giants like Amazon, Walmart and others which saw logistics as ripe for innovation, they have helped supercharge distribution's turn toward automation. Other large and small organizations with a large labor content also employ this strategy. They strive to make these jobs more secure and safer, while still being focused on using robotics as a cost-saving measure to reduce aspects of human labor. The wholesale industry has always been concerned with the cost of warehouse labor, but it has been hesitant to trim employees in a tight labor market.

Adoption of robotics in warehouses will increase +50% or more in the next five years, according to surveys taken by the Materials Handling Institute. The goal is the "mechanical orchestration" of workflow, in which a team of autonomous mobile robots (AMR's), steered by sophisticated software and artificial intelligence, can move pallets, cartons and piece-pick products in a seamless environment — in collaboration with the appropriate positioning of warehouse associates. This strategy covers most typical warehouse functionalities from receiving and put-away to picking, order staging and shipping, as well as many other product transport requirements typical of distribution centers and warehouses.

I see a parallel in this adoption of technology in the media business. Netflix was the only company that could figure out streaming video, until suddenly it wasn't. In a similar fashion, I see an emerging middle class of robotics users in the distribution industry. Other companies, of all sizes, will start to catch up.

There's increased demand for "goods-to-person" robots offered by firms like Zebra/Fetch, Locus Robotics, 6 River Systems and Orange-Grey. These so-called co-bots, which can look like a bin-carrying Segway, move back and forth among workers throughout the facility, significantly reducing the walking for warehouse associates. With these robots also bringing cheaper and quicker ways to deploy, some robotics providers have even introduced "robots as a service" business models — leasing these machines to warehouse operators — reducing initial capital costs.

Moving forward. Automation is one major lever that companies can pull. Robots won't replace workers in the near term, but rather make them more efficient and productive. Humans will be "crew chiefs," commanding and maintaining teams of robots. Robots can also help with your worker recruitment while closing the generation gap among warehouse workers.

It will improve the quality of experience for the work force because instead of constantly walking and doing rote manual things, individuals will learn how to manage the robot to keep it up and running. It will create a career path and a more sophisticated skill set and make sure the evolution of jobs does not leave longtime workers behind.

Some experts believe "lights out" warehouses run by robots around the clock without requiring air conditioning or lighting will arrive in three or four years. I don't know about that time-frame. But I do see a need for more companies in the distribution industry to evaluate the potential of robotics to increase efficiency and reduce costs and worker accidents. This could double throughput and reduce cost per transaction.

The urgency? I worry about the owners and senior operations managers who don't pay attention to this fast-moving trend of robotics over the near-term. Why? Because, even

today, many distribution centers and warehouses are just “racks, carts and a clipboard.” They’re just not going to be able to keep up with the service demands and cost factors to remain competitive.

HOWARD COLEMAN and his team at MCA Associates helps distributors and manufacturers implement continuous improvement solutions focused on business process re-engineering, inventory and supply chain management, sales development and revenue generation, information systems and technology, organizational assessment and development. MCA Associates may be contacted at 203-732-0603, or by e-mail at hcoleman@mcaassociates.com

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HPG Gearheads

CHAPTER 2:

Meeting the Technical Demands for AMR & AGV Wheel Drives

JIM LEONARD, Director, Channel Sales, *Harmonic Drive LLC.*

Drive wheels for autonomous mobile robot platforms benefit from the inherent characteristics of Harmonic Planetary® gearheads. This paper will discuss those characteristics as a function of the HPG series planetary design and technology.

The Harmonic Planetary® HPG Series stands out from the crowd. Its design enables exceedingly smooth, high-torque transmission in a very compact form factor.

The compact form factor, which is a typical design requirement for AGV and AMR propulsion systems, is largely achieved by incorporating an integral full complement cross roller bearing (CRB) assembly. The CRB, by design, comes in a narrow, single row configuration and can handle moment loads comparable to a double row bearing or a pair of angular contact bearings which are significantly wider.

The CRB used in the HPG Series is preloaded and provides an accurate and highly rigid output to which the wheel can be directly attached. Inherent in roller bearing technology is the line contact between rolling elements and hardened raceways. Line contact minimizes elastic deformation under extreme loads and as such, the single row CRB exhibits high-load capacity and a resistance to shock loading. In a CRB design, roller elements are placed orthogonally to one another between the raceways. The resulting construction is capable of accepting loads from all directions simultaneously. As such, radial, axial and tilting moment loads are all supported within the compact CRB construction. CRB service life is a function of load and speed and can be reliably calculated, thus ensuring service life expectations can be met with proper product selection.

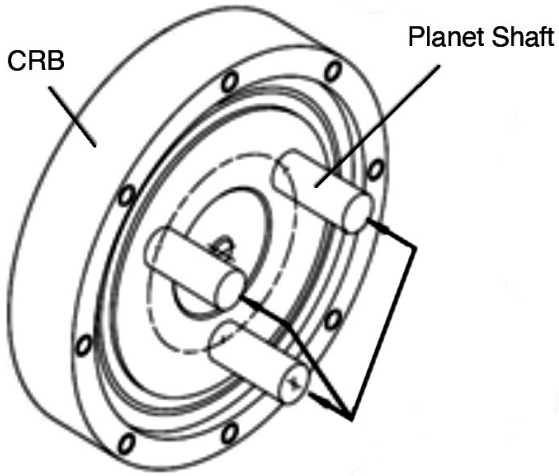
Cross Roller Bearing Construction

The structure of the Harmonic Planetary® gear is highly integrated with the CRB. This integration allows for further size reduction of the gear-

head envelope and also simplifies the internal design. The inner race of the roller bearing is multi-functional. It acts as both the output planet carrier of the planetary gear as well as the rotating output flange. The output flange includes a piloting feature and a tapped mounting hole pattern that makes wheel attachment easy and error free. Cross roller bearing technology and its integration provides a compact solution that can handle the reaction forces of the wheel drive configurations that are typical of mobile robot platforms.

To provide a smooth and reliable transmission, a compensating ring gear is incorporated along with tightly toleranced planet pin locations combined with a true running planet carrier.

The elasto-mechanical behavior of the ring gear design compensates for slight interferences between meshing parts, allowing for the gearbox to be easily back driven.



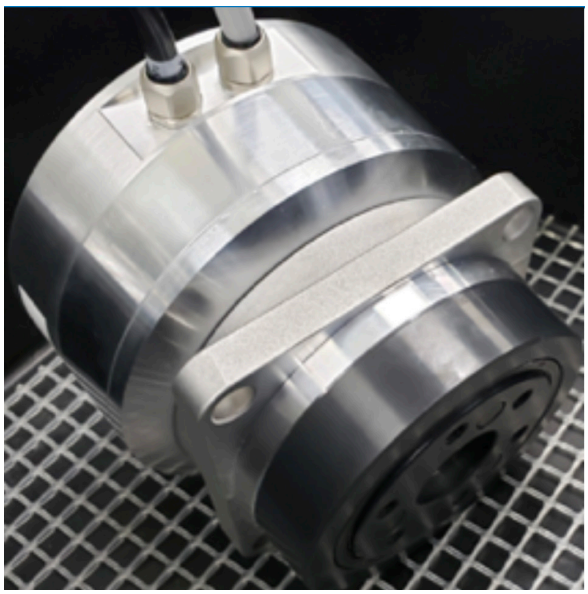
True position tolerance on planet shaft locations ensures smooth and accurate motion.

While torsionally rigid, the compensating ring gear exhibits radial compliance in the area of 1-2 microns.

Harmonic Planetary® Advantages and Characteristics:

- The maximum backdriving torque is quantified in the product ratings; in an automated platform, backdrivability can be a convenient feature in the event that a robot requires a tow to a charging station or maintenance area.
- Ring gear compensation minimizes concentrated tooth contact stresses, results in predictable starting torque characteristics and minimizes torque ripple in the transmission.
- The HPG gearing with ring gear compensation yields a high-efficiency transmission reaching 90-95% at rated input torque and speed.
- Aluminum alloy housings are employed, minimizing weight yet providing sufficient strength and rigidity to provide reliable propulsion for mobile robots.
- HPG planetary gearheads are lubricated for life and maintenance free.
- Planetary design in an HPG gearbox includes either 3 or 4 planet construction, depending on the power density required by the application.
- Load sharing in a planetary drive train with ring gear compensation is optimized, ensuring equal planet gear loading on needle bearings and gear teeth.

- Harmonic Planetary® gearheads are available with straight cut gear geometry. This produces lower friction at the gear mesh and requires less bearing constraint; as such, straight cut gear trains can be more compact axially. Automated mobile robots benefit from a light weight, compact drive train as more of the available power can be used to accelerate and transport loads.
- Helical gearing is also an option with the Harmonic Planetary® design. Inherent in helical gearing is a smoother and more gradual tooth engagement. This results in lower audible noise levels and lower vibration. Due to the nature of helical gearing, reaction forces from the mesh require additional bearing support. As such, gearheads with helical gears tend to have a slightly longer overall length.
- Harmonic Planetary® gearheads are configured with a Quick Connect® motor adaptation for easy motor mounting. This motor mounting system includes a compression coupling designed to clamp onto a smooth motor shaft. Input flanges and coupling bores are machined to ensure concentricity and perpendicularity requirements for optimal performance and service life.



Integrated servo actuator using Harmonic Planetary® technology

Quick Connect® motor adaptation allows for quick and error free motor assembly.

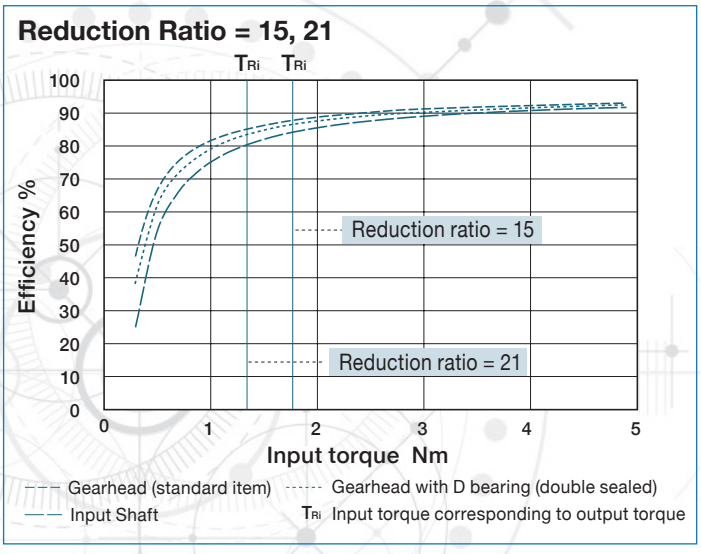
- The Quick Connect® system connection method provides quick and reliable connection between the gearhead and motor. It also allows for motors and gearheads to be disassembled for maintenance and serviceability.
- Actuators (motor and gearhead integrated into a single housing) using Harmonic Planetary® technology are also available. Actuator solutions are engineered in close consultation with original equipment manufacturers who require specific motion control attributes in their motor technology. Position feedback, winding design, communication and drive compatibility are just a few of the many considerations for successful actuator development and deployment. Benefits include the optimization of size, weight, and inertia, all of which benefits a drive train for mobile robot propulsion.

HPG Cross-Roller Bearing Construction

Integrated cross-roller bearing and planet carrier provides a compact solution with excellent load and rigidity characteristics.

High Efficiency

95%+ efficiency; curves available for every size and ratio*



Low Backlash for Life

Innovative ring gear inherently compensates for interference between meshing parts, ensuring consistent, low backlash for the life of the gearhead.

High Load Capacity Output Bearing

A cross-roller bearing is integrated with the output flange to provide high moment stiffness, high load capacity and precise positioning accuracy.

Easy Mounting to a Wide Variety of Servomotors

Quick Connect® motor adaptation system includes a compression style servo coupling and piloted adapter flange.

Flange Output Standard

Flanged output is standard for convenient, stable wheel mounting.

Lightweight with Good Shock Resistance

Designed for lightweight and impact resistance.

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CHAPTER 3:

Automation is the Future of Logistics

YAQING SUN, *Omron Automation*

3 robotic order picking solutions that can ease logistics challenges.

The global warehouse automation market is estimated to grow at a compound annual growth rate (CAGR) of 14%, reaching $30 billion by 2026. The number of OEMs and system integrators who are trying to grow their business by serving more logistic customers is growing year by year.

Omron has more than 80 years of history of supporting manufacturing automation by offering key solutions such as sensing, automation control system, machine vision, safety and robotic. One of the top challenges for manufacturers has always been handling the products and materials with high accuracy while maintaining high throughput.

The evolution from manufacturing automation to warehouse automation demands similar operational efficiency and throughput, yet the nature of unknown objects (for example eCommerce orders) adds extra layers of complexity.

Warehouse operations involve labor-intensive processes, but where are the labor resources?

The current labor shortage and the high cost of hiring skilled workers have dramatically impacted the logistics industry, particularly at a time when the increasing popularity of customization is making it a challenge to predict customer demands. Customization adds complexity for warehouse workers to handle different products from multiple suppliers. It's difficult for workers to operate at high speeds while maintaining accuracy throughout a more cumbersome process. Warehouses need more workers, but they simply can't find them, and training will take away time from the existing skilled workers.

How can warehouses deal with the unperceptive changes of customer demand and ensure maintain the throughput time and the cost as well as optimize space is critical. Although warehouse automation requires more advanced technology developments and high upfront investment, the results from these initiatives are usually highly flexible and

repeatable. The general process usually starts from inbound to storing then to picking and sorting then eventually go to outbound. The labor time in the warehouse was mostly spent on picking followed by searching. Automation can help to save time by taking away the non-value-added steps in the process such as walking to pick items.

Three robotic order picking solutions that can ease logistics challenges

- **Goods2Person picking solution**. Many companies have invested in automated storage and retrieval system (AS/RS) to save space and increase inventory traceability in their warehouses. As such, a Goods2Person (G2P) picking strategy is usually applied. In this scenario, an autonomous mobile robot (AMR) can interact directly with the AS/RS system to bring totes or storage shelves to a designated location where a warehouse associate will collect them and move on to the next step. The AMR-cobot combo (also known as a "mobile manipulator" can pick items from multiple shelves and then return to a designated location where a warehouse associate will collect them and move on to the next step.
- **Follow me robotic order-picking solution**. In the case of a traditional setting, a warehouse uses static shelves such as pallet shelves. The workers usually need a cart or totes to collect items during the picking process. This solution can help to assist human workers to pick and move items around the warehouse by applying a zone-picking strategy. The mapping and navigation function in a mobile robot allows workers to teach the robots to perform tasks depending on warehouse needs and space settings.
- **Fully automated order picking solution**. This solution combines the AMR and cobot with 3D vision and artificial intelligence (AI) to achieve complete non-human operation.

As mentioned above, customers want customized products to arrive without delay, and they want their orders to be fully accurate. A robotic solution that incorporates traceability elements can improve the pick-and-place process to satisfy rapidly changing customer demands.

Traceability ensures accuracy

A barcode reading system is important for tracking the accuracy of pick-and-place. AI-enhanced 3D vision systems can perform automated inspections to verify the standard quality of the product. These technologies can be integrated into a streamlined, easy-to-implement system.

Historically, traceability was implemented with barcodes that were printed on paper-based labels. These unfortunately were prone to getting worn out or washed off over time, so workers needed to check frequently to make sure the labels were still present. When replacing a label, the new one would have to be consistent with the previous one to ensure accurate reading of the label information.

For multi-side code reading, Omron presents an innovative scan tunnel solution that uses industrial cameras in converse to smart cameras. This approach separates image acquisition and processing devices and creates architectural flexibility and lower overall solution costs.

However, in some industries such as apparel, code reading can be very challenging, as it's difficult to always ensure the labels face outside of the product package. To avoid such issues relating to missing labels or those with inconsistencies, many warehouses

have adopted RFID technology in the place of printed barcodes. This offers peace of mind that no label loss or misprint will occur. Over time, RFID helps drive down the total cost of ownership by removing non-value-added tasks.

Overcoming space-related issues

The next challenge that the logistics industry needs to solve is limited space. The automated storage system optimizes space usage by using robots that can easily perform tasks within a narrow area or on high shelves that humans can't reach. Omron's sensing and automation control systems are being used by leading AS/RS manufactures for our high-quality products and easy-to-use programming platform Sysmac.

By saving space, increasing flexibility, and reducing the dependence on labor resources, intelligent automation solutions can help companies in the logistics arena thrive. As fully integrated automation technologies become easier and easier to implement, we're likely to see more companies jumping on the bandwagon and finding ways to optimize their processes with collaborative and mobile robotics.

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Image: Rightpoint

CHAPTER 4:

A Robot Dog Demonstrates How Mobile Manipulation Affects Automation

YAQING SUN, *Omron Automation*

Agile mobile platforms can deliver a new set of capabilities. Dynamic sensing for autonomous inspection is just one.

Spot was conspicuous by its absence during Marc Raibert's keynote presentation at Automate 2022. But that didn't stop the captive audience of robotics and automation enthusiasts from cooing over the tricks the robot dog was able to pull off in a video clip.

For the most part, attendees would have been familiar with Spot's YouTube videos released over the years, where its dance antics and bloopers have become fodder for viral public relations campaigns. In one video celebrating the acquisition of Boston Dynamics by Hyundai Motor Group in 2021, Spot grooves with K-Pop sensation BTS. In another, the Rolling Stones team up with a pack of robot dogs that mimic Mick Jagger's dance moves.

On the surface it seems antithetical that the Boston Dynamics founder/chairman should be on stage to sanction a dancing robot dog. Make no mistake; Raibert, a roboticist with a PhD in robotic techniques that model biological behavior, is acutely aware of the mass market appeal of the choreographed videos—where the use of legs and arms are used as a form of expression and alter perceptions of what a robot can actually do.

Humans tend to anthropomorphize robots—whether it is from Boston Dynamics or anywhere else—and public misperceptions can partly be chalked up to a lack of everyday experience with robots. "The fact is, we're not very far along with mobile robotics doing precise operations, but we're making progress," said Raibert, who spent decades developing robots with advanced mobility, dexterity and perception intelligence before he designed Spot to navigate rough terrain, climb stairs or augment dangerous human work where traditional automation has failed.

What the dancing robot does demonstrate, Raibert argued, is that mobile manipulation is one of the most important robotic opportunities. He said static manipulation is proving to be successful in some kinds of manufacturing, but remains limited.

During his keynote at Collision on June 8, 2022, Raibert discussed his Today and Tomorrow robot concepts. “Spot is a general-purpose robot, and as I’ll describe, you can adapt it for a wide variety of things,” said Raibert. “It’s not an appliance; it doesn’t just toast your bread, it toasts your bread, delivers your margaritas, it does a lot of things.”

READ MORE:Universal Robots’ Latest Cobot is Redesigned for Palletizing

During a public relations campaign, Boston Dynamic’s robots were programmed to conduct physical movements to mimic the choreography of K-pop group BTS. The video is about the enormous potential offered by Hyundai’s new robotics in daily life and enabling progress for humanity. Image: Hyundai Motor Company

Mobile Manipulation

Spot is a general-purpose, four-legged mobile platform that weighs 60 lb. It is compact, rugged and portable, and is designed to go where humans go. The robot dog is an omni-directional, customizable platform that can be adapted for a variety of different tasks; it can be mounted with a range of payloads to enhance data gathering such as thermal imaging, LiDAR or 3D scanning intended for such tasks as digital twin creation.

Spot has sensors built in on all four sides that help navigate through simple functions. In industrial applications, the platform may be integrated with a thermal camera, an arm for grasping objects (some people see it as a head), a Spot CAM (which comes with an optional PTZ camera), Spot CORE I/O (dedicated processing for additional on-robot computation) and Spot GXP (a power regulating and Ethernet port).

Since it moves around, tasks are no longer performed in a fixed location, and this allows businesses to think differently about the function of robotics. Singularities (a configuration in which the robot end-effector becomes blocked in a certain direction) and self-interference

"are really different when you have a base that can move around," said Raibert.

Part of Boston Dynamics go-to-market approach is a reliance on early adopters to help cultivate use cases across industries, ranging from mining, power and utilities, manufacturing, and oil and gas to NASA's Jet Propulsion Lab. According to Raibert, there are about 1,000 Spots; 100 universities doing experiments; and about a variety of industrial facilities using Spot for such tasks as preventive maintenance inspections, remote detection, thermal, radiation and gas leak detection, and scanning facilities with a view to developing digital twins.

IMAGE GALLERY: A Robotic Menagerie

Spot is a general-purpose, four-legged mobile platform that weighs 60 lb. Image: Rightpoint

Perception and Intelligence

A human pilots the robot dog so it can collect data and piece together a map of the path. Spot can then be instructed to go around the path autonomously. This procedure is especially relevant where Spot is preprogrammed for "rounds and readings" in environments where routine, repeatable inspections are needed or where hundreds of pieces of equipment need to be scanned. In facilities where legacy equipment need inspection and where adding fixed sensors would not be economical, Spot can read analog gauge readings.

Raibert characterized Spot's body manipulations for the most part as being athletic intelligence—how the robot perceives its environment and functions by moving, balancing and maneuvering around obstacles—as opposed to cognitive intelligence, which involves planning for events. Boston Dynamics has interest in leveraging both types of intelligence to bolster a fully functioning hardware system.

Operationalizing Autonomous Data Collection

Before Spot's commercial release in 2020, Boston Dynamics turned to Rightpoint, a Chicago-based IoT consultancy, to address a gap in its user experience. "They were using a fairly bulky laptop that you had to sling over your shoulder and walk around with, and it just

wasn't a great experience to drive or control Spot," said Ben Johnson, senior vice president of digital product, Rightpoint.

His team collaborated with Boston Dynamics in concepting, designing and developing line-of-site manipulation using either an Android tablet or a joystick to control directly where Spot was going, as well as the use of telemanipulation—or non-line-of-sight control—using the cameras to view what Spot sees in parallel with the development of Boston Dynamics' cloud-based software (Scout).

READ MORE: Energy-Efficient Legged Robot Runs Like a Bird

In industrial applications, Spot, a robot dog, may be integrated with a thermal camera, an arm for grasping objects and a thermal imaging camera, as well as dedicated processing (Spot CORE I/O) for additional on-robot computation. Image: Rightpoint

High Fidelity Experience

From where Johnson stands, Spot is at its core an image processor and a robot that moves from Point A to Point B. "So much of the control system is the processing," he said. Among the bugs his team needed to resolve was how to convert sensor data into a user-friendly control experience, as well as to enhance Spot's line of sight by reimagining Spot's camera positioning and the image the user sees. "Initially, Spot had two cameras in front that were pointing down to the ground and the two image streams intersected," explained Johnson.

Mobile gaming provided the inspiration. "Thinking through joystick controls, we also wanted to think about a driving experience that included the ability to see the camera," Johnson said. In addition to a straight-on view that would allow the person driving the robot to see where the robot was headed, his team would figure out how to use image processing on the tablet to transform the two image streams from the robot into an image that a human operator would expect to see. The current version, a composition of multiple images, was "a big hurdle to overcome," said Johnson.

Thankfully, it wasn't all work and no play. The Android tablet translates touch gestures into

commands and articulations for the robot. Occasionally, those commands would get backed up and Spot would not know what to do. The results can be comedic, he said, as some of the parody videos on stress-testing can attest. "The robot just did not know where to go because the instructions it was receiving were confused or jumbled up," Johnson quipped.

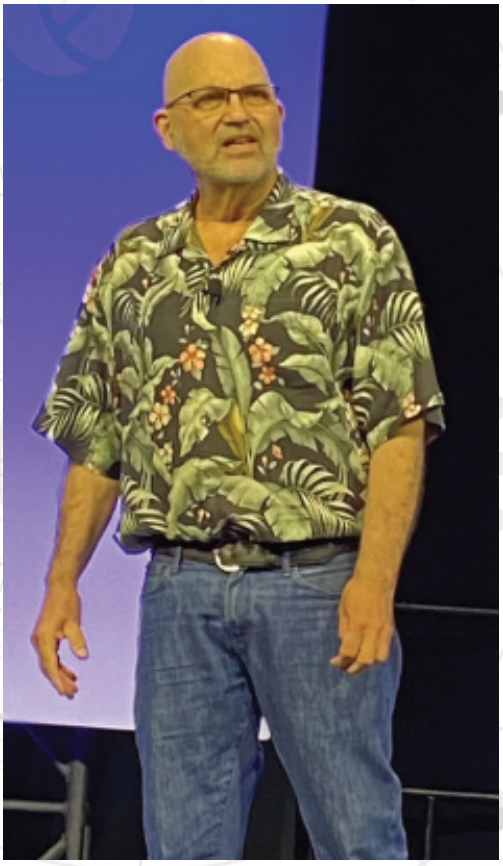
"But robotics is hard; when engineers are thinking about a connected product, so much of the challenge is in building the physical manifestation of servos and motors and positioning systems," Johnson said. "The user experience on top of this is just a thin layer. A lot of the time you have to focus on the core mechanics, and that can be challenging."

The robot dog has gone through many iterations since then, and Rightpoint continues to help build a safe and more robust platform. "As a society, we have gravitated to where we really do expect high fidelity experiences," Johnson said.

Today, Tomorrow and Future Ambitions

Spot did make an appearance at IMTS 2022, where it put on a show to the delight of attendees. During the presentation, Eric Foellmer, vice president of marketing at Boston Dynamics, shared a slide depicting New York City's Easter Parade in 1900. The procession was made up of horse-drawn carriages, except for one car. His next slide, an image taken just 13 years later, depicted the reverse: the parade was made up of a cavalcade of cars and just one horse and buggy. "The automotive industry had transformed the entire parade in a little more than a decade," explained Foellmer, hoping to impress upon the audience that the introduction of robots into our daily lives has similarly triggered an inflection point.

In addition to Spot, Boston Dynamics is paving the way forward with two other applications. Stretch is a commercial robot designed to unload boxes and containers in warehouse, shipping and logistics applications. Atlas is a humanoid, bipedal R&D robot with a dynamic hydraulic power unit. The HPU enables it to deliver high power to 28 hydraulic joints that give it the ability to perform parkour, including the agility to perform backflips.



Marc Raibert, chairman and founder, Boston Dynamics talks about the agility, dexterity, perception and intelligence of advanced robots. Image: Machine Design

"Adding cognitive intelligence to the robot is really going to be important, and I am starting to work on that problem," said Raibert at IMTS. "That means making robots understand their surroundings. Robots should be aware of their own behavior. So, if they knock over boxes, they are going to have to figure out a plan to pick them up. I think someday, they will be able to watch another robot or a person do a task, and figure out how to do the task themselves. And they also need to use reasoning and cognitive sense."

Raibert's IMTS presentation in June concluded with a cliffhanger: "Stay tuned…"

Those paying attention would have guessed impending plans. In August, Hyundai and Boston Dynamics announced an initial investment of $400 million to establish the Boston Dynamics AI Institute. Located in Kendall Square research community in Cambridge, Mass., the institute will be led by Raibert with the goal to invest resources in four disciplines—namely, cognitive AI, athletic AI and organic hardware design, as well as ethics and policy.

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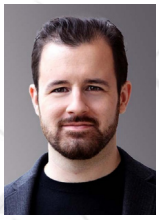
CHAPTER 5:

Warehouses Feel the Touch of Automation

MIKE BACIDORE, Editor, *Control Design*

AMRs and AS/RS set the pace

Which technologies have allowed warehouses to increase throughput rates while expanding product ranges and still maintaining accurate order fulfillment?



Ryan Gariepy, CEO and co-founder, Otto Motors: The continued evolution of vision-system performance and flexibility in sorting, picking and quality-control workflows has had significant impact when it comes to addressing the demands for ever-increasing fulfillment rates and ranges. Flexible manipulation is also starting to show early promise, but it has not yet been deployed at scale.

Also read: Warehouse automation with the human touch

Because of the warehouse's physical nature, how much of the facility's hardware can be replaced with software in order to facilitate easier upgrades, expansions and reconfigurations?

RG: Facility hardware won't be replaced with software on a 1:1 basis. Physical goods need to be moved. But hardware itself is becoming more software-enabled. Possibly more important is the fact that users are more open to regular updates and data sharing, where in the past their systems had software frozen for years and supplier data access was forbidden.

How have automated storage and retrieval systems' roles changed over the past 10 years?

RG: Ten years ago, automated storage and retrieval systems (AS/RS) were the more flexible part of a warehouse when it came to capital equipment and tended to feed less flexible solutions such as conveyors and sorters. Unfortunately, the minimum investment for an AS/RS was and remains significant. Now, we're seeing AS/RS interact with AMR-

based systems, which are even more flexible and have an even lower minimum investment requirement.

Will autonomous mobile robots (AMRs) replace automated guided vehicles (AGVs) altogether, or is there room for both, based on the application or complementary functions?

RG: In time, they will become one and the same. For example, our AMRs offer AGV-like functionality including full magnetic tape following. Likewise, we've seen growing indications that AGV suppliers are looking to increase the level of intelligence in their products.

How will ANSI/RIA R15.08 affect robotic solutions in warehouse environments?

RG: ANSI/RIA R15.08 will affect robotic solutions in warehouse environments for the better. It'll help new entrants to the market build safer systems faster and help users and system integrators who aren't familiar with AMRs ask the right questions to ensure safety in their particular facilities.

Given the extraordinary percentage of manual operation in most distribution centers, will the 24/7 fully autonomous warehouse order-fulfillment center ever become commonplace?

RG: In time, yes, a 24/7 fully autonomous warehouse order-fulfillment center can become commonplace. The reliability, robustness and flexibility of robot manipulators continues to increase, as does the willingness of warehouse operators to commit to larger investments in modern AS/RS and AMR deployments.

About the author: Mike Bacidore

Mike Bacidore is the editor in chief for Control Design magazine. He is an award-winning columnist, earning a Gold Regional Award and a Silver National Award from the American Society of Business Publication Editors. Email him at mbacidore@endeavorb2b.com.

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