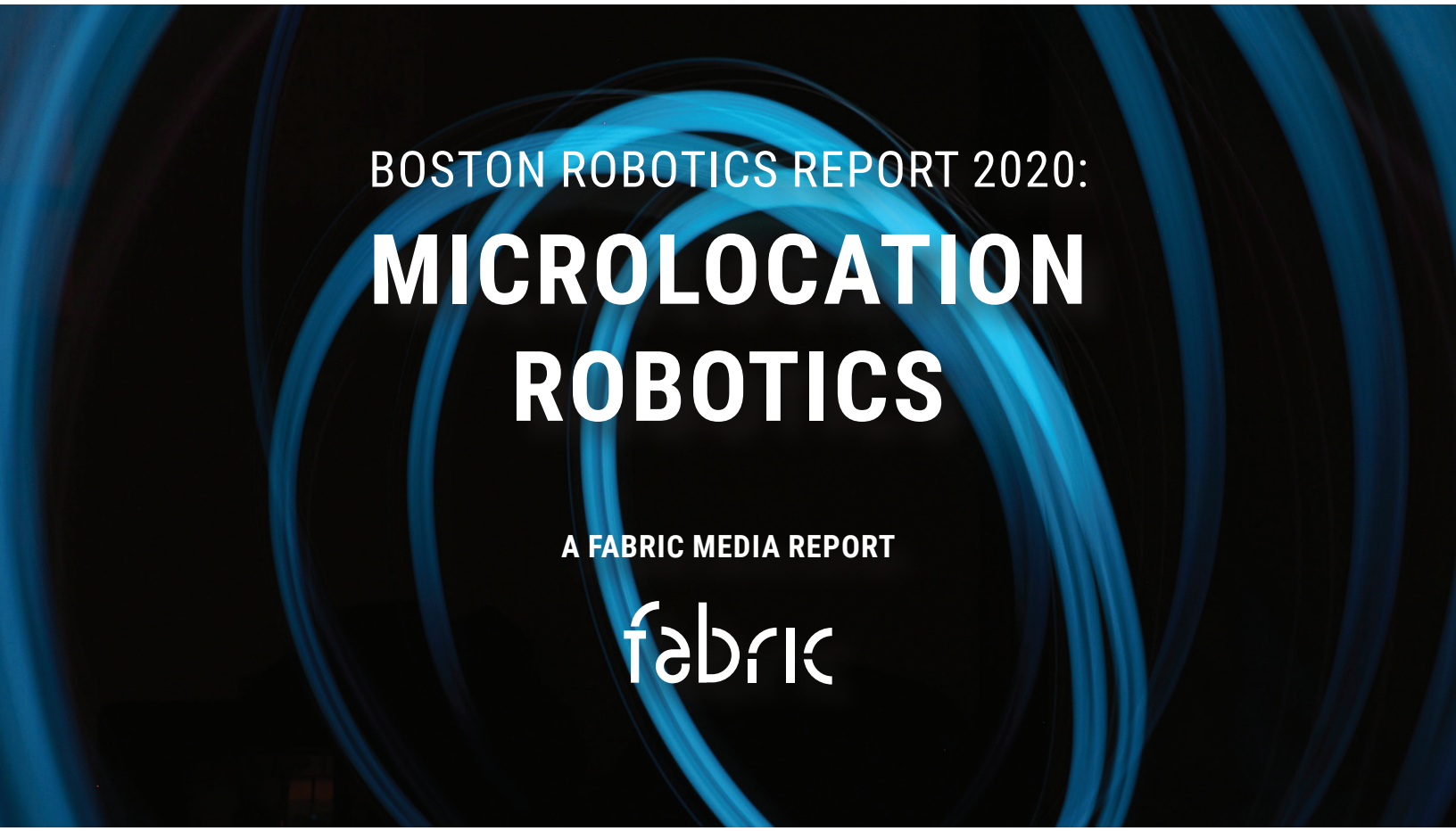

BOSTON ROBOTICS REPORT 2020:

MICROLOCATION ROBOTICS

A FABRIC MEDIA REPORT

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LETTER FROM EXECUTIVE EDITOR

Hello, Boston. Zach Servideo from Fabric Media. It's always irked me how much global innovation is driven right here from Boston, and yet our vibrant, venture-backed startup ecosystem is wildly underserved from a global media perspective (I'm talking the Bloombergs and Business Insiders of the world). Our aim with this report and future ones is to take a proactive analyst approach to documenting what we believe is the world's most dynamic innovation hub.

When we set out to write this report, we did so with the theory that there was a great deal of industry-leading robotics industry innovation from Boston that is ***hiding in plain sight***. (We believe that to be the case across industries: fintech, climate tech, AI, you name it. Robotics is one that stands out as a particular center of excellence in Massachusetts.)

Over the course of our research, we uncovered multiple Boston-area robotics technology companies driving robotics innovation globally. Our assumptions were further confirmed when two case studies from this report were featured in TechCrunch.

Rest assured, while this is the first report from Fabric Media on a Boston business sector driving innovation globally, it won't be our last. If you have vertical industries or specific companies you feel our analysts should take a closer look at, please contact me directly at **zach@fabricmedia.net**.

Enjoy the report. We're grateful for your interest.

Sincerely yours,

Zach Servideo

INTRODUCTION

In one of the largest hubs for robotics technology development, the same technologies used in driverless cars are being applied in the beginnings of a different technology revolution, one that will take place on factory floors. The promise of microlocation robotics is far less overbought than that of autonomous vehicles, and recent developments in the Boston-area robotics cluster show it may be closer to a breakthrough. The opportunity is to expand robots' viability into new industries and enable new manufacturing strategies by allowing robots and humans to work in close proximity.

In Massachusetts' robotics industry alone, no less than eight venture-backed companies on a regional list of the top-valued firms, compiled by PitchBook Data Inc., are working on systems to allow robots to work in human manufacturing environments. The top four firms are all focused on this space.

The following report summarizes the result of an NEVCA-sponsored review of this technology's emergence in Boston, including case studies with three of its most promising companies. The same effort has also yielded two articles in TechCrunch's premium section for research and resources, covering these emerging technologies and specific companies in the Boston cluster. You can read them **here** and **here** with a TechCrunch Extra Crunch subscription.

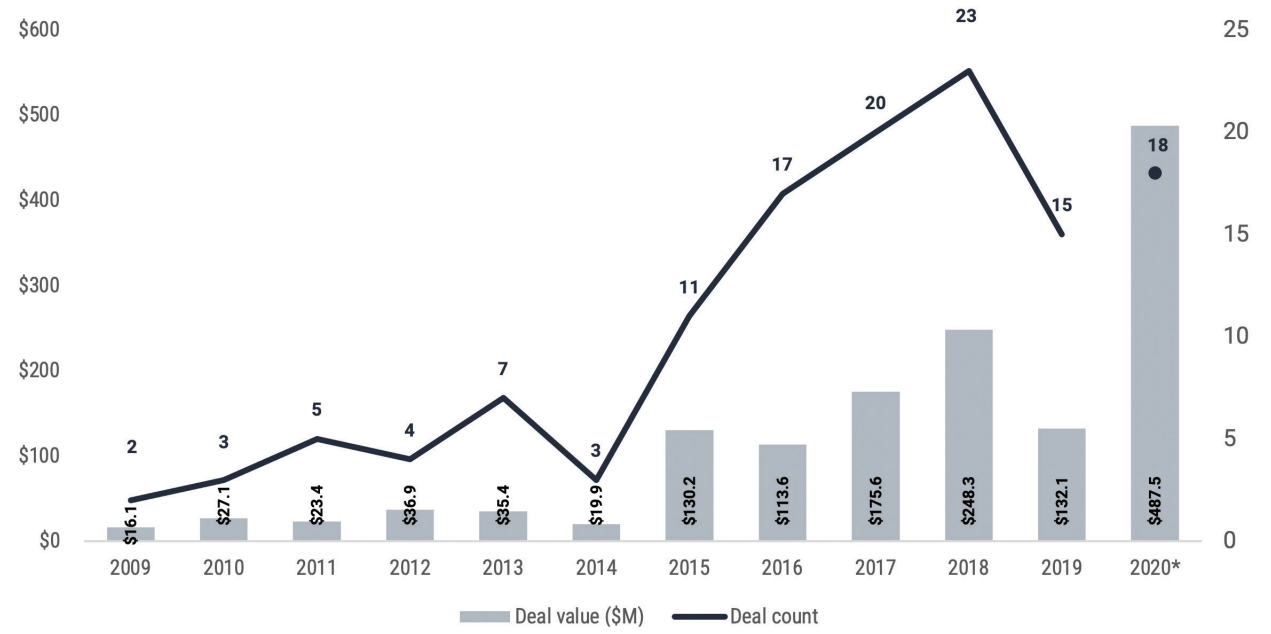
OVERVIEW

A MULTI-DISCIPLINARY CLUSTER

VC Robotics deal flow in Boston MSA

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020*
Deal value ($M)	$16.1	$27.1	$23.4	$36.9	$35.4	$19.9	$130.2	$113.6	$175.6	$248.3	$132.1	$487.5
Deal count	2	3	5	4	7	3	11	17	20	23	15	18

*As of 10/23/2020



Source: PitchBook Data Inc.

Boston's large robotics technology employers support a cluster of venture-backed startups numbering in the dozens: Amazon Robotics, Draper Labs, iRobot and Raytheon are on this list. In a recent interview, Bilal Zuberi, a West Coast-based VC and an investor in robotics companies, said Boston is one of only a few places with a talent pool sufficient to support this kind of symbiosis. Zuberi ticked off the requirements: mechanical engineering, electrical engineering, computer science, firmware engineering, manufacturing and computer vision.

Another robotics investor, Denver-based Trevor Zimmerman, pointed to what he calls "precompetitive collaboration" among startups. "If I was going to start a robotics company, it would be in Boston, because the caliber of the network would improve the probability of success," he said.

This collaborative talent pool leads to what Zuberi calls "a natural affinity for almost 'sci-fi'-like companies." For those who grumble that tech innovation has become too derivative, this is its leading edge.

TOP VC BACKED ROBOTICS COMPANIES IN BOSTON MSA BY POST VALUE (2016-2020*)

COMPANY NAME	POST VALUE (millions)	STAGE	INVESTOR(S)
***TakeOff (Logistics)**	$498.0	Later Stage VC	Forrestal Capital
Locus Robotics	$360.9	Later Stage VC	Scale Venture Partners, Zebra Ventures
Vecna Robotics	$225.0	Early Stage VC	Fontinalis Partners, Tectonic Ventures, Drive Capital, Blackhorn Ventures, Highland Capital Partners
Berkshire Grey	$214.1	Early Stage VC	SoftBank, Khosla Ventures, New Enterprise Associates, Canaan
Humatics	$200.0	Early Stage VC	Fontinalis Partners, Lockheed Martin Ventures, Blackhorn Ventures, Tenfore Holdings, Airbus Ventures, Presidio Ventures
Soft Robotics	$115.0	Early Stage VC	Calibrate Ventures, Material Impact
RightHand Robotics	$88.0	Early Stage VC	Menlo Ventures, GV, Playground Global, Dream Incubator, Matrix Partners
Sea Machines	$70.0	Later Stage VC	Accomplice, Toyota AI Ventures, Brunswick Corp (through investment partner TechNexus), Geekdom Fund, NextGen Venture Partners, Eniac VC, LaunchCapital
Veo Robotics	$69.5	Early Stage VC	Baidu Ventures, Next47, SBI Investment, Nikon, Lux Capital Management, GV
Realtime Robotics	$62.0	Early Stage VC	Mitsubishi Electric, Hyundai Motor
Spyce	$61.0	Early Stage VC	Khosla Ventures, Collaborative Fund, Maveron
Neurala	$56.9	Later Stage VC	Pelion Venture Partners, Sherpa Capital, Motorola Solutions Venture Capital, 360 Capital Partners, Draper Associates Investments, SK Ventures, Idinvest partners
Redpoint Positioning	$30.0	Later Stage VC	BHY Investment
Ava Robotics	$21.7	Seed Round	Innospark Ventures
Kiwi Technologies	$19.5	Seed Round	Pillar VC
Root AI	$19.2	Seed Round	Rob May of PJC, First Round Capital's Josh Kopelman, Jason Calacanis, Austin McChord of Outsiders Fund
RISE Robotics	$18.3	Seed Round	The Engine
Raptor Maps	$18.1	Early Stage VC	Blue Bear Capital, Data Point Capital, Buoyant Ventures, Congruent Ventures, Powerhouse Ventures, Massachusetts Clean Energy Center, Y Combinator
GreenSight	$17.4	Early Stage VC	The Toro Company, Tabard Venture Capital, Emerald Development Managers
Nextdroid	$14.0	Seed Round	Alumni Ventures Group, Fraser McCombs Capital, State Farm Ventures

**As of 10/23/2020. Source: PitchBook Data Inc.; Fabric Media*

**Due to a data provider error, an earlier version incorrectly reported TakeOff's post-money valuation. It is $498 million.*

KEY TECHNOLOGIES

COBOTS

The first generation of startups to pursue the promise of human and robot collaboration in a factory setting were companies developing "cobots." One of the largest of these, Rethink Robotics, raised nearly $150 million before ceasing operations and selling off assets in 2018. Rethink's trajectory is similar to that of the entire nascent cobot technology: It brought with it a brief and intense hype cycle, followed by disillusionment as industry impact failed to materialize. Companies have successfully deployed cobots, but the rate of adoption is lagging behind expectations, by 2019 reaching just 3 percent of the total industrial robots installed. To ensure safe operation, cobots come with built-in constraints, like limited strength and speed. Those limitations have also limited their adoption: Companies cannot achieve return-on-investment without the strength and speed advantages offered by traditional robots.

Microlocation robotics represents a new wave of companies developing for the same opportunity, but with a different approach. In this wave, sensor and artificial intelligence technologies are added to traditional manufacturing robots. Instead of a new generation of hardware, this technology is enabling these fast, high-powered robots to come out of their safety cages and work alongside humans.

Here are some of the specific technology categories involved in this new generation of microlocation robotics:

UWB RADIO

Ultra-wideband (UWB) radio frequencies are an update to GPS and camera-based tracking systems that have been widely used in private industries like shipping and retail since the late 1990s. Radio-frequency-based systems have become available with changes in the regulations covering use of radio spectrum. UWB radio frequencies received approval for commercial use in the United States in 2002. Since then, standards-setting organizations like IEEE have created guidelines for how UWB can be safely used for positioning and security applications, such as secure mobile transactions.

Apple announced in September 2019 that the iPhone 11 would include the Apple U1 chip, a UWB-compatible RFID tag. In the same year, a consortium named FiRa (short for "Fine Ranging") was initiated by technology manufacturing companies Assa Abloy, Bosch, HID Global, NXP and Samsung, with the goal of developing interoperability standards for using UWB in tracking and security applications. Massachusetts-based Humatics, covered in a case study below, is developing such systems. Elsewhere, Decawave (owned by Qorvo Inc.), Estimote and Zebra Technologies are developing similar systems.

3D VISIONING

Two companies in the Boston area are focused on developing vision systems, which are distinct from other types of sensors: Realtime Robotics and Veo Robotics. University of Illinois Urbana-Champaign associate professor Kris Hauser, director of the Intelligent Motion Lab, a research group focused on human-robot interaction, said that advances in computer vision algorithms have made 3D visioning an apt technology for use in microlocation robotics. These algorithms "nowadays give decent performance off-the-shelf for a variety of detection, tracking and 3D shape estimation tasks," Hauser wrote in responses by email. He noted limitations to 3D vision, however: "[3D vision systems] have a hard time recognizing dark, transparent, and reflective objects, and certain technologies suffer in outdoor lighting conditions."

These concerns are negligible in a setting like a factory floor, where lighting can be easily controlled. Installing and integrating a 3D vision system with existing industrial robots can be straightforward and quick. According to Veo Robotics CEO Patrick Sobalvarro, Veo's FreeMove platform can be installed in as little as one day, and pre-trained computer vision algorithms can be used to rapidly develop new processes.

ROBOTICS SENSING PLATFORMS

Also called "control systems," robotics sensing platforms are a combination of external sensors and software for monitoring robots and humans while operating inside controlled areas called work cells.

The essential technologies used in developing robotics sensing platforms are real-time motion planning (RTMP) and speed and separation monitoring (SSM). RTMP is the general tracking of all objects in a robotic work cell, including the robots, materials and human operators.

RTMP (also called real-time path planning) allows autonomous systems to not only respond to new obstacles, but to make plans to avoid them. Autonomous vehicles like Google's self-driving car and Tesla's autopilot systems are among the most widely known applications using this technology today. The technology is also used in mobile robots that can be programmed for tasks outside a manufacturing setting. Other potential applications outside the factory include telepresence robots. Not all situations require it. For example, iRobot's autonomous robotic vacuum cleaner, the Roomba, does not use real-time motion planning.

SSM is the specific tracking of robots and human operators. It functions as a digital version of safety cages used with high-powered industrial robots, by applying a minimum separation distance between robots and human operators. In industrial settings where SSM is deployed, humans can enter areas that would have otherwise been walled off by protective cages. These areas are scanned by sensors to detect entering humans, **which puts nearby robots into a safer, "collaborative" operating mode**. SSM **has been deployed in newer generations of cobots**, like Fanuc's CR series, that are designed to reduce some of the speed-and-power issues that come with the cobot category.

CASE STUDIES

VEO ROBOTICS

Veo Robotics founders Clara Vu, Patrick Sobolvarro and Scott Denenberg (courtesy Veo Robotics)

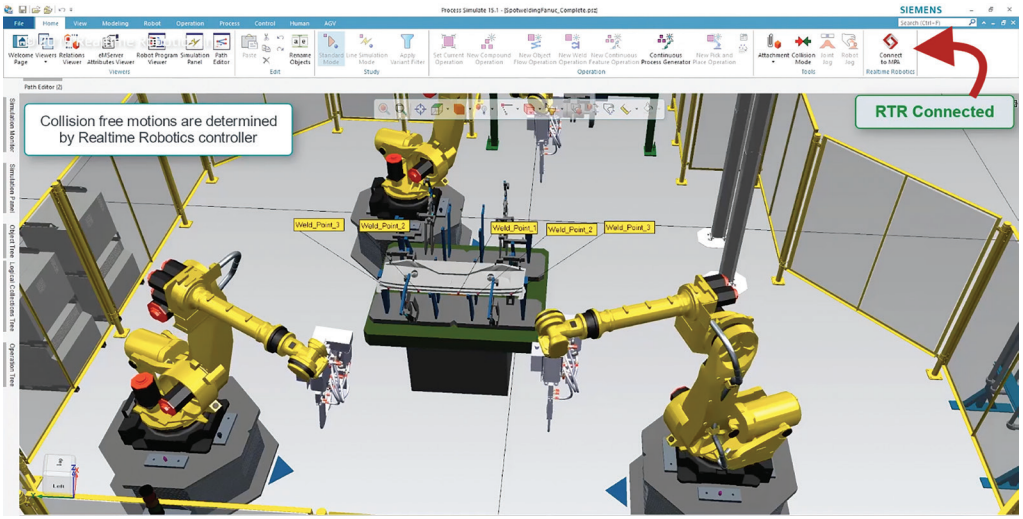
Veo Robotics sells a software and hardware platform called FreeMove that uses 3D vision sensing to plan and monitor the activity of industrial robots, enabling safe operation with humans in a shared space. Its product is a system of multiple camera sensors and software that monitors the movements of both humans and machines inside a limited area.

Veo's technology is based on speed and separation monitoring (SSM). Covered above among key technologies in the microlocation robotics area, SSM is one of **four standard methods** used in settings where robots and humans collaborate. The others are safety-rated monitored stop, hand guiding, and power and force limiting. Veo chose SSM, co-founder Clara Vu told Automation World in a July article, because it doesn't limit speed or power. Rather, it limits how close a moving robot can be to a human, halting its motion when the distance is close enough to be dangerous.

Advances in 3D vision technology are important enablers of this system. Artificial intelligence and machine learning, not so much: AI technologies and machine learning require trial-and-error, which is a non-starter in an industrial setting involving humans and powerful robots, for obvious reasons.

Veo Robotics made a developer kit available for the FreeMove platform in June 2019, and has partnered with robot manufacturers such as Kuka, Fanuc, ABB and Yaskawa to conduct trials using the technology in the automotive, consumer packaged goods and household appliance industries. Veo Robotics has also been working with certification agencies to have the technology's safety verified. According to the company, FreeMove will be generally available in early 2021.

REALTIME ROBOTICS



A screen shot of Realtime's product in collaboration with Siemens (courtesy Realtime Robotics)

Realtime Robotics began in 2017 with researchers out of Duke University. It offers a hardware- and software-based solution that manufacturing engineers can use to run simulations in a virtual environment to optimize movements, configure robots in a work cell and actively intervene in real environments to avoid collisions with humans.

The simulation program uses a "hardware-in-the-loop" approach, which takes into account all the physical elements of a manufacturing environment. "By utilizing a hardware-in-the-loop approach and offering robotics cells the ability to instantly plan and replan paths based on any and all dynamic obstacles," said Realtime Robotics CEO Peter Howard in an interview with Fabric Media for this report, "manufacturers will have the ability to safely and affordably deploy industrial robots with human operators in the loop. This will be an inflection point for robotics, enabling the automation of broad new applications."

Realtime Robotics recently announced a partnership with Siemens Digital Industries Software to simplify the integration of Realtime Robotics' hardware with industrial robots that do not have dedicated vision systems. The result of this collaboration, Howard said, is a major reduction in the "time to deploy and adapt to modifications, both during simulation and on the shop floor." In recent projects with automotive OEMs, Howard said this collaboration "has enabled an 80%+ reduction in programming time and cost."

Realtime's intellectual property includes a custom processor designed for real-time motion planning. Recently, it has been used in autonomous vehicle development as well as industrial settings.

HUMATICS

A *Humatics sensor deployed on New York subway track (courtesy Humatics)*

Founded in 2015, Humatics is an MIT spinout backed by Lockheed Martin and Airbus. It makes sensors that enable fast-moving and powerful robots to work alongside humans without accidents. Its sensors use ultra-wideband radio (UWB) technology, the significance of which is detailed above in the section titled Key Technologies.

Humatics obtained some of the patents for its UWB technology when it acquired 5D Robotics and its subsidiary Time Domain in early 2018. According to an article in RFID Journal from 2018, Time Domain had by then reduced the cost of manufacturing its chips in two significant ways: by optimizing the product designs to make them mass production-friendly and by increasing the effective range of the radio beacons so customers would require less equipment for full coverage.

Humatics has sold more than 10,000 UWB radio beacons, the base unit for their real-time tracking system, to manufacturers of sensor systems, the company says. They pinpoint the location of hundreds of RFID tags at a range of 500 meters, using multiple tags on an object to measure orientation. The company has been testing its technology with New York's Metropolitan Transportation Authority since 2018, and today is tracking five miles of a New York subway route, showing the MTA where six of its trains are, down to the centimeter. UWB sensors may resolve problems that the subway's extreme environment causes for sensors that use wi-fi, GPS or cameras.

As it builds a business in transportation and manufacturing, Humatics is developing new, more precise systems to measure location at the submillimeter level using radio frequencies distinct from UWB. Potential applications include robotic welding, assembly and automated guided vehicles (AGVs). Humatics CEO David Mindell says that Humatics is the "first company able to provide submillimeter precision using RF-based tracking."

PATH FORWARD: CERTIFICATION

THE FUTURE OF AN INDUSTRY: SAFETY CERTIFICATION

Achieving safety certifications for RTMP and SSM systems is critical to the growth of companies developing robotics sensing platforms. These safety certifications ensure that the platform complies with standards set by organizations such as ISO or the American National Standards Institute (ANSI). For a robotics sensing platform, this distinction is the "holy grail," said Peter Howard, CEO of Realtime Robotics, covered in a case study above. In responses by email, Howard wrote that he expects safety certifications to unlock "massive" potential for his company's niche. "Robots will be able to be deployed in markets and applications that were previously prohibitive due to safety and resulting cost/complexity," he wrote.

Existing standards are set to identify what safe operation of robots looks like. ISO technical standard 15066 identifies the four methods by which robots can operate safely around humans, as described above. ISO 13849-1:2015 provides requirements for the safety-related software and hardware components used in industrial control systems shaped to the contours of this emerging industry niche.

Companies like Realtime and Veo are attempting new applications of these standards that involve novel risks and parameters. Certifying that their products and services meet the safety requirements set by these standards is key to unlocking the new technologies' market potential.

The initial wave of enthusiasm for cobots was, at least in part, based on the idea that collaborative robots could bring new efficiencies and advanced manufacturing techniques into manufacturing niches where robots had not previously been used. That vision has faced some headwinds. The new generation of microlocation robotics technologies proposes a more prosaic idea: combine legacy robots with new or existing vision and computing technology in novel ways. If this new approach proves more successful, it will repeat a pattern seen in the likes of Apple's iPhone: It's often not a new technology, per se, but a new combination of existing technologies, that revolutionizes an industry.

ABOUT FABRIC MEDIA

Fabric Media is an analyst firm, storytelling studio, business incubator and talent consortium focused on media strategies, marketing services and business development for companies at the intersection of technology and entertainment.

As analysts, we cover the rapidly changing world of business wherever technology is transforming a market.

As a storytelling studio, we develop custom branded entertainment productions across all forms of media — film, TV, video, audio, photography, street art, you name it.

As a business incubator, we develop media, marketing and business development strategies with disruptive companies poised to positively impact the future.

As a talent consortium, we collaborate with an ever-growing group of journalists, analysts, marketers, artists, consultants, videographers, photojournalists and changemakers from all walks of life.

To learn more about Fabric media, visit: **www.fabricmedia.net**.

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