Abstract—Light Detection and Ranging (LIDAR) has been used for years with a variety of applications, including the efficient creation of digital terrain models (DTMs) for large-scale, high-accuracy mapping. LIDAR technology offers fast, real-time collection of 3-D points so that allows the production of higher-accuracy orthophotos than traditional stereo-compilation methods. The technology is moving quickly toward offering more efficient collection techniques for applications such as city modelling and true orthophoto production. Traditional orthophoto production suffers from the fact that buildings (and any other objects above ground) are not correctly placed in the orthophoto. True orthophoto production overcomes these deficiencies by taking the digital surface model (DSM) into account. However, the resulting true orthophotos still suffer from occluded areas and unsharp edges of buildings and roads. The experimental investigations with different data sets show that it is essential to use high quality DSMs to produce high quality true orthophotos.

In this paper, aspects of the improvement of true orthophoto production will be discussed: (a) in the first approach which has been widely used in photogrammetry, the DSM is used for generating true orthophotos and (b) in comparison to the DSM based method, semi-automatically collected vector data of buildings are superimposed on DTM and are used as input data for generating true orthophotos in the second method. The processes and problems of both true orthophoto production procedures will be investigated in detail and results include the comparison of true orthophoto productions based on DSM (from LIDAR data) and DTM plus vector data. For the experimental investigation, a LIDAR data set for downtown Stuttgart is used.

Keywords-component; LIDAR; Orthophoto; True Orthophoto; DTM; DSM

I. INTRODUCTION

Nowadays, LIDAR systems are rapidly becoming a popular technology in Photogrammetry and Remote Sensing society due to capability for direct acquisition of three – dimensional (3D) dense information along the homogenous surface. Due to its advantages as an active technique for reliable 3D determination, LIDAR has become a rather important information source for generating high quality 3D digital surface models [1]. Up to now, acquisition of 3D information over the surface has been done by conventional photogrammetric methods rather complicatedly, but the achievable quality of DSM via conventional stereo-compilation is sometimes not meet required accuracy in the case of 3D object modelling and true orthophoto production. Recent advance in LIDAR systems make use of efficient DSMs for the variety of studies such as feature extraction, 3D object modelling and true orthophoto generation. Different approaches have been presented several times for the 3D building extraction and true photo generation based on DSM as automatically or semi automatically [2], [3], [4]. However, all methods are principally based on height information and the digital orthoimage is only as accurate as the surface model provided [5]. Photogrammetry is a current method for GIS data acquisition, but especially data acquisition for detailed modelling of objects in urban areas by photogrammetric methods is a very complex, sensitive and time-consuming task[5], [6]. On the other hand, LIDAR also provides useful approximations for urban features and buildings in urban areas [1]. It is an advantageous to integrate LIDAR data and digital images for generating the city model [6]. In this regard, true orthophoto production is becoming important issue for the needs of realistic 3D representation of the surface, including the accurate DSM, especially for the 3D building and city modeling applications.

In this paper, we deal with automatic and semi automatic true orthophoto production by using LIDAR data (from last pulse reflection) and digital aerial images for the 3D model generation purposes. Recent experimental investigations have shown that modelling DSMs efficiently take a vital part for producing high accuracy true orthophoto. The objective of this research is to improve the quality of true orthophoto imagery, essentially based on investigation of efficient DSM creation. In the following sections, LIDAR systems and Orthophoto production are shortly explained. Chapter 2 describe proposed algorithm of the investigation. Comparisons of the achieved results are mentioned in the Chapter 3 and ended by conclusions.

A. LIDAR System

LIDAR, also referred to as Airborne Laser Scanning (ALS) is an active remote sensing technique similar to the RADAR, but LIDAR sensors operate at short wavelengths instead of
radio waves. Laser transmitters are used that fire thousands of pulses per second. By scanning the laser pulses across the terrain using a rotating mirror, a dense set of distances to the surface is measured along a narrow corridor. Early versions of laser altimeters measured the distance to the first feature reflecting the laser pulse. In areas of dense vegetation that is usually the top of the vegetation canopy [7]. The most important feature of recent airborne LIDAR systems is its ability to discriminate first and last pulse reflections. A laser pulse that is fired over vegetation usually has multiple reflections. Some particles of the laser pulse may be reflected by leaves or branches of trees often represented in the first returning pulse (see Fig. 1a). Others may be reflected by the ground and the last returning pulse is most likely to be reflected by the terrain surface beneath trees (see Fig. 1b) [8]. 3D information over the Earth’s surface is captured by integration of the ALS system with a Global Positioning System (GPS) and an Inertial Navigation System (INS). LIDAR can provide very precise horizontal and vertical information with nominal accuracy of ±30 cm in the vertical plane and, depending on altitude and ground slope conditions, the same also in the horizontal plane [9]. Recent development in the positioning and navigation technology allowed higher levels of accuracy to be attained from LIDAR scanners leading to more accurate and realistic capture of physical surfaces. The integration of imaging and LIDAR datasets will lead to the acquisition of high resolution datasets over urban areas with a higher level of detail [4].

This distortion shows up in the form of leaning buildings and warped bridges [10]. As for true orthophoto, it overcomes such deficiencies by taking the DSM into account instead of DTM during the rectification process. However, the occluded areas show up as the man made structures are corrected into true position. The main task for removing this effect is to run the visibility test during the rectification process so that occluded areas are located. According to the visibility test result, all occluded areas are filled with data from adjacent images where the areas are visible (Fig. 2). If no analysis of the visibility of the terrain close to buildings is carried out, this results in the effect of double mapped objects, so called ghost images [5]. Overall processes, the achievable true orthophoto lead to reliable and realistic representation of Earth’s surface since all the objects on the DSM are repositioned correctly and occluded areas are filled with the real image information.

II. PROPOSED ALGORITHM

A. Automatic Approach for the True Orthophoto Production

As mentioned previous chapter, even though the orthophoto imagery eliminates the relief displacement effects on the terrain, man made objects like buildings still leaning away from the image centre (nadir point) due to the terrain does not include the buildings any other objects above the ground. In this approach, to overcome these deficiencies automatically, we take the advantages of LIDAR data, which includes dense reliable 3D information of buildings, to create efficient DSM for the needs of true orthophoto production. On the other hand, both first pulse and last pulse contain sufficient 3D information for the DSM generation, the difference between them is known as the presence of trees. In this case, DSM is created from the last pulse measurement due to elimination of vegetations (see also Fig. 1b in previous chapter). For the true orthophoto production, the first task is to run rectification process based on reprojection by taking the DSM with (RGB) digital aerial images into account. During the rectification process, building outlines correctly match with digital buildings model which are included in DSM so
that man made structures like buildings are correctly placed in the resulting true orthophoto imagery. Although the man made objects are correctly placed, rectification process causes other shortcoming so-called occluded areas. As the buildings are rectified into the true locations, the occluded areas are occurred on where the buildings were leaning. Therefore, during the rectification process, we check the visibility at the same time. The rectification processes and visibility test run simultaneously so that all occluded areas are marked with a specified colour. The second task is to run mosaic process, so all parts of the occluded areas, which are visible in one of the orthophotos, are filled with real image information based on the results of the visibility test. The main steps for the automatic true orthophoto production are summarized by the following workflow (Figure 3):

Hence, DTM plus semi-automatically collected vector data are taken into account with the digital aerial images in order to generate true orthophoto. The main steps for the semi automatic true orthophoto production are summarized by the following workflow (Figure 4):

**B. Semi Automatic Approach for the True Orthophoto Production**

According to first approach, true orthophoto imagery is generated by using the integration of DSM with the digital aerial images. Even though achievable true orthophoto overcomes the deficiencies of orthophotos concerning the relief effects of buildings, in the resulting true orthophoto roof borders and roof ridges of buildings are not represented in the realistic shape. All sort of man made structure’s outlines such as building, roads and bridges are incorrectly modelled. Almost all of them suffer from the fact that unsharp edges on the borders, especially on the ridges and edges of the roof. The experimental investigations with different data sets show that it is essential to use high quality DSMs to overcome such shortcomings.

In this semi automatic approach, for creating DSM not only utilize from LIDAR data but also digitized roof borders and ridges are used. Firstly, DTM is derived from the LIDAR data instead of DSM so that any objects above the ground are removed. Next step, borders of the roof and ridge are delineated in photogrammetric stereo workstation and superimposed on the DTM for the purpose of DSM creation.

Figure 3. Workflow for the automatic true orthophoto production.

**III. EXPERIMENTAL INVESTIGATION**

For the experimental investigation a LIDAR test data and RGB digital images covers the downtown area of Stuttgart, which is located the west of Germany, were used. The test data sets have been provided by TopScan Company, in Germany. LIDAR test data has been recorded as the first pulse and the last pulse by ALTM 2050 Laser scanner with a density of 4.8 per m² on the average. RGB digital images have been taken simultaneously by using the Rollei AIC-modular-LS digital metric camera with a 20cm ground resolution.

For the aspect of automatic true orthophoto production, the DSM (from last pulse measurement) and digital aerial images have taken into account. The resulting true orthophotos are shown with the traditional orthophoto to point out the relief displacement effect, especially for the tall buildings (see Fig. 5). Fig. 5a shows that the effect of relief displacement for the building in the orthophoto imagery based on the DTM. The next Fig 5b shows that the ghost effect is caused by running the rectification process without testing visibility. The other Fig. 5c shows that the result of the rectification process and the visibility test in which DSM was taken into account. All the buildings were repositioned correctly and occluded areas were marked. The last figure 5d show that the resulting true orthophoto in which all occluded areas were filled with the corresponding real image information from the adjacent orthophotos during the mosaic process. On the other hand, in the resulting true orthophoto also shows that borders of the building are not represented in realistic shape even the buildings are correctly repositioned.
The resulting true orthophotos based on second approach shows that not only buildings are correctly placed into true locations but also overcomes the unsharp borders on the edge of buildings (see fig. 6b). Fig 6a shows that the previous true orthophoto based on the first approach and fig. 6b shows that the resulting true orthophoto based on second approach so that two approaches may be observed comparatively. It is clearly seen that roof edges and roof ridges are sharply represented in the resulting true orthophoto based on second approach (see fig. 6b). As shown fig 6a, there are some distortions on the edges of the roof, particularly on the nested roof. Because, nested roof of buildings are made of glass so that the laser beams are not reflected properly from that part of building. This effect causes blunders in DSM and resulting true orthophoto as well (see fig. 6a).

IV. CONCLUSION

Two methods, automatically and semi automatically true orthophoto production were investigated in this comparative study. DSM was modeled in two different ways for the purpose of improving true orthophoto quality.

The automatic method is a fast and efficient method for the generation of true orthophoto based on DSM (only from LIDAR data). The achievable result gives an approximation about building features in correct position, but not realistic representation. This effect probably comes from some blunders and gaps in LIDAR data set. Because laser beams might be scattered or not reflected from the target like glass structures, so positions are sometimes obtained wrongly. This may causes such deficiencies in the resulting true orthophoto considering the large urban areas. On the other hand, DTM plus delineated borders of buildings were used as DSM to make use of accurate digital building models for the true orthophoto production in the semi automatic method. In this resulting true orthophoto, realistic representations of buildings were achieved by using mixed data for the creation of DSM.

As a result, this experimental investigation shows that derived DSM only from LIDAR data is sometimes not sufficient for the production of true orthophoto imagery in the urban areas. Accuracy of true orthophoto is strongly dependent to accuracy of DSM. Therefore, DSM might be modeled not only from LIDAR data, but also blended with building outlines for the generation of high quality true orthophoto purposes.

ACKNOWLEDGMENT (Heading 5)

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression, “One of us (R. B. G.) thanks . . .” Instead, try “R. B. G. thanks”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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