NavVis - Enabling Digital Value Creation Indoors

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SUMMARY

NavVis is a spin-off from the TU Munich and builds on the results of its own long-term research and development in the fields of robotics, computer vision, data visualization and sensor fusion. NavVis develops hardware and software for digitization and web-based visualization of interior spaces.

The M3 Mapping Trolley allows customers to capture the centimeter-accurate and photoreal 3D mapping of buildings - in a fraction of the time required today and at much lower cost. Building on these detailed building data, NavVis offers a completely new technology for navigation in buildings. This works like human navigation via image recognition and is therefore not dependent on additional and maintenance-intensive hardware (e.g., WiFi or beacons). The NavVis IndoorViewer allows the enrichment of the virtual environment with digital information and enables the integration of site-specific services in interior spaces for a wide range of applications. The first public release of the Navigation App (Technical University Munich Campus Maps) is now beta testing. The Campus Maps is the first app that incorporates our groundbreaking indoor positioning and navigation technology.

NavVis' customers include leading global automotive, manufacturing, transportation, retail and insurance companies. NavVis products will be distributed among other things in building management, for visitor navigation as well as in logistics and planning / simulation. NavVis technology enables the digitization of space and space and is therefore a key building block for industry 4.0.

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1. INTRODUCTION

Though laser scanning is possible since the 1960's, it's breakthrough in the surveying happened in the 1990's. "Laser scanners create a large quantity of points in a systematic pattern - also called point cloud" (BOEHLER & MARBS, 2004) that are used to create models or floor plans. 20 years later, laser scanners are still the frontrunner for taking three dimensional measurements. Several different companies started a race for the highest precision possible. While in 1994 a deviation of 20 to 30 cm was seen as acceptable, only a few years later selected laser scanners had a precision as high as 1.5 mm (PETZOLD et al. 1999). Other than continuous improvements in precision, no game-changing innovations appeared in recent years (KUZMINSKY & GARDINER, 2012).

Laser scanning is seen as a cost-effective way for the creation of a digital record of a scanned area (KUZMINSKY & GARDINER, 2012) if compared with the gain the scans offers for the user. Nevertheless, laser scanning is rarely used to assess the as-built status of a production line or construction site; though it would identify discrepancies, and would support the decision-maker in defining next steps in planning installations (GOLPARVAR-FARD et al. 2011).

Likewise, there is no digital twin of shopping malls, airports, museums, office buildings, and train stations – though the application possibilities are numerous. Airport operators or a museum's management could facilitate several processes with a digital record: (1) Facility Management (FM) requires field workers, that need to be delegated across vast indoor and outdoor spaces to carry out tasks. A digital record can make the workflow more efficient. (2) In a building with several floors and/or large areas, the routing of travelers and visitors is complicated. With a digital twin, the routing and also the experience is enhanced by a fast and seamless navigation to the required location. (3) Moreover, an online image helps retail stores and museums expand real-world "viewership" with a virtual 3D model. The model can target specific customer groups or provide information to people that cannot travel to the facilities.

All the above applications need up-to-date maps and digital records. Thus, mappings have to be conducted at least once per year and – depending on the use case – even as often as weekly. Though laser scanning is often seen as being cost-effective, the scanning plus modelling are seen as being too expensive to conduct scans periodically. The driving force is the time a highly-educated employee has to spend on site to conduct a scan and to do the modelling work afterwards. In 2014, there were 14'000 surveyors in Germany, of which 1.5 % were unemployed. At the same time, several companies were searching for employees (BUNDESAGENTUR FÜR ARBEIT, 2014). Thus, with today's workforce and equipment, it would not be possible to scan large areas periodically.

2. MOBILE INDOOR MAPPING

While most companies are aiming for higher precision, the above mentioned problem is rarely considered. Innovations in reducing the time on-site, or developing a semi-automatic to automatic capturing device, are required.

2.1 Traditional Indoor Mapping Systems

Today, laser scanners for indoor environments are mostly static (tripod-mounted). The first step of a scan is the positioning of the scanner over a known point (often called a reference point) and the orientation to a second known point (LICHTI & PFEIFER, 2016). Usually conducting a mapping of a room from a single position is not possible as many objects obscure parts of the room. Hence, several scans from multiple different positions have to be merged via several reference points. Scanning one sphere can take between 1.5 and 45 minutes, depending on the resolution and the desired quality. After one scan, the laser scanner has to be moved to a second point known to the system. Overall, a professional surveyor has to conduct the scan, as creating reference points and handling a laser scanner is not trivial and between 350 to 1`500 m^2 a day can be scanned.

2.2 Mobile Mapping Systems

Outdoors, three dimensional measurements of large areas are conducted with a mobile system, that creates point clouds and 360°, high-quality pictures. Many mapping results can be viewed free of charge in any browser with Google Earth. More than a third of the world's land surface has been mapped (TAYLOR, 2008). Though the outdoor systems were very successful, there were no comparable successful systems for indoor environments. A mobile laser scanner requires the continuous tracking of the position. There are several signals outdoors that support the tracking, e.g. GPS, wheel odometry and inertial measurements units (IMU). Indoors, a mobile system has to rely on another technology. Though an IMU could be used indoors, the usage is very complex as, without constant recalibration, the drift grows exponentially.

2.3 Mobile Indoor Mapping System

A spin-off of the Technical University of Munich called NavVis has developed a mobile mapping system (NavVis Trolley) based on a simultaneous localization and mapping (SLAM) positioning algorithm. Though the systems starts in an 'unknown' location, it is able to build a map of the surrounding environment during travel, as one horizontal laser scanner is mounted on top of the system and simultaneously creates a map of its surroundings. The scanning plane of the top laser scanner building the map is parallel to the moving direction (generally horizontal). The map contains nodes and edges, while every node corresponds to a pose of the robot during mapping and every edge between two nodes corresponds to a spatial constraint between them. The latter are obtained from observations of the environment or from movement actions carried out by the robot. The map is then used to compute the location of the system while it is pushed through the room. The scanning planes of the two laser scanners on the bottom of the NavVis Trolley are perpendicular to the moving directions and create a 3D representation of the environment.

Challenges – such as real-time matching of individual scans and obtaining a highly accurate point cloud despite redundant information – are typical, as observations are affected by noise. Once a graph is constructed, the crucial problem is to find a configuration of the nodes that is maximally consistent with the measurements. This requires solving an error minimization problem. Yet, indoor mapping systems are required to scan extensive environments of some hundred thousand square meters. The algorithms developed for the M3 Trolley exploit all the redundant information contained in the individual scans to obtain a highly accurate map of a building. The absolute error of these scans is in the range of a few centimeters. This absolute accuracy is further improved by the ability to detect and close large loops in the trajectory of the platform. Further improvements to the quality of the scan are explained in Chapter 3.

In addition to laser scanners, the mobile mapping device for indoor spaces uses digital cameras. Six cameras, five on each side of the Trolley's sensor head and one on the top of the Trolley's sensor head, create high definition images. Every few meters the Trolley captures six single photos, which are stitched to create a panoramic image during the post-processing. The color information of the photos is used to color the point clouds.

Fig. 1:
The NavVis M3 Trolley – a mobile indoor mapping robot.

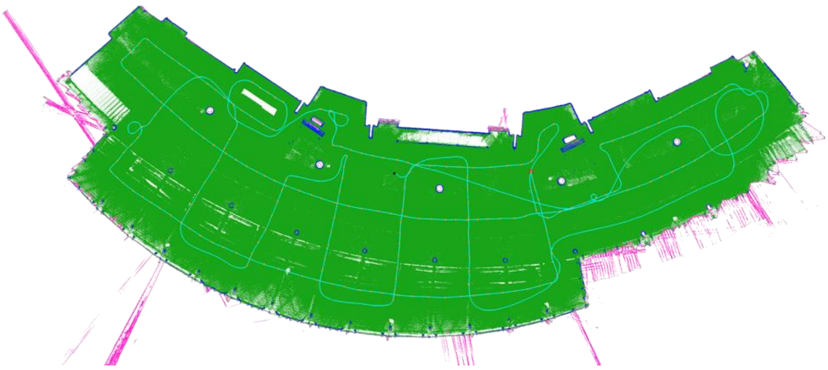

Fig. 2: The Trolley provides a visual feedback on its trajectory and the scanned parts.

In comparison to terrestrial laser scanners, the NavVis Trolley does not need suitable scan positions, but the operator must ensure that the whole area – including spots behind pillars, corners and other obstructions – has been covered. Therefore, visual features, which layout the scanned data simultaneously, are an advantage (NEWMAN & HO, 2005). On the screen of the NavVis Trolley, the outlines of the map generated by the top laser, are constantly built up (see Fig. 2). Furthermore, it marks in green the parts that were captured by the two other lasers and shows the route the operator has taken.

3. SLAM Anchor

As outlined above, the ability to build a map of the environment and to simultaneously localize within this map is an essential skill for navigating in unknown indoor environments – denied of external referencing systems such as GPS.

A common solution for this problem are SLAM algorithms that incrementally build a 3D model of the environment from local sensor information. This incremental approach makes the system powerful and flexible, but it also means that there can be a drift error in the position estimate. This may show up as minor distortions in the mapping results, such as a slight bending of long corridors compared to the true building geometry.

As demands on accuracy are still high, NavVis developed two approaches to obtain accurate scans while using SLAM algorithms. Firstly, when the NavVis Trolley reenters a known area after traveling in a previously unknown region for some time, the algorithm seeks for matches of the current scan with the past measurements (also referred to as "loop closing"). The algorithm performs the optimization whenever a loop closure is detected. While the algorithms recognize previously visited places and use that knowledge to reduce distortions, loop closures may not be feasible in every building layout.

In case of a building geometry in which a loop closure is not possible, NavVis developed a second mechanism called SLAM Anchors. Higher map accuracy is achieved by incorporating external information about the Trolley's position at specific times of the mapping. SLAM Anchor-enabled Trolleys are equipped with calibrated laser crosshairs pointing from the Trolley body to the floor. The operator can place the Trolley with millimeter accuracy on specific points placed on the building floor. SLAM Anchors can eliminate distortions in mapping artifacts and, simultaneously, gauge the maximum remaining errors.

The main algorithm in this framework follows an approach, in which a priori knowledge about the exact position of the Trolley is introduced. That results in quality and consistency improvements of every solution. Exact positions can be measured with the help of a total station and correspond to a pose of the robot during mapping. Therefore, more constraints are introduced in the graph and, again, the algorithm is trying to find a node configuration that minimizes the error.

Both the advancements of SLAM algorithms and the easy incorporation of external information of the device´s position can further improve the accuracy of mobile indoor scanning devices in the future.

4. Comparison of point clouds

Precise point clouds are valuable and essential in order to create a CAD (computer-aided design) model. The workflow from a point cloud generated with NavVis technology to a finished CAD model comprises four steps: First, the NavVis Trolley collects measurement points using 3D LiDAR scanners and the NavVis Mapping Software then generates a filtered and colored set of 3D data points. Precisely colored point clouds with 5mm resolution can easily be loaded into existing point cloud processing tools. While point clouds can be directly rendered and inspected, they are generally not directly usable in most 3D applications. Therefore, point clouds are converted to polygon mesh or triangle mesh models, NURBS (non-uniform rational B-splines) surface models, or CAD models through a process commonly referred to as surface reconstruction.

Fig. 3: A 5 mm colored point cloud of the Audimax at Technical University Munich captured with the M3 Trolley.

Depending on the purpose and the scope of the work, either a static laser scanner or a mobile indoor scanner can be used. The NavVis Trolley, according to the categories of the U.S. Institute of Building Documentation, achieves a Level of Accuracy (LOA) of 20, while traditional high-definition laser scanners reach LOA30. The exact accuracy of the point cloud depends on several factors such as usage of SLAM Anchor, loop closures and experience of the mapping operator. In addition to that, the relative accuracy achieved by NavVis is 20-30 mm between two points within 100 m.

For the accuracy of scans, the resolution plays an important role and is of interest to the device operator or user of the results. Fig. 4 and Fig. 5 show that for the representation of edges, it is beneficial to use a higher spatial resolution. This results in a higher number of individual points (centroids) to work with. Currently the M3 Trolley can produce a resolution of up to 5 mm.

Mobile indoor mapping devices, like the M3 Trolley, come into use when ultra-fast and cost-efficient indoor scans with sufficient accuracy is of interest. In contrast, to obtain a highly accurate absolute position of the building structure in a mapping coordinate system traditional systems are preferable. Both mobile indoor scanners and static laser scanners also can be used in combination to utilize the respective benefits of both systems. The achieved accuracy levels make the NavVis M3 Trolley practical for many – but obviously not all – indoor mapping applications. Ultimately the question is, if the increase in speed and cost effectiveness outweights the sufficient, but not ultimate, accuracy. Current projects and results demonstrate that the indoor mapping technology is ready for widespread adoption for a variety of surveying and mapping tasks. Concrete applications will be shown in chapter 6.

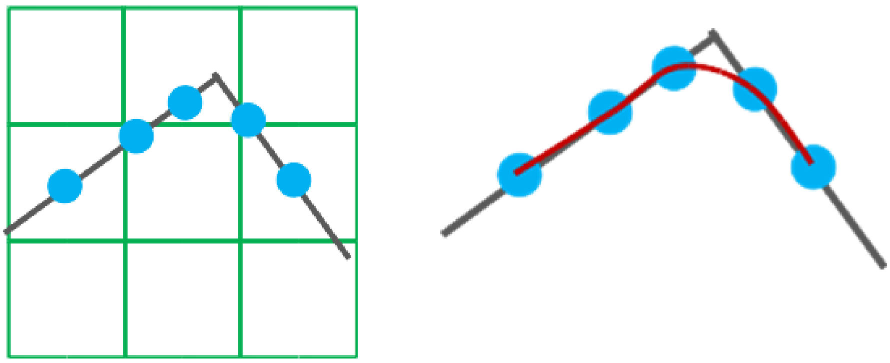

Fig. 4: The edge with a 2 cm voxel structure (green grid) applied to it and the resulting centroids (light blue dots) of the “raw” measurements. The red curve represents the edge derived from the centroids.

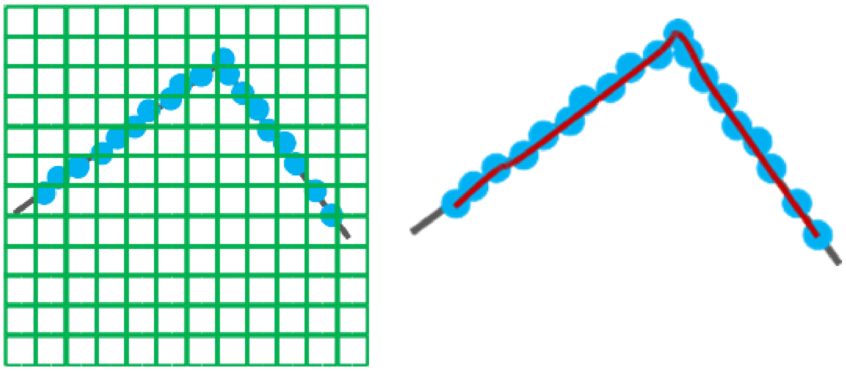

Fig. 5: The same edge with a 5 mm voxel resolution (green grid) applied, and the new centroids (light blue dots) of the “raw” measurements. The red line represents the approximate curve and, consequently, the edge is more accurate.

5. Data visualization

The collected data, both point clouds and high-definition images, is only valuable if it can be visualized and made available to the people who will eventually work with it. In this regard three developments are observable in the industry, that will now be shown along the example of NavVis.

Firstly, the data from the indoor scans should be visualized in any common web browser and should not require the installation of specialized software. Browsers are established programs on desktop computers, tablets and smartphones and anyone with such a device is a potential user of the data. For this purpose NavVis developed a browser-based software (called IndoorViewer) that allows to display both the 360° images and the point clouds. Together these two data formats give a holistic impression of the interior space. One efficiency gain in this procedure is that no 3D modelling of the data is necessary – eliminating this expensive step in the processing chain. In the IndoorViewer the point clouds are shown in color at a resolution of up to 5 mm (see Fig. 6). This allows precise measurements of distances between individual points with the help of the built-in measurement tool.

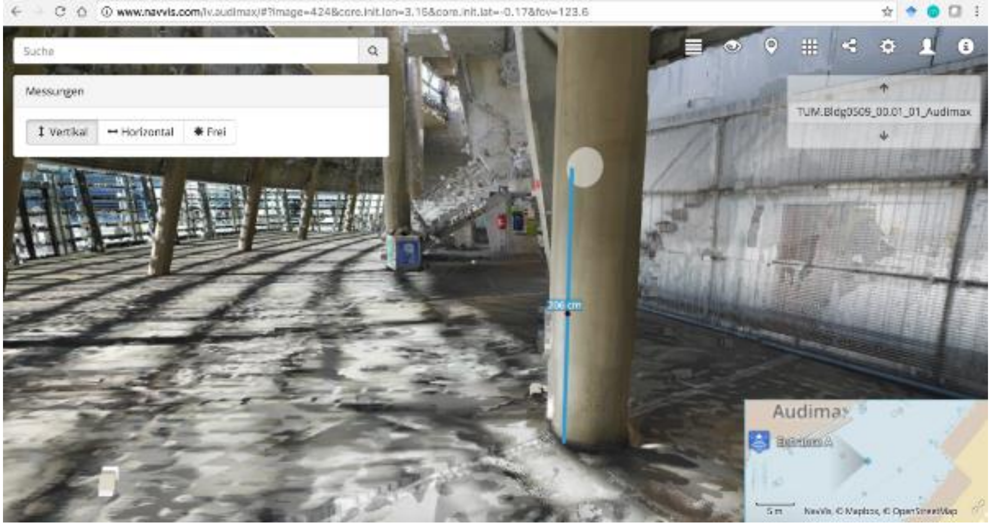

Fig. 6: Browser-based IndoorViewer that displays point clouds and permits measurements (light blue line) in the Audimax of Technical University Munich.

The second differentiation level refers to the usability of the data. As point clouds are accessible to a wide audience through the browser, the interaction with that data needs to be simpler. As one does not need specialized software to visualize the data, the features and tools to work with that data are adapted accordingly. Referring to NavVis´ IndoorViewer, the handling of the data is intuitively possible with a mouse and basic keyboard commands. A user can freely move around in the point cloud and view it from any perspective. This enables use by non-experts and thereby facilitates the democratization of 3D information.

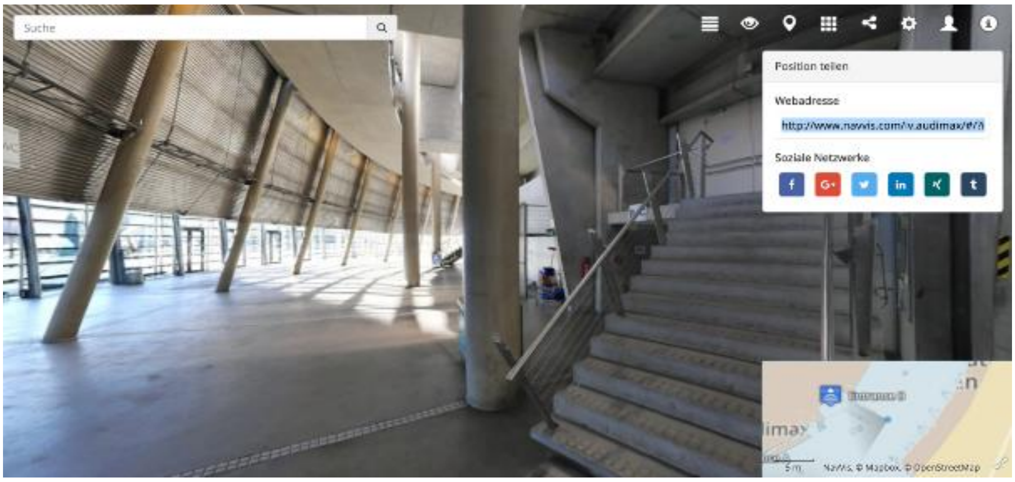

Fig. 7: Data can be shared with a link or directly in social media channels, as highlighted on the right-hand side. The example shows the Audimax of Technical University Munich.

Thirdly, the possibility to share data and work on it collaboratively is a key element. Data captured with NavVis technology is stored in the cloud or on an organization's servers. This means that several people can access it simultaneously and annotate it with additional information. Annotation could be tasks or reminders as well as discussions or references to other sources of information such as documents or videos. Giving others access to the data is done by sharing a link of that specific location and view of the indoor space. A user authentication mechanism ensures that data is only shared with people who are permitted to have access. These elements make clear how working with 3D data may change. Online collaboration has become a standard way of working in many areas such as project management, writing or communication. With new technology and procedures, online collaboration is also emerging in the 3D interior sector.

6. Application areas

So far, we have shown that the digitization of indoor space is based on two building blocks: Firstly, the possibility to map large spaces in short time and thereby reaching significant efficiency gains compared to stationary laser scanners. Secondly, making the data available to a wide audience as it is browser-based, which allows for new ways of collaboration. Together, these two building blocks enable a new range of use cases, that are suddenly technically possible and economically feasible.

One of the application areas in which indoor digitization can bring advantages is the management of construction projects. In this case, a construction site is scanned periodically over the course of its completion and made accessible to authorized persons online. This provides an accurate documentation over time and serves as a reference for the project manager and building owner. On-site visits are necessary less often as the progress can be monitored in the browser, eventually leading to savings in time and cost. Over the course of the project, the project manager can monitor progress, compare the actual build status with plans and check if construction phases are on time. Additionally, the data can be shared with subcontractors to highlight certain project areas and support the communication of tasks with visual information. A further relevant use case is to involve external experts by sending them the link and discussing issues based on the point clouds and images. The ‘digital construction site’ allows less time- and place-dependent work, providing greater flexibility and leading to efficiency gains.

Also in retail environments, a digital model of an indoor space can provide valuable benefits. Users can browse through retail shops independent of opening hours or their personal schedule and view the displayed products. The high definition images help to make small products and details visible. Every product can be advertised with a Point of Interest (POI) that contains additional information like further configurations (color, size, styles), prices or delivery possibilities. For retail shops, this provides the chance to extend the sales area to the virtual shop. A digital model can bring many of the features of physical shops, such as nice decorations and an appealing atmosphere, online and thereby compete well against purely online shops. Lastly, the virtual shop in the IndoorViewer can be directly connected to the retailer’s online shop, which allows product purchase from the IndoorViewer. This means a POI not only contains additional information, but also a functional check-out process connected to the retailer’s backend.

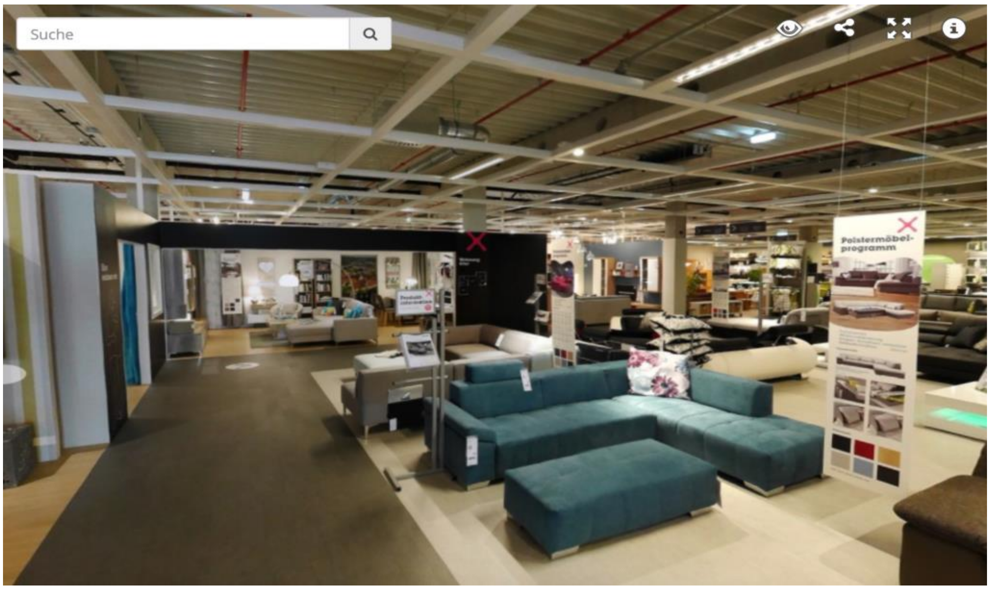

Fig. 8: The online furniture store allows to virtually walk through the sales area and get additional information on products.

7. Conclusion

The recent years in scientific and technological development in indoor scanning led to tremendous capability advancements and paved the way for indoor scanning to reach wide-spread adoption. New algorithms combined with commercially available mechanical and electrical components resulted in a new technology that radically increased mapping efficiency. A range of new application areas requiring faster, better and chapter solutions emerged. The data produced with an indoor mapping device, such as NavVis' M3 Trolley, can be used for facility and real estate management, retail operations plus indoor positioning and navigation. Now, once a building has been scanned, the incremental costs for adding further applications are very low. This leads to a promising future for indoor digitization. Currently, a tiny share of the available indoor area has been scanned. Building operators, users and technology providers are just starting to understand the possibilities. In an increasingly digital and connected world, where efficiency gains are the goal of all organizations, digitized indoor spaces are a promising solution. With continuous improvements in hardware and algorithms, building interior data capture can become better and less expensive while data availability can be extended to many more users.

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BIOGRAPHICAL NOTES

Marcus Bergsli, Business Development Manager

Marcus is responsibility for the NavVis` international expansion in the Nordic region. In addition, he is leading NavVis` vertical development within VR (Virtual Reality) and IoT (Internet of Things). Before joining NavVis in October 2016, Marcus worked as Global Strategic Alliance Manager at Premier Farnell, where he was responsible for business development for several world leading technology companies. Marcus has a Bachelor in Public Relation from BI Norwegian School of Management and Master in Communication and Business from Copenhagen Business School.

Dr. Georg Schroth, CTO

Based on the experience in positioning systems, gained during his stay at the Stanford GPS lab, Georg began with first considerations of a vision based indoor positioning system. The Institute for Media Technology (LMT) at Technische Universität München allowed for the concrete exploration of this idea as part of his PhD project and provided initial funding. 2011 the Federal Ministry of Economics and Technology provided a grant to extent the research team and to continue research in this promising direction. Inspired by his studies in the field of Technology Management (CDTM), Georg worked from the very beginning towards starting a company in this area.

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