LASER SCANNING AND ITS POTENTIAL TO SUPPORT 3D PANORAMIC RECORDING

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ABSTRACT:

Today very fast terrestrial laser scanners are available which can be very well combined with panoramic cameras to make 3D-panoramic recording possible. Due to the very precise depth information of the laser scanner and the high resolved color information provided by the CCD sensor of the panoramic camera 3D-panoramic images of high quality can be obtained. In order to assess the performance of such integrated systems, this presentation gives a short introduction in the ranging principles applied in terrestrial laser scanning. Commercially available terrestrial laser scanners using the measurement principles applicable for panoramic mapping will be presented. Their technical parameters will be discussed with regard to range, angular and depth resolution. Also the problem of moving panoramic mapping will be addressed.

1. INTRODUCTION

In recent years very fast and precise terrestrial laser scanners with ranging capabilities of up to more than 100 m (Fröhlich, 2004) have been developed. These devices offer very precise depth information with high point densities and sampling rates of up to 600 kHz, however deliver in many cases poor intensity images compared with cameras. Some laser scanners obtain an intensity image by detecting the intensity of the backscattered laser light (Fröhlich 2004, Wehr 1999). This results in monochromatic images. If color information is required additional sensors or CCD cameras must be implemented. Besides CCD array sensors possible optical sensors for color images are panoramic cameras. Panoramic cameras are realized by turning azimuthally a vertical CCD-line with accessory optic. Panoramic laser scanners scan their surroundings with a vertical line scan and turn the sensor head like the panoramic camera. As both systems feature identical surveying geometries the combination of laser scanners with panoramic cameras is a logical consequence.

This presentation gives a short introduction in the ranging principles applied in terrestrial laser scanning. Commercially available terrestrial laser scanners using the measurement principles applicable for panoramic mapping will be presented and their technical parameters will be discussed with regard to range, angular and depth resolution. Also the problem of moving panoramic mapping will be addressed.

2. RANGING PRINCIPLES

In terrestrial laser scanning ranging is carried out either by triangulation or by measuring the time of flight of the laser signal. The triangulation measurement principle is applied for laser scanners with low depth dynamic. In close range applications of e.g. up to 5 m accuracy better than 1 mm are possible. Such scanners are produced by Mensi and Minolta. Due to the very limited range performance and ranging dynamic they are not well suited for panoramic mapping and will not be regarded in the following.

Higher range dynamic can be achieved by radar measurement principles. Ranging by radar means is basically a time-of-flight measurement. As lasers produce short pulses with very high peak power pulse laser ranging is commonly used. Here the travelling time of the laser pulse is measured. Another possibility to determine the travelling time of a signal is realized by measuring the phase difference between the transmitted and received signal. Both methods are going to be explained and their performance will be discussed in the following.

2.1 Pulse Ranging

Carrying out ranging by measuring the travelling time of a short laser pulse from the laser aperture to the target surface and back

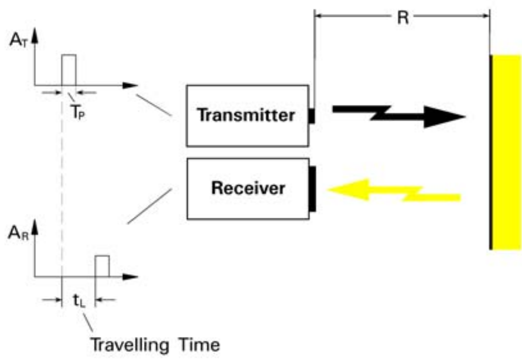


Figure 1. Pulse ranging

to the receiver (two way ranging) is the typical laser ranging method. It makes optimum use of the laser transmitter which has the capability to generate very short pulses with very high peak power levels with high repetition rates. The pulse length T_P determines the ranging resolution ΔR and the ranging accuracy σ_R (s. Figure 1). The range resolution ΔR tells how far apart two targets have to be, so that they can be resolved as two targets. The power loss of the received signal determines the maximum possible range. Range resolution ΔR and accuracy σ_R are calculated by

$$\Delta R = \frac{c}{2} \cdot T_P \quad (1)$$

$$\sigma_R = \frac{c}{2} \cdot \frac{T_P}{\sqrt{SNR}} \quad (2)$$

where c is the speed of light and SNR is the signal-to-noise ratio. The resolution of the range measurement Δs is determined by the resolution of the time interval counter Δt_L:

$$\Delta s = \frac{c}{2} \cdot \Delta t_L \quad (3)$$

Δs is generally lower than ΔR and may not be mixed up with it.

2.2 CW-Ranging by Measuring the Phase Difference

In continuous wave (cw) laser ranging the laser intensity is modulated with a well defined function, e.g. a sinusoidal or a square wave signal. The modulation signal is repeated continuously with period time T_{Pd}. The laser emits light continuously with moderate average power levels and therefore is called cw-laser. The time of flight of the signal T_L is determined by measuring the phase difference between the transmitted and received signal. The period time T_{Pd} or its equivalents the frequency f or wavelength λ defines the

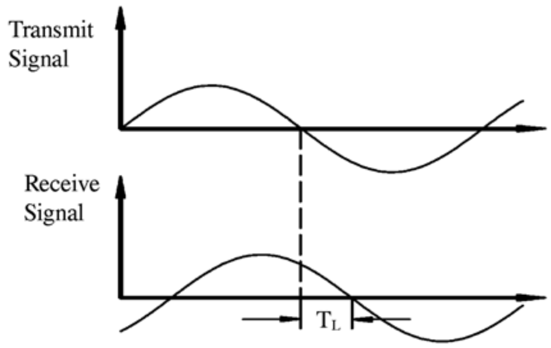


Figure 2. Phase difference

maximum unambiguous range R_{un}, which is $\lambda/2$ for two-way ranging, and the range resolution Δs. For a given phase resolution $\Delta\theta$, the range resolution Δs is calculated by

$$\Delta s = \frac{\lambda}{2} \cdot \Delta\theta \quad (4)$$

Formula 4 shows, that the range resolution can be easily improved by using signals with shorter wavelengths if the phase resolution is kept constant. However, shorter wavelengths mean reduced maximum unambiguous ranges. Therefore, satisfying ranging capabilities with high range resolution are only possible if several modulation signals with different frequencies are applied. Such method is also known as multi-tone-ranging or multi-frequency-ranging. Here the highest frequency determines the resolution and the achievable accuracy and the lowest frequency the unambiguous range. The accuracy σ_R is determined by

$$\sigma_R = \frac{\lambda}{4\pi} \cdot \frac{1}{\sqrt{SNR}} \quad (5)$$

This method can be easily realised with semiconductor laser diodes, because here the intensity of the light can be directly modulated by the drive current. Due to the high electrical bandwidth of the laser diodes high frequencies up to more than 10 GHz are possible. However, the available cw-power is very limited. Therefore, the ranging method of measuring the phase difference is primarily applied in near range scanning systems.

In contrast to pulse laser systems single targets within the laser beam cannot be resolved. Therefore, ΔR is not defined. The receiver detects only the resultant phase of all returns. As the modulation signals are recovered by synchronous demodulation techniques, the intensity of the backscattered laser light can be detected without disturbing background radiation. This means that these systems are very robust against high background radiation, e.g. sun light and external illumination.

3. SCANNING PRINCIPLES

In order to obtain 3D-information of the surface of an object the laser beam and the receiving optical path have to be moved across the surface by a certain scanning pattern. Knowing for each sample the slant range and the instantaneous direction of the laser beam the 3D-coordinates can be computed. Accordingly to Figure 3 the instantaneous field of view (IFOV) is determined by the divergence of the laser beam and the field of view (FOV) defines the sampled area. For scanning the IFOV various opto-mechanical deflection systems can be applied. They are selected in dependence of the application. Typical scanner drives are stepping motors, brushless dc motors and linear drives mostly in the form of galvanometer scanners. Table 1 presents a compilation of scanners applied in terrestrial laser scanning.

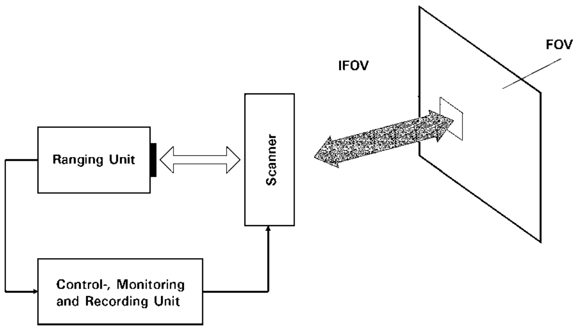


Figure 3. Main components of laser scanners

For imaging systems two galvanometer scanners are arranged orthogonally to each other. But also a combination of a polygonal scanner and a galvanometer are possible. Here the polygonal mirror carries out the fast scan. For hemispherical coverage a fast vertical line scan in combination with an azimuth rotation of the total opto-mechanical head is applied. The fast vertical line can be realized with e.g. galvanometer scanners, polygon scanners or a shaft scanner. The azimuth rotation requires powerful drives with very precise bearings. Either steppers or motors with gears can be applied. Using analogue motors an angular encoder is required.

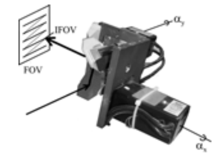
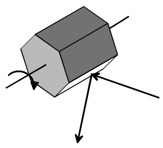
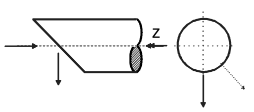
Principle	Name
	**Galvanometer Scanner** Scanning speed dependent on mirror inertia. Max. scanning rate: 5 kHz, max. FOV ±45 deg Application: Imaging laser scanner
	**Polygonal Scanner** Typical drive for fast line scans. If one rotation direction is possible very fast scans can be obtained. Speed up to 40000 rpm
	**Shaft Scanner** Typical drive for profile scanners. Very fast scans possible. Often applied for hemispherical scanning. Speed up to 40000 rpm

Table 1. Different scanning devices

Which scanning mechanism is optimum, is very dependent on the application, the size of the optics and required FOV. The goal for every scanning device is to be as fast as possible. The scanning speed is determined by the inertia of the device to be moved. This means e.g. the optics should be as small as possible. However, small optics mean a reduction in received energy and by that a reduction in range. This discussion makes clear that the design of scanners is a result of an engineering trade-off. One can conclude generally, if an oscillating movement of the sampling beam is not required either polygonal scanner or shaft scanner are an optimum choice.

4. PANORAMIC CAMERAS

Before laser scanners are selected which are suitable for panoramic mapping, a closer look to panoramic cameras has to be taken. Searching the commercial market for digital panoramic cameras makes clear that the number of available systems is very limited. The panoramic cameras can be grouped in:

1. cameras, where the camera body is turned in azimuth and
2. fixed mounted cameras, which use either special refracting or reflecting optics, which allow a hemispherical coverage.

Figure 4. CCD-line panoramic camera

For the first panoramic recording principle either CCD arrays or CCD line sensors are applied. If very high resolved panoramic images are required a CCD line containing e.g. 10000 pixels is used (s. Figure 4), which is mounted on a turntable parallel to the rotation direction with a resolution of about 65000 pixels. Moving the turntable generates the second image direction. According to Figure 5 the surveyed points are imaged on a cylinder. The radius of the cylinder is given by the focal length of the optic. Manufacturers of panoramic cameras using this principle are KST Dresden and JointMetriX. The typical technical data of the EYESCAN panoramic camera are compiled in Table 2.

Number of Pixel	3*10200 (RGB)
Radiometric dynamic/resolution	14 bit / 8 bit per channel
Shutter speed	4ms up to infinite
Data rate	15 Mbytes / s
Data volume 360° (optics f=60mm)	3Gbytes
Acquisition time	4 min
Power supply	12 V

Table 2. Technical parameter of the digital panoramic camera

As shown in Figure 4 the sensor system consists of the camera head, the optical and the high precision turntable with DC-gear-system motor. The objective can be changed in accordance to the application. The camera head is mounted on a tilt unit for vertical tilts of ±30° with 15° stops. Axis of tilt and rotation are

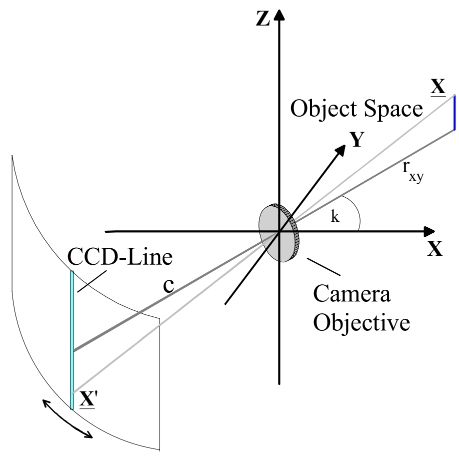


Figure 5. Sampling geometry of CCD-line panoramic camera

in the needlepoint. The cameras of the second group are realized with state-of-the-art CCD-arrays with 1280 x 1024 pixels. The hemispherical view is achieved either by an extreme wide angle optic (s. Figure 6, left) or with a special mirror in front of a standard optic (s. Figure 6, right). The extreme wide angle optic is used by Sony. The advantages of these cameras are, that no moving parts are used but the poor resolution is disadvantageous and the optics may exhibit aberrations.

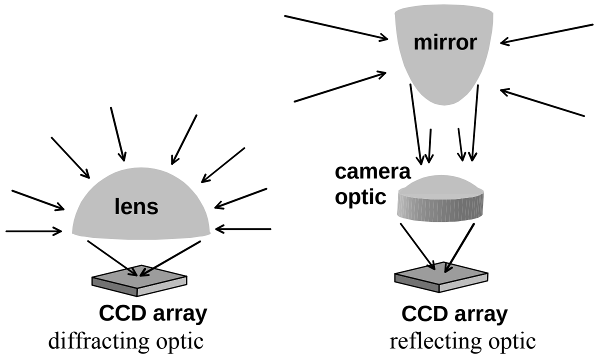


Figure 6. Panoramic camera with CCD-array

5. LASER SCANNERS FOR PANORAMIC MAPPING

Up to date only panoramic cameras which have CCD-line sensors are used if they are applied for surveying, This kind of camera has got the required accuracy for this purpose and the measurement results can be processed by photogrammetric evaluation means. As these cameras image a vertical line at the object and this line is rotated in azimuth, it is obvious to use laser scanners having the same sampling geometry, if laser scanners and panoramic cameras should be used in combination to achieve 3D panoramic recording. Therefore, in the following only this kind of lasers will be regarded.

In accordance to Table 1, fast vertical scans can be realized with e.g. polygonal mirrors or the rotating shaft. The second dimension is realized by a rotation of the whole opto-mechanical head. Possible commercial laser scanners are:
iQsun 3D Laserscanners of iQvolution, Imager 5003 of Zoller & Fröhlich, the HDS series of Leica and the LSM series of Riegl.

In the following it will be studied, how the performance of 3D laser scanners may support high definition image recording to obtain 3D-panoramic surveys.

5.1 FOV and Resolution

In this chapter the FOV, the resolution in the object space and the surveying time will be compared. Most available scanners cover ranges of 20 m or 50 m respectively. This satisfies the needs for many indoor measurements and even for some outdoor surveys. Up to now only laser scanners using the pulse measurement technique reach ranges of up to several hundred meters (s. Table 3, part 1). In Table1 the relevant data for the evaluation are compiled. Here R_{max} is the maximum range and f_{samp} is the sampling rate for one pixel. The standard deviation of the measured slant range σ is related to 25 m. The angular resolution of the scanners is separated in azimuth (horiz.) and vertical (vert.) direction. Leica does not show angular resolutions in their data sheets. It is obvious that the scanners of the Riegl company perform vertical scan with a field of only 90 deg or 80 deg respectively. The reason for this is that a scanning drive with a polygonal mirror is used. The table makes clear that the laser scanners of the companies Zoller&Fröhlich, iQsun and Leica show the best accuracy. However, they are limited in range, because all work by the measurement principle of measuring the phase difference. In the Riegl systems pulsed units are implemented. To make a comparison easier the slant range accuracy is related to 25 m for all scanners.

Laser Scanner	**FOV** [deg] vert.	horiz.	$\mathbf{R_{max}}$ [m]	$\mathbf{f_{samp}}$ [kHz]	$\boldsymbol{\sigma_{25m}}$ [mm]
Zoller&Fröhlich					
LARA25200	310	360	25.2	625	4,5
LARA53500	310	360	53.5	500	9
iQsun 880HF40					
	320	360	40	120	3
	320	360	80	120	3
Leica					
HDS 4500	310	360	25	500	7
	310	360	53.5	500	11
Riegl					
LMS-Z360i	90	360	60	12	12
LMS-Z420i	90	360	250	12	10
LMS-Z210i	80	360	120	12	25

Table 3. Performance of typical laser scanners (part 1)

Laser Scanner	**Δφ** [deg] vert.	horiz.	**Δs** [mm] vert.	horiz	
Z&F					
LARA25200	0.018	0.018	8	8	@25 m
LARA53500	0.018	0.01	16	9	@50 m
iQsun					
880HF40	0.01	0.0008	4	0.35	@25 m
	0.01	0.0008	9	0.7	@50 m
Leica					
HDS 4500	---	---	---	---	@25 m
	---	---	---	---	@50 m
Riegl					
LMS-Z360i	0.01	0.01	4	4	@25 m
& Z210i & Z420i	0.01	0.01	8	8	@50 m
LMS-Z420i	0.01	0.01	44	44	@250 m

Table 3. Performance of typical laser scanners (part 2)

In order to make the evaluation clearer the resolution on the object Δs in a slant range distance of 25 m and 50 m is calculated from the angular resolution Δφ in Table 3, part2.

5.2 FOV and Resolution of Panoramic Camera

In order to study if laser scanners can support 3D panoramic mapping a similar table with key performance data is set-up for the CCD-line panoramic camera Eyescan M3 Metric built by KST Dresden. The technical data of this camera are compiled in Table 2. The camera can be used with different objectives. The following focal lengths f are available:

35 mm, 50 mm, 60 mm and 100 mm

Knowing the length l of the CCD-line which is 72 mm and the number of pixels on the CCD the vertical FOV can be calculated by

$$\mathrm{FOV} = 2 \cdot \arctan\left(\frac{l}{2 \cdot f}\right) \qquad (6)$$

and the vertical resolution Δφ can be computed by

$$\Delta\varphi = \frac{\mathrm{FOV}}{N} \qquad (7)$$

where N is the number of pixels of the CCD-line which is 10000 (s. Table 1). The horizontal angular resolution is determined by the azimuth drive and is independent of the objective. The standard step width is 0.008 deg. This means in 25 m and 50 m distances the following horizontal resolution on the object's surface can be calculated:

$$\Delta s_H(25\text{ m}) = 3.2\text{ mm}, \Delta s_H(50\text{ m}) = 7.2\text{ mm}$$

In Table 4 the angular vertical resolution Δφ and the resolution on the object´s surface Δs_V are compiled in dependence on the focal length.

f [mm]	**FOV** [deg]	**Δφ** [deg]	**Δs_V @ 25 m** [mm]	**Δs_V @ 25 m** [mm]
35	92	0.009	4	8
50	72	0.007	3	6
60	62	0.006	2.6	5
100	40	0.004	1.7	3.5

Table 4. Vertical resolution of panoramic camera

Assuming the line of sight of the camera is aligned horizontally the heights compiled in Table 5 can be surveyed.

f [mm]	**h @ 25 m** [m]	**h @ 50 m** [m]
35	18	36
50	14.6	29
60	13	26
100	8.6	17

Table 4. Heights above ground

5.3 Performance comparison of laser scanners and panoramic cameras

To carry out the comparison between laser scanners and panoramic cameras, first the angular resolution in elevation is regarded. The discussion is based on the wide angle objective with a FOV of 92 deg. This comes closest to the field of view of the panoramic scanners which either perform 310 deg or 90 deg. However, having a vertical FOV of 90 deg means, that an extra survey has to be carried out with an additional elevation to obtain a full hemispherical coverage. Nevertheless the comparison is realised with FOV of 90 deg. In accordance to Table 4 the panoramic camera offers a vertical angular resolution of 0.009 deg whereas the laser scanners perform about 0.01 deg (s. Table 3, part 2). The resolution in azimuth is given with 0.008 deg for the panoramic cameras and varies between 0.0008 deg and 0.01 deg for the laser scanners (s. Table 3, part 2). The very high resolution of 0.0008 deg is only mentioned for the laser scanners of iQsun. So it seems that 0.01 deg is the more practical and realistic standard. It can be seen that both systems fit together very well with regard to their angular resolution.

Now, the surveying time is going to be looked at. The panoramic camera samples the vertical FOV in 4 msec. This is the shortest time possible and requires a very good illumination of the target. The values in Table 5 are calculated under the assumption that the horizontal and vertical resolution are 0.01 deg. Then the scanning time for one vertical line can be computed by

$$t_{sc} = \frac{FOV}{\Delta\varphi_{vert} \cdot f_{sampl}} \tag{8}$$

if FOV is the vertical field of view, $\Delta\varphi_{vert}$ the vertical angular resolution and f_{sampl} the measurement rate for each pixel. For the Zoller&Fröhlich and iQsun laser scanners the FOV was determined with 360 deg, because here shaft scanners are used which rotate with constant speed over 360 deg. The Riegl scanners are realized with polygonal scanners which have a FOV of 90 deg. Therefore, in this case FOV equals 90 deg.

Laser Scanner	**Sanning Time** vert.	horiz.
Zoller&Fröhlich		
LARA25200	29 msec	17.4 min
LARA53500	36 msec	21.6 min
iQsun 880HF40		
	300 msec	180 min
	300 msec	180 min
Riegl		
LMS-Z360i	750 msec	450 min
LMS-Z420i	750 msec	450 min
LMS-Z210i	667 msec	400 min

Table 5. Scanning times of laser scanners

The fastest laser scanner needs already 29 msec for the total vertical FOV of 310 deg (s. Table 5). With regard to Table 5 the Riegl scanners require the longest vertical scanning time which is 750 ms. The Riegl scanners are designed for much higher scanning rates which is 20 scans per sec. However, this cannot be achieved with a resolution of 0.01 deg. The vertical scanning time determines directly the horizontal scanning time t_{horiz} which is

$$t_{horiz} = \frac{360\text{ deg}}{\Delta\varphi_{horiz}} \cdot t_{sc} \tag{9}$$

Based on equation 9, the calculated results are compiled in Table 5, which makes clear that the surveying time easily reaches several hours.

As the panoramic camera exhibits a vertical sampling rate of 4 msec, a total panorama is surveyed in 2.5 min with a horizontal angular resolution of 0.01 deg. The sampling rate of 4 msec is only possible with optimum illumination, this means very bright sunlight. Especially in rooms much longer sampling rates are required. In our experiments with the M3metric camera typical sampling rates were between 25 ms and 50 ms. This means a total panorama takes about 15 min to 30 min.

This performance comparison clarifies that panoramic cameras and laser scanners may work very well together. Especially the laser scanners of Zoller&Fröhlich show comparable surveying times. However, also the other scanning systems compiled in Table 3 can well be applied together with panoramic cameras to achieve 3D-panoramic recording.

6. INTEGRATING LASER SCANNER AND DIGITAL PANORAMIC CAMERAS

In chapter 5 it was worked out, that laser scanners and digital line scan panorama cameras have comparable surveying geometry and sampling performance. The main advantage of the panoramic camera is the very short measurement time. However, this time is dependent on the illumination of the target. Laser scanners are active measurement devices with their own illumination source and therefore independent on external light. At this point the engineering problem becomes obvious combining a passively working system with an active one.

Nevertheless before integrating both surveying systems in a single device several surveys were accomplished where the same scene was sampled independently by a panoramic camera and a laser scanner. Only the recording point of views were identical. Very impressive and promising results are published by (Abmayr, 2004). Here a digital panoramic camera and a laser scanner of Zoller&Fröhlich were mounted on the same tripod. In this setup it was ensured that the location of the camera's optical center was almost identical with those of the scanner unit. In addition both devices were adjusted to each other so that both horizontal rotation axes were aligned in parallel. Due to the special set-up only a simple co-ordinate transform regarding the instantaneous horizontal rotation angle was required. This simple calculation satisfies the needs of a demonstration. Further studies concerning the accuracy in combining laser scanner data with panoramic camera data were carried out by (Reulke, 2003 and 2004). In these references the necessary processing steps for a quantitative analysis are presented.

These experimental results lead to the idea to integrate CCD-line and laser scanner in one device. A first possible solution is offered by Riegl with its laser scanners LMS-Z360i and LMS-Z420i. Here either a Nikon D100 with 3008 x 2000 pixels or a Canon EOS 1Ds MARK II with 4992 x 3328 pixels supports the survey. However, these cameras have got array sensors. Therefore, imaging geometry differs. Optimum with respect to the surveying geometry will be a solution with a CCD-line sensor.

7. MOBILE MAPPING

The very emerging market for realistic 3D city models requires new advanced sensors capable to provide high definition image and depth data. Surveying e.g. total streets lined with houses cannot be carried out with a static panorama survey as discussed in the previous chapters. This application demands mobile surveying platforms. The additional feature of mobility means, that for each measurement point the instantaneous position and orientation of the sensor system must be measured. Knowing the position in a geographical co-ordinate system and the exterior orientation the surveyed data can be geocoded. In this chapter a feasibility assessment will be accomplished with a mobile mapping system comprising the following devices:

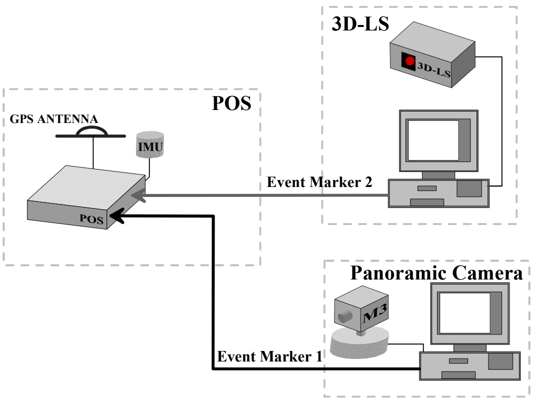


Figure 7. Mobile mapping system and synchronization

CCD-line camera, laser scanner and position and orientation system.

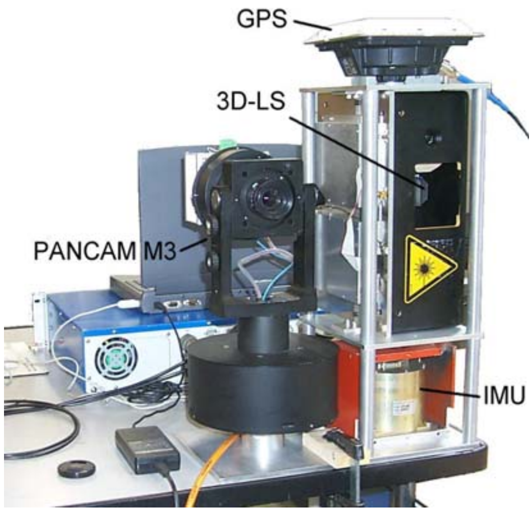


Figure 8. Experimental MMS

The position and orientation system (POS) can be realized with an inertial measurement unit (IMU) which measures the instantaneous orientation angles. The instantaneous position is primarily determined by differential GPS using the carrier phase and the lateral accelerations are measured by IMU. To obtain valid surveying results the three systems must be synchronized very precisely. A possible synchronization is shown in Figure 7. Figure 8 presents a realization of this mobile mapping system (MMS). This unit was used for verification tests.

7.1 Feasibility Assessment

In a first approach the geometrical parameters are studied. The analysis is based on the typical system parameters presented in chapters 4 and 5. Table 4 already clarifies that panoramic cameras may be used for gathering data for city models. Optimizing the line of sight of panoramic cameras the front of houses with a height of about 30 m can be surveyed already in a distance of 7.5 m, assuming the camera is mounted 2 m above ground and looks with an elevation angle of 30 deg. The laser scanners with a vertical FOV of 310 deg do not have to be adjusted. However, going close to the objects with a very large FOV means very flat incident angles. In this case it would be an angle of 75 deg measured from the normal of the object's surface. The required FOV is not critical. In a second step specifications for POS will be derived. In the following a typical angular resolution of 0.01 deg in horizontal and vertical direction is assumed for imaging and ranging sensors. If the resolution of the sensors should not be degraded by POS, a required angular accuracy of 0.001 deg should be achieved by POS. As discussed by (Reulke, 2004) angular accuracy of 0.008 deg is achievable with high precision commercial POS. This value is chosen for further calculations. Using this value means already a degradation of the system performance, because the accuracy of POS is very close to the resolution of the camera. However, in near range mobile mapping the position is much more critical. This fact is studied by the following formula:

$$\Delta p_{perm} \leq \sqrt{\Delta s_{perm}^2 - D^2 \cdot \left(\Delta\alpha^2 + \Delta\gamma^2\right)} \qquad (10)$$

Δp_{perm} is the permissible lateral error of POS, D the distance to the target, $\Delta\alpha$ the angular resolution of sensor either panoramic camera or laser scanner, $\Delta\gamma$ the angular resolution of POS and Δs_{perm} the total permissible error. If $\Delta\alpha$ and $\Delta\gamma$ are equal and are determined to 0.01 deg, equation (10) becomes:

$$\Delta p_{perm} \leq \sqrt{\Delta s_{perm}^2 - D^2 \cdot \left(\frac{\pi}{180\,deg} \cdot 2 \cdot 0.01\,deg\right)^2} \quad (11)$$

This formula is evaluated as a function of distance D with $\Delta s_{perm} =$ 50 mm in Figure 9. This figure shows that the permissible lateral error is primarily determined by the position accuracy in close range. If distance D increases the permissible lateral error for the position Δp_{perm} decreases, because angular errors predominate. In case of POS-AV of Applanix the instantaneous position is primarily determined by the GPS. Even using differential GPS with carrier phase measurement errors of at least 10 cm must be expected. It is obvious, in this application the position determination is critical. First experiments with POS-AV and a panoramic camera show very promising results (Reulke, 2003). A heraldic animal at Schloß Solitude in Stuttgart was surveyed. The object is hardly recognizable (s. Figure 10) from the original camera data. However, after correcting the data a high quality image is obtained. The zoomed in part in Figure 11 illustrates the high camera performance and depicts that the position determination must be much better than 10 cm, because the heraldic sign is well resolved in detail. The higher accuracy is possible, due to the joint post processing of IMU-data and GPS-data with special Kalman filters. Further experiments indicate, that GPS reception is very degraded close to houses or in narrow streets. This means some surveys failed because of GPS. Here alternative devices for position determination are desired.

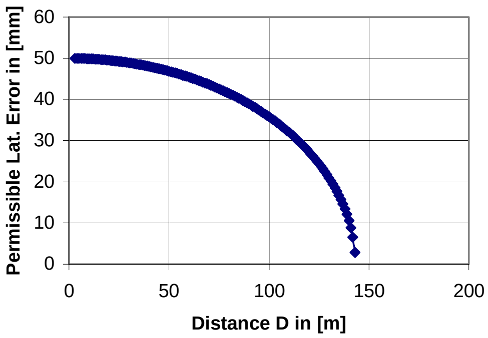


Figure 9. Permissible lateral error

To study the possible precision of a slow moving platform camera and laser scanner were mounted on a robot (s. Figure 12). Here the position and orientation was measured by ARTtrack2. Therefore special tracking targets were mounted on top. Here the position was measured with mm accuracy.

Another important parameter for mobile mapping is the maximum possible velocity of the surveying platform. Assuming the recording system moves parallel to a wall at a distance of e.g. 30 m and each 5 mm a sample is taken in vertical direction with angular resolution of 0.01 deg. If the spacing in horizontal direction - this means in the direction the platform is moving - should be equal, the maximum possible speed is 1.25 m/sec, if the exposure time is 1/250 sec. This is only a speed of 4.5 km/h. Driving with 50 km/h a vertical line will be sampled every 5.6 cm. This means that the horizontal resolution is one tenth of the vertical one. Preferable is an equal resolution in both directions. As the exposure time cannot be reduced, the sensor is oversized in vertical direction. The laser scanners can be adapted better to this application, because the number of samples along a scan and the scanning speed are programmable.

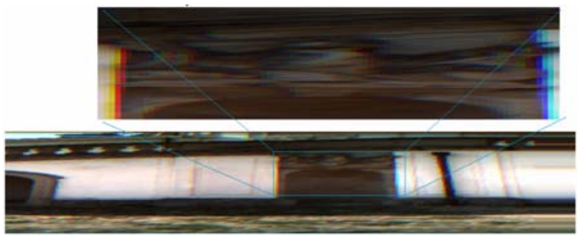


Figure 10. Original scanned data with panoramic camera

Figure 11. Result after correction

With regard to reduced resolution the application of CCD-arrays should be considered. For example the Canon EOS 10s MARKII with 4992 x 3328 pixels offers the required resolution. Due to the larger horizontal FOV the rate of the images is much lower than line scan rate of the CCD-line camera. For instance with a horizontal FOV of 30 m, an image rate of 1 image/sec and an exposure every 15 m, a driving speed of 50 km/h is possible.

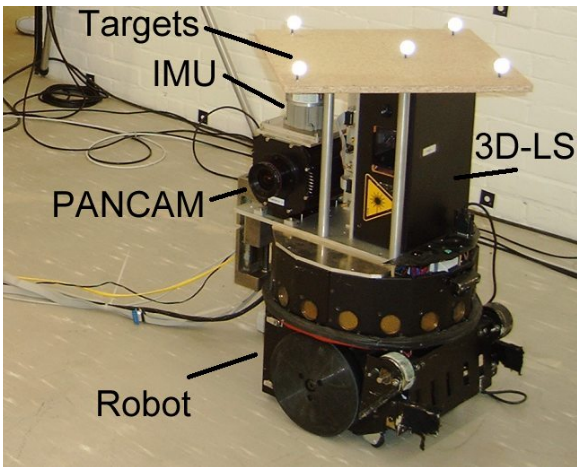


Figure 12. Mobile robot platform

8. CONCLUSIONS

In this paper the survey of commercially available laser scanners proves that these devices can be well combined with digital panoramic cameras using CCD-line sensor. First, both systems have the same surveying geometry and secondly the measurement rate and the resolution are in the same order of magnitude. First experiments with an integrated set-up demonstrated the feasibility to obtain high definition colour 3D panoramas. The tests confirm that the depth accuracy satisfies the envisage applications. However, more quantitative studies must be carried out in the future. Though the experiments look very promising, one has to take into account that a passive sensor is used in combination with an active one. Therefore, the advantage of the active sensor gets lost. Laser scanners are active sensors. They work independent of other illumination sources. Therefore, they can be employed under poor illumination conditions or even in darkness. With regard to today's technological state-of-the-art the integrated use of both systems is an optimum choice for many applications.

A very promising and demanding application field is the photo realistic modelling of cities. Here mobile mapping systems are needed to gather the required 3D image data in a reasonable time. The rough system calculations and demonstration experiments document the feasibility. The required POS is a key item and must work very precisely. The discussion in chapter 7.1 makes evident that different concepts are possible. More detailed system and design calculations are necessary.

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