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Point Clouds As A Geometric Data Basis For Factory Planning - Comparison Of Several Mapping Techniques

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Abstract

This article examines the use of point clouds as a geometric data basis for factory planning and compares different mapping techniques for generating these point clouds. Data and information acquisition is a crucial step in factory planning and thus in developing efficient production processes. In this context, different mapping techniques are analysed: photogrammetry (using drones and action cameras) and LiDAR scans (performed both from drones and from the ground).

The methodology and results of this investigation are discussed in detail, highlighting the advantages and disadvantages of each mapping technique. The focus is on comparing the generated point clouds in terms of completeness, recognisability and geometric tolerance. This comparison provides valuable insights into which technique is best suited for the data acquisition of factory planning.

The outlook of this paper includes the further development of recording techniques, particularly with regard to autonomously flying drones. In the future, these could enable more efficient and precise data acquisition for factory planning and thus further strengthen the basis for optimising production processes.

Keywords

Drone; Photogrammetry; LiDAR; Point cloud; Factory planning; Data acquisition

1. Introduction

Factory planning is a central component of logistics and is used to plan, reorganize, or expand production facilities. In a structured process, factory planning goes through various phases, from setting of objectives, through (layout) planning in varying degrees of detail, to ramp-up support. An important and central element of the factory planning process is the factory layout, which is subject to the project objectives and the basis of which the factory is realised [1]. For factory redesigns and expansions, a model of the current factory layout created as part of the establishment of the project basis is a requirement for further processes such as material flow planning or the design of the production environment [2]. During the establishment of the project basis, the geometric data of a factory is collected and processed into a 2D or 3D factory layout. The traditional methods of the establishment of the project basis are limited to analog techniques such as error-prone manual measurements, e.g. with a tape measure or a handheld laser distance meter [3]. However, it is known that data acquisition and analysis can account for up to 50% of the project effort and thus have a significant impact on the (cost) efficiency and time required for the factory planning project [4].

New digital technologies bring many benefits. In many fields such as geodesy, geoinformatics and factory planning, LiDAR sensors and image-based recording devices are now being used to create a digital representation of reality. These technologies can be used from the ground or in combination with drones (UAV) from a bird's eye view, creating new mapping techniques. The recordings can be used to measure

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changes in the surface of earth or water [5], [6], to perform cadastral mapping [7], or to analyse plant growth in fields [8]. In the context of factory planning, these recordings can be used to generate point clouds and 3D models that can be used both as a basis for measuring a factory building during the establishment of the project basis and as a basis for 3D layout planning with a high level of recognition as part of digital factory planning. On this basis, for example, existing transport routes or storage areas can be analysed and optimized [3]. The point clouds can also be used, for example, to plan the flight routes of drones or for augmented reality and virtual reality applications in the context of factory planning.

Despite the wide range of possible applications, there is currently no research comparing these digital techniques, such as LiDAR, photogrammetry or stereoscopy and drones or ground-based mapping and evaluating the results in the context of factory planning, so that a targeted and well-founded selection of a suitable technique to support the establishment of the project basis is possible. The aim of this article is therefore to fill this gap and to carry out a first qualitative comparison of these techniques and different application variants, such as drone or ground-based mapping, in the context of factory planning using a case study.

2. Test environment and introduction of techniques

In this section, the test environment is presented and the different technologies such as photogrammetry, LiDAR and stereo camera and movement types such as ground-based mapping and drone mapping are presented and briefly described. The hardware selection is also explained.

2.1 Test environment

A cutting area was selected as the test environment (Figure 1). This area contains processing machines such as a modern (partially) enclosed lathe, an older milling machine in a dark colour and various other factory objects such as cabinets and tables. The diversity of the factory objects and the colour design as well as the close arrangement in the layout are intended to highlight the advantages and disadvantages of the individual techniques.

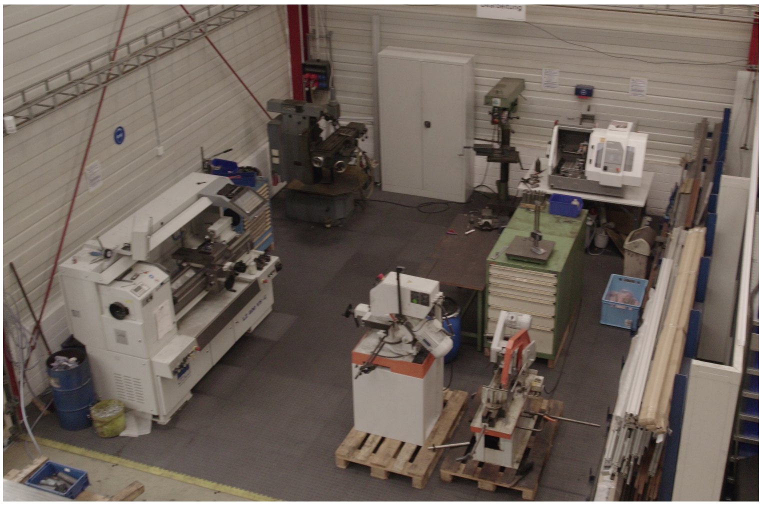


Figure 1: Photo of the test environment

2.2 Mapping techniques

2.2.1 Photogrammetry

In photogrammetry, the area to be mapped has to be recorded from as many different perspectives as possible by photo or video. In addition to the use of standardised camera settings, such as light sensitivity, the overlapping of the individual images is essential. This overlap enables an algorithm to calculate the exact position of the camera after the image has been taken without GPS data or measured values from the Inertial

Measurement Unit - IMU for short - and then reconstruct the mapped area in three dimensions. External influences such as the incidence of light, the colour contrast between individual factory objects and shading need to be taken into account when planning the recording route and thus selecting the overlap size and the variance of recording angles [9], [10].

A GoPro10 Hero Black action camera was selected to take pictures of the test environment. Due to its low weight of 156 grams, it can be mounted under an indoor drone without significantly restricting its ability to fly. Furthermore, there are various shots that can also be used with commercially available camera gimbals. Further criteria for selecting the GoPro10 HeroBlack is the very large field of view of 132° due to the fisheye effect, which enables efficient recording through the large imaging area. In the "series photo" operating mode, photos with up to 23 MP can be taken at defined intervals, while the "video" operating mode enables recording at 5.3K and 60 FPS. The action camera also offers various image stabilisation techniques such as HyperSmooth, which can improve the quality of the images [11]. By selecting the DJI Air2s drone, the camera of this drone was also included in the tests. Compared to the action camera, the camera permanently installed on the drone has a significantly smaller field of view of 88°. However, the photo and video quality is similar with 20 MP and 5.4K at 30 FPS. In particular, the distortion-free lens, in contrast to the action camera, also offers advantages by minimising software-related work steps such as rectification [12].

2.2.2 LiDAR mapping

Light Detection and Ranging, or LiDAR for short, is a technology for measuring distance using light, reflection and runtime. Due to the very precise scanning of the space to be imaged, LiDAR images can be used, for example, to precisely and reliably record crane cables, power lines or other objects with a small cross-section in the factory. Furthermore, it is possible to achieve a higher geometric accuracy compared to photogrammetry [13], [14], [15], [16]. When planning the recording routes for LiDAR recording, only the shading of the individual factory objects needs to be taken into account. The LiDAR sensor needs a direct line of sight to the object to be imaged for at least one scanning process. Compared to the use of photogrammetry, there are therefore fewer restrictions. In addition, the simultaneous use of slam algorithms such as Fast-Lio or Exwayz when using LiDAR techniques makes it possible to visualise the generated three-dimensional model ad hoc while the image is being captured. The algorithms estimate the position of the LiDAR scanner and calculate the three-dimensional model based on the scan and partly with the help of the IMU data. As with photogrammetry, the use of GPS data is therefore not necessary [17], [14].

The MID-360 by Livox with an integrated IMU was selected as the LiDAR scanner. Due to the low weight of only 265 grams and the dimensions of 65mm*65mm*60mm, operation on an indoor drone similar to the GoPro10 Hero Black action camera is possible without restrictions. In addition, the range of at least 40 metres and the 360° all-round field of view with 59° vertical height are well suited for recording in factories [18].

2.2.3 Stereo camera mapping

The stereo camera image can be used to create textured point clouds. Due to the limited suitability for creating geometric point clouds as a basis for factory planning, the images taken with the Intel RealSense Depth Camera D435i are shown in the appendix.

2.3 Movement types

2.3.1 Ground-based mapping

To achieve the different recording perspectives, the recording equipment must be moved through the factory layout. The simplest way is ground-based movement, where one person can carry the recording equipment through the areas to be recorded. In order to maintain a stable recording, a handheld gimbal was used in the tests to compensate for unwanted camera movements caused by footsteps, for example. As an alternative to human movement, camera trolleys or automated guided vehicles (AGVs) can also be used. When planning the ground-based movement, both the walking routes and the sensor movements were designed to ensure that each area was recorded from as many different perspectives and distances as possible.

2.3.2 Drone mapping

An alternative to ground-based mapping is the use of drones to map the factory layout. The advantages, such as the bird's eye view, which is often used in planning, and the possibility of flying over complex systems and machines, have already been described by MELCHER [9], [10].

Two different drones were used in the tests. The DJI Phantom 4 Pro is a drone weighing 1380 grams and measuring 247mm * 247mm * 195mm with a maximum flight time of 30 minutes [19]. This large drone was used to transport the action camera presented above. This was attached under the drone using a rigid mount. Due to the size and weight of the drone, the flight behaviour is more cumbersome compared to the other drone used in the tests, so that narrow areas cannot be approached safely, which basically leads to a minimisation of the different perspectives. The second drone used in the tests is the DJI Air 2S with a weight of 595g and a size of 183mm * 253mm * 77mm and also a maximum flight time of 30min [12]. Due to its smaller size, the drone is more manoeuvrable during flight manoeuvres, but the attachment of an additional camera significantly restricts the flight behaviour, which is why only the drone's built-in camera was used.

When planning the flight path, as with the ground-based mapping, attention was paid to considering as many different recording perspectives as possible, but with the possibility of flying up to heights of up to 5 metres. Especially when using the DJI Air 2S, the possibilities of low agile flying between the factory objects could be utilised.

3. Results

The point cloud results are presented in this section. In addition, information on the recording time and other data of the respective mapping technique is compared and described using tables.

3.1 Comparison LiDAR Phantom 4 vs. LiDAR ground-based

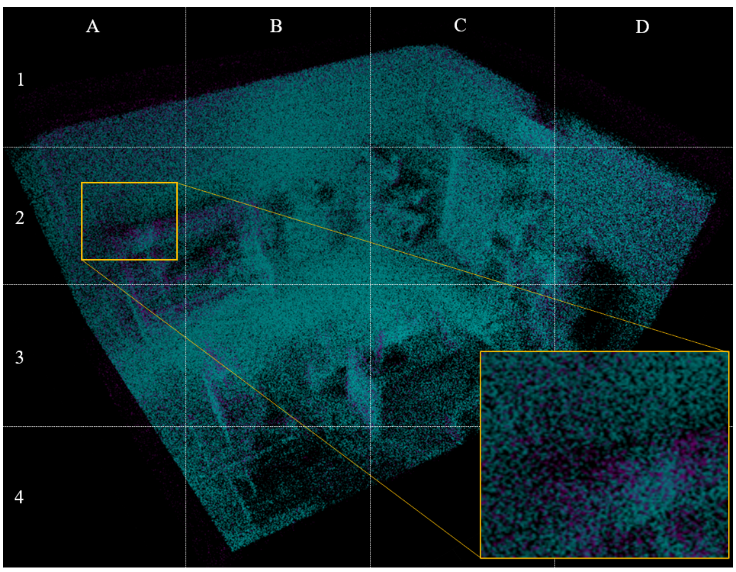


Table 1: Data LiDAR

LiDAR	Point cloud **Phantom 4**	Point cloud **ground-based**
Recording time	93 Sec	68 Sec
Number of scans	806	637
File size	13,76 MB	6,5 MB
Texture	No	No

Figure 2: Comparison of point clouds by LiDAR (drone cyan colour, ground-based pink colour)

Figure 2 shows the LiDAR point clouds of the drone and ground-based recordings in a common coordinate system for comparison. As both point clouds have no texture, the LiDAR point cloud of the drone is visualised in cyan and the ground-based LiDAR point cloud in pink. Due to the small deviations of the individual points between the two point clouds, only very small proportions of pink points can be observed. If the points are overlapped, the colour cyan is displayed. For a more precise visualisation of the deviations, part of area A2 in the bottom right-hand corner of the image has been enlarged. Due to the very small deviations and the resulting small differences, only the LiDAR point cloud of the drone is used as a reference for comparisons with the photogrammetry results in the further course of the tests.

3.2 Comparison LiDAR Phantom 4 vs. Photogrammetry

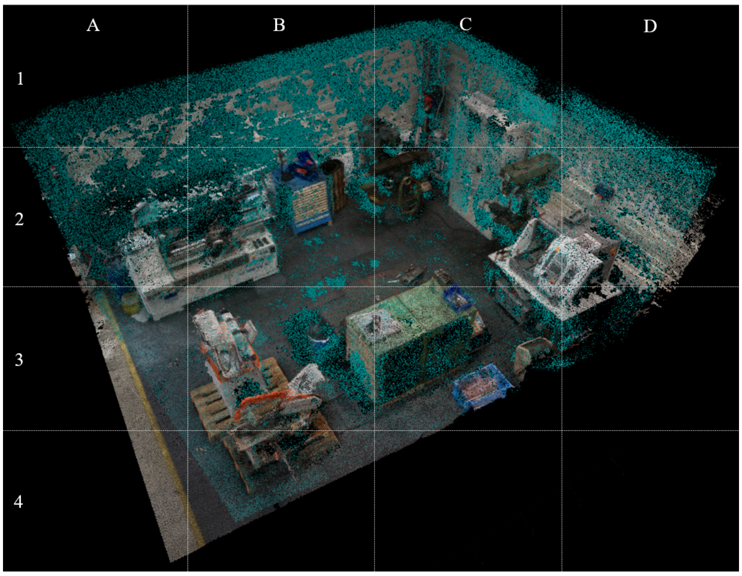


Table 2: Data Phantom 4

Photogrammetry	Point cloud **Phantom 4**
Recording time	206 Sec
Number of photos	142
Resolution	5568 x 4176
Tie points	78020
Alignment accuracy	Medium
File size	481 MB
Texture	Yes

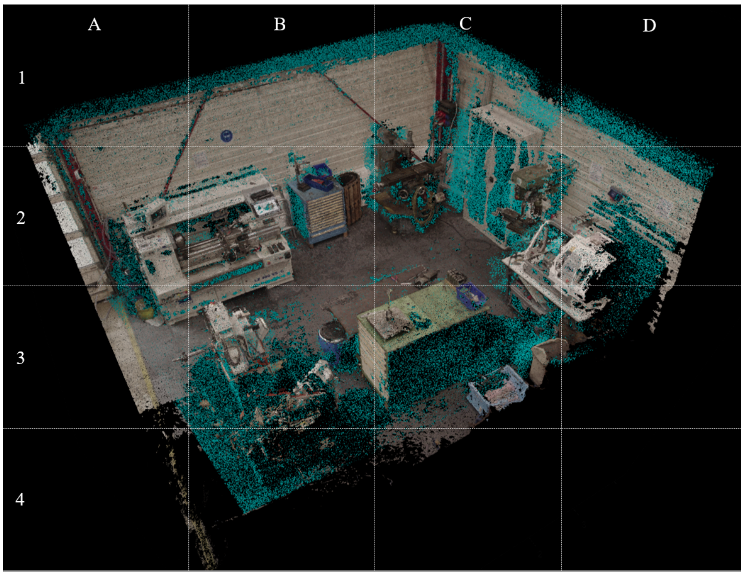
Figure 3: Comparison of point clouds (Phantom 4 with action camera textured, LiDAR Phantom 4 cyan colour)

Figure 3 shows the comparison between the LiDAR point cloud of the Phantom 4 drone and the point cloud created using the action camera and the Phantom 4 drone, with the textured areas resulting from the point cloud of the action camera. If the cyan-coloured dots show through, this indicates holes in the point cloud under comparison. Noticeable in the photogrammetrically created point cloud is the precise representation of the factory objects in areas B3, B4 and C4, which could be recorded from many different perspectives, as well as the weaknesses in the representation of flat, low-contrast surfaces such as the outer wall in areas A1, A2 and B1 and the front cabinet surface in C1 and C2. Furthermore, the area behind the lathe in A2 and B2 is covered with few dots. The reasons for this may be the lack of brightness and the long distance during recording due to the drone's lack of manoeuvrability.

3.3 Comparison LiDAR Phantom 4 vs. Air2 camera

The point cloud compared with the LiDAR point cloud in Figure 4 results from the images taken with the DJI Air 2S drone's built-in camera. In contrast to the point cloud shown in Figure 3, the area behind the lathe could be visualised well in this point cloud. Overall, there are few areas that could not be represented by points. Noticeable, however, are the areas in D2 and C3, which are located behind factory objects and are therefore contained in few images and are only partially represented. In addition, the ground-level surroundings in areas B3 and B4 are only partially mapped.

Table 3: Data Photogrammetry Air2s

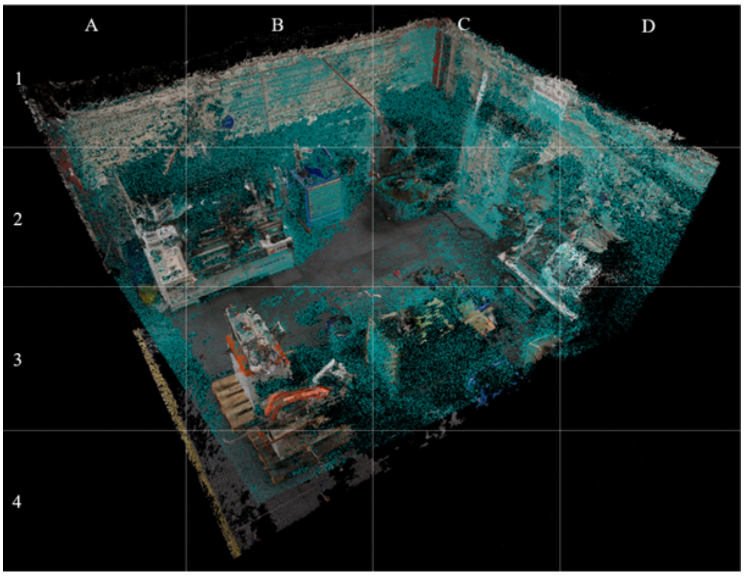


Photogrammetry	Point cloud **Air2s**
Recording time	91 Sec
Number of photos	106
Resolution	3840 x 2160
Tie points	55623
Alignment accuracy	Medium
File size	1044 MB
Texture	Yes

Figure 4: Comparison of point clouds (drone with Air2s camera textured, LiDAR drone cyan colour)

3.4 Comparison LiDAR Phantom 4 vs. ground-based action camera

Table 4: Data Photogrammetry ground-based



Photogrammetry	Point cloud **ground-based**
Recording time	68 Sec
Number of photos	77
Resolution	5568 x 4176
Tie points	34713
Alignment accuracy	Medium
File size	241 MB
Texture	Yes

Figure 5: Comparison of point clouds (ground-based with action camera textured, LiDAR drone cyan colour)

The point cloud shown in Figure 5 together with the cyan-coloured LiDAR point cloud was created using the handheld gimbal and the action camera. The areas behind the factory objects, such as in A2, B2, D4 and C3, which are barely covered with points, are noticeable in this point cloud. Due to the ground-based mapping, it is not possible to create usable images of these areas for photogrammetry, as they are hidden by factory objects. In area B2, the straight line clearly shows the effect of shadowing; in this case, the lathe has hidden the area. Overall, this point cloud has the most gaps.

3.5 Mesh models from photogrammetry

Figure 6: Mesh from action camera attached Phantom 4

Figure 7: Mesh from Air2s camera

Figure 8: Mesh from ground-based action camera

Table 5: Data Mesh

Photogrammetry	Mesh Phantom 4	Mesh Air2s	Mesh Gimbal
Model surfaces	787059	943402	1791930
File size	93 MB	112 MB	214 MB
Texture	Yes	Yes	Yes

Once the photogrammetric point cloud has been created, it is possible to create a polygonal mesh. This mesh enables the further processing step of texture creation. With the help of this texture, it is possible to increase the recognition value of the three-dimensional models (see Figure 6-10) and at the same time minimise the file size (see Table 5) by using the mesh structure.

4. Comparison and conclusion

Table 6: Assessment of the comparison parameters

	LiDAR (ground-based/drone)	Photogrammetry (ground-based)	Photogrammetry (Phantom 4)	Photogrammetry (Air2 S)	Stereoscopy (ground-based)
Completeness	●	◑	◑	◕	◔
Recording time	●	◕	●	●	○
Recognisability	◔	◕	◕	●	◑
Technical applicability	◕	◕	◕	◕	◑
Geometric tolerance	●	◑	◑	◕	◔
● Good / high			○ Bad / low		

In this paper, three techniques for generating point clouds respectively meshes were presented. In this section, they are compared using the case study. The recorded point clouds or generated meshes are intended to be used in the context of factory planning as a geometric basis for layout creation and planning and to support the establishment of the project basis. To assess the suitability of the methods for this purpose, the following aspects are compared: Completeness of the recording results, recording time and effort, recognition potential, technical applicability and geometric tolerance. The assessments of the methods with regard to these comparison parameters are presented in tabular form (Table 6).

Completeness is the most important criterion for geometric layout planning, because incomplete recordings with missing factory objects, for example, carry the risk that the factory planned on the basis of the factory layout cannot be realised, resulting in expensive adjustment costs after the planning phase. In addition, the factory layout may have to be re-measured manually, increasing the effort and cost. Furthermore, the techniques used to determine the basic layout in factory buildings should require a short recording time so that the recordings can be made during production breaks. The recognisability of the factory layout plays a central role, especially when involving people who are not involved in the planning process. The potential for recognition can be increased by integrating colours and textures. Technical applicability refers to the form of the results. The mapping techniques must ensure that data formats are generated that allow further use, e.g. in CAD software. The geometric tolerance describes the tolerable dimensional deviation of the generated model compared to the real image and depends on the application.

Considering the assessment of the techniques (Table 6) and a weighting of the comparison parameters adapted to the use case (e.g. high weighting of completeness in geometric layout planning or high weighting of recognisability for 3D planning), the techniques can be evaluated with regard to their suitability for use in the context of the establishment of the project basis of factory planning. As explained in the appendix, stereoscopy is poorly suited for the establishment of the project basis, in particular due to the high time requirement and the comparatively incomplete results.

LiDAR technology either with a drone or ground-based is characterised by a very complete and accurate result that can be generated with little effort. This makes this technique particularly suitable for recording geometric data. In contrast to photogrammetry-based techniques, the results of the LiDAR-based techniques have a low recognition potential as the point clouds do not contain any colour information. Although less completeness and geometric accuracy can be achieved with photogrammetry, the results are similarly suitable for factory planning due to the short recording time and good technical applicability. Above all, however, the recognition of the photogrammetry results is significantly higher, as the mesh generation produces a realistic 3D model that can be used in 3D layout planning. The comparison within the photogrammetric techniques shows that the Air2s drone with integrated camera achieves better results in terms of completeness and accuracy than the Phantom 4 drone with action camera and, in particular, than the ground-based mapping with action camera. The decisive factor for this advantage is the better accessibility and easier navigation in the test environment, which allows images to be captured from different perspectives that cannot be achieved by the other two variants.

Despite these limitations, this study presents the main differences between the recording techniques for creating a geometric data basis for factory planning and shows that LiDAR techniques are particularly suitable for collecting geometric data and photogrammetric techniques for creating realistic, recognisable 3D models.

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5. Appendix

5.1 Stereo camera recording

Another option for recording three-dimensional objects is using stereo cameras. The technique of stereoscopy is used here, i.e. two lenses attached to the camera each record a (partial) image synchronously. These can then be combined to form a stereoscopic image [20]. The Intel RealSense Depth Camera D435i was used for the tests. With a weight of 200 grams and dimensions of 90mm * 25mm * 25mm, this stereo camera can be mounted both on a gimbal and under a drone [21]. However, during the first tests with this technology, the result was negatively influenced by the very short range of 0.3m to 3m and the small field of view of 87° * 58°. The actual field of view of the stereo camera is shown in Figure 9 in the form of green cubes. Data was only recorded and, if necessary, updated in this area. Several attempts were required to create the depicted area due to the loss of orientation and the associated errors such as overlaps in the 3D model. The final recording attempt took 87 seconds, required great manual ability and still only mapped a very small production area. Due to the short range and sometimes abrupt flight maneuvers, using the technology on an indoor drone is not possible or does not lead to a usable result. This technology was therefore no longer used in the following test.

Figure 9: Recording with stereo camera (Real Sense D435i)

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