Multi-sensor based Surveying of House Drainage System

The current state of the art

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***Abstract*— In the last years, the private sewer networks got more focus of the sewage industry. Due to aging and other time-dependent problematic issues, specialists suspect a high risk for humans and the environment because of damages in those networks. Information about the exact location of the damages in the pipe system is very important for reparation and reclamation concepts. This paper presents the current state of the art in geometrical documentation of private sewer networks with respect to the multi-sensor system called geoASYS. The main components of the geoASYS system; a low-cost INS sensor, an odometer and a processing software module are described. The latter is of specific importance as so-called motion model conditions have to be considered. Specific measuring strategies had to be developed to handle the drift of the low-cost INS sensor as well as the irregular motion of the inspection unit and to guarantee the required accuracy which is about 50 cm in position and 1 cm per meter in height. The paper also includes the results of practical tests in a surveyed test sewage network which have on the one hand shown that the required accuracy can be achieved for sewer networks of 25 – 30 meters in length but have on the other hand also shown that the system concept has certain limitations.**

Keywords-component; multi-sensor system, geoASYS, INS, sewage network surveying

I. Introduction

Private sewer network connects buildings and other facilities with the public sewage system (main sewer) and is also referred to, in this paper, as house drainage system (HDS) (see Figure 1). Experts estimate the overall length of the HDS in Germany to be about 1.500.000 kilometers. In recent years, the sewerage industrial sector has been focusing more on the inspection of these private sewer networks as specialists suspect high risks for humans and the environment because of sewage water leakages due to damages of pipes. A single leakage may lead to a cascading effect to other surrounding underground infrastructure, for example by contaminating the ground water which is most often exploited for drinking purpose [1]. For this reason, these networks have to be inspected and also the existing damages have to be located and repaired.

Because of the circumstance that the HDS is installed underground and usually there are no available plans of the HDS, the determination of the exact course of the sewer network pipes respectively the position of the damages is not a simple task. Classical geodetic measurement methods for documenting HDS cannot be used and therefore alternative methods have to be developed. Also the required accuracy specification of 50 centimeters in planimetric position and 1 centimeter per meter in height at a length of the network up to 30 meters with small diameters of 80 to 200 millimeters is a challenge for a measurement system [2].

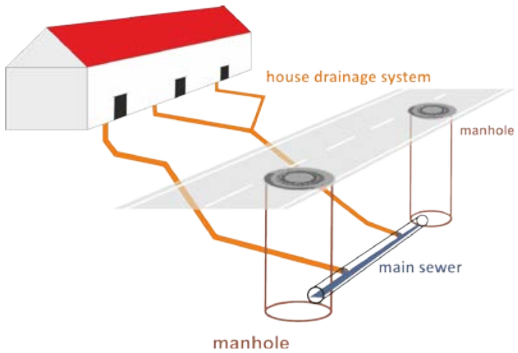

Figure 1. Schematic draft of a simple house drainage system

A variety of different measurement systems exist which try to document the position of damages, in particular the geometrical course of an HDS. The measurement systems can be subdivided in two categories:

The first category contains the indirect measurement methods, like passive magnetic field positioning, active magnetic field positioning, geo-radar positioning or the usage of sound rods. All indirect measurement methods try to detect the underground pipe system from the surface. This paper will not discuss the above mentioned methods in more detail because they are not able to achieve the required accuracy and reliability specification. The accuracy of those methods always depends on the present underground environmental conditions. In addition, all results of the indirect measurement methods have to be transformed into a local geographic system with the help of geodetic measurement techniques like GPS or tachymetric surveying. This process usually involves a high amount of work and high costs [3].

The second category contains the direct measurement methods. These methods rely on sensors and algorithms to calculate the exact position of a HDS directly in a local geographic system. At the moment, geoASYS takes the market lead in Germany as a direct measurement system [3].

II. THE GEOASYS SYSTEM

The geoASYS system is a real-time measurement system designed to acquire and record the 3D geometry and topology of HDS during the inspection. The measured course of the sewer pipes can be visualized during acquisition and committed to geographical information systems (GIS). The system is built up of two sensors, a miniaturized Inertial Navigation System (INS) and an odometer as well as the software module which control the complete measuring process including the communication with the sensors (see Figure 2).

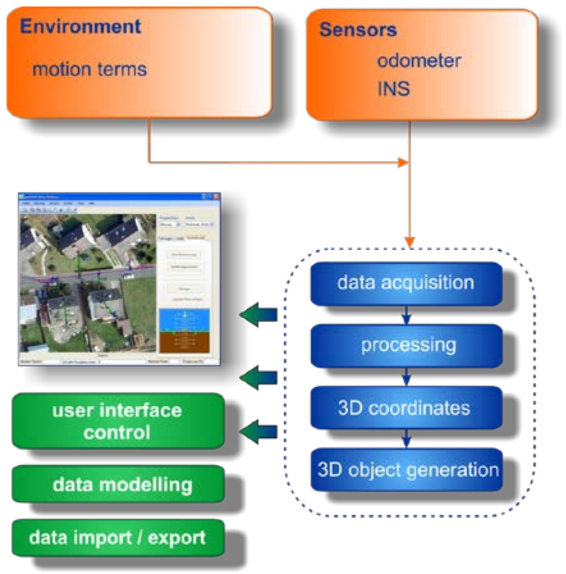

Figure 2. Schematic overview of the geoASYS system

The initial concept of the system was developed by the University of the Bundeswehr Munich in collaboration with JT-elektronik late 2005 [4]. Another industrial partner PPMsys is responsible for the further development and support of the measurement strategy of the current geoASYS system.

A. *Hardware components*

1) Lindauer-Mini-Schere (LMS)

The LMS is a standard inspection unit of JT-elektronik which was specially constructed for the inspection of HDS. The LMS is equipped with a pivoted TV camera, flood light and a special reeve mechanic which enables the flexible bending of the unit in pipe segments, especially in the area of branch fittings (see Figure 3). The forward movement force of the inspection unit works with the help of water pressure. The water pumped through the jet nozzles creates pressure which drives the inspection unit through the pipe system.

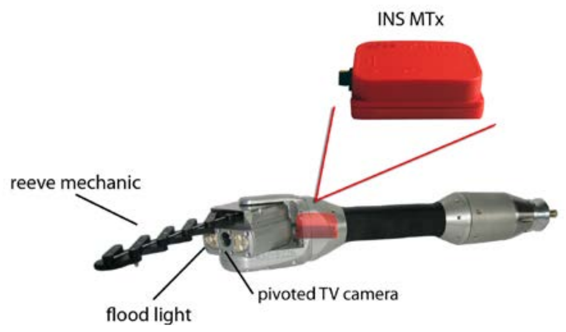

Figure 3. Main components of the Lindauer-Mini-Schere

2) INS

Inside the LMS, there is a miniaturized, low-cost INS installed. It is a Micro-Electro-Mechanical Systems (MEMS) based measurement unit called MTx of the company XSens [5]. The MTx is provided with 3D sensors: rate gyroscopes, accelerometers and magnetometers. Table 1 contains some technical specification from the manufacture about the MTx.

TABLE I. COMPENDIUM OF THE TECHNICAL SPECIFICATION OF THE MTX [5]

size		
length – width – height	38x53x21 mm	
attitude and heading		
static accuracy (roll and pitch)	smaller 0.5 deg	
static accuracy (heading)	smaller 1 deg	
Dynamic accuracy	2 deg RMS	
Angular resolution	0.05 deg	
Onboard processing	120 Hz	
individual sensor specification		
	rate of turn	**acceleration**
Bias stability	1 deg / s	0.02 m / s^2
Noise	0.05 deg/s/√Hz	0.002 $m/s^2/\sqrt{Hz}$
Alignment error	0.1 deg	0.1 deg

The INS enables a continuous measurement of the acceleration and attitude changes of the LMS during the inspection. With this information, it is possible to determine the 3D orientation of the LMS respective to a local geographic system. The measurement concept of geoASYS uses the standard filter scenario from XSens without magnetic field sensors. Practical tests have shown that because of, for example, iron materials near the HDS, the attitude measurement performs poorly when a scenario including the magnetic field sensors is used. But without magnetic field sensors turned on, the yaw angle of the attitude measurements is not reliable. The INS may also measure rotation in a rest position or state. This is very important to consider for the yaw angle measurements which are directly impacted by this instable behavior. This effect is commonly referred to as drift.

3) Odometer

The second sensor is an odometer, which measures the covered distance of the LMS in the HDS. The odometer is installed in the inspection craft and records the distance with the help of the length of the unrolled supply cable attached to the LMS. The sample rate count is set to 20 Hz and has an accuracy of 2% of the measured distance. During the inspection the system can register the covered distance at any time.

B. Procedure

At first the LMS has to be transported to the house connection (HC) point of the HDS in the main sewer. From an inspection craft, a small carriage is set into the main sewer through a manhole. The carriage transports the LMS to the connection point (see Figure 4). From there the geometric documentation of the HDS starts.

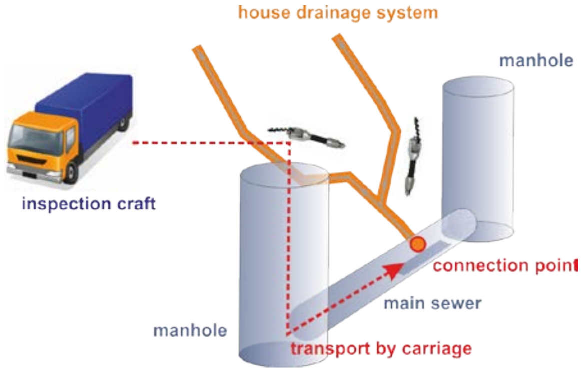

Figure 4. Starting point for LMS measurement procedure

For the whole measurement concept of geoASYS, it is important that the start position and start attitude, in particular the bearing of the LMS in the main sewer, are established. Usually the bearing is calculated from the coordinates of the two manholes (these are usually known), with the assumption that the main sewer has a straight course. Using the bearing and the data feed from the odometer, the start position can be determined. The calculation of the start position and orientation with geoASYS is the basic requirement for the geometric documentation of HDS. The next step is the inspection of the complete HDS with the LMS. The geoASYS system continuously calculates the geographical position of the LMS based on the results of the two above-mentioned sensors.

C. Algorithms and motion terms

With the measured data from INS and odometer combined with different algorithms (for example, the mean filter, etc.), it is possible to calculate changes in attitude and distance measurements of the LMS according to the starting point and attitude in the main sewer. The geometrical position of the pipe system is determined with the help of the geodetic practice known as “dead reckoning”. The geoASYS system computes discretely each waypoint of the LMS in the HDS from the current attitude and distance measurements. The description of trajectory (curves or branches) is carried out by approximation with small line elements.

In this described procedure, there is one main problem, namely the instable yaw measurement of the INS because of the disconnected magnetic field sensors, as already mentioned in chapter about “INS”. This causes systematic errors in the documentation of HDS, which increase with time. For example: if the change in yaw during the measurement of a straight pipe element is 1° (degree), then there is a position error of around 0.5 meters after a traveled distance of the LMS of 25 meters. Projecting the traveled distance to 80 meters, the position error increases to 1.4 meters.

To compensate the impact of the instability of the yaw measurement, the geoASYS concept applies the so-called motion terms. During the video-inspection of the HDS the inspector can provide the system with additional information about the current course of the pipe system. This information is integrated in the system as motion terms. There are different types of network elements that can be considered as motion terms: straight pipe system and flexible pipe system or contingent available information like angle of curve elements or known positions of inspection chambers.

The motion term “flexible pipe system” is always used to inspect pipe elements which cause attitude changes in curve or branch elements. During the inspection of flexible pipe systems all INS measurements are integrated in the calculation process to document the position changes of the HDS. In contrast, during the inspection of straight pipe systems the yaw measurements of the INS are not used in the calculation process. Only the pitch and roll angle measurements are used for example to calculate altitude profile of the HDS. This approach reduces the time interval in which the yaw measurements of the INS have to be used and this in turn reduces systematic effects on the whole measurement process.

III. MEASUREMENT STRATEGIES

The geoASYS system consists of two different measurement strategies: the forward and the backward measurements. A forward measurement is an inspection into the pipe system. A backward measurement on the other hand describes the way out from the pipe system. During the forward measurement the system documents the geometrical course of the HDS as mentioned in chapter “Algorithm and motion terms”. Also the topology of the pipe system is documented. The difficulty of the forward measurement is the irregularity of the path of motion of the LMS. The small pipe diameter especially in curve elements or the folding in a different pipe section in branch elements leads to a stop and go motion and this results in a very rough path of motion during the inspection.

These conditions are unprofitable for the following reasons:

- the INS is exposed to extreme accelerations and shocks which can lead to incorrect measurements
- the incalculable motions lead to incorrect attitude measurements

During the development of the system, practical tests have shown that the forward observation can document the HDS under these conditions but has its limitations concerning the

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accuracy of the measurements. On the contrary, the backward observation runs smoothly and continuous, hence reliable and accurate. This is because the LMS is manually drawn out of pipe system without water jetting. For this reason the measurements of the backward observation are used to improve the orientation measurements of the forward observation.

The impact of this approach concerning the accuracy of the inspection is presented in the next chapter on the basis of an inspection of a surveyed test sewage network.

IV. Practical Test

A. *Test network*

The measurement strategy described in the above section was tested in a HDS Test network of the Kassel Municipality (KEB – in ger. Kasseler Entwässerungsbetrieb). Figure 5 shows the layout of the network.

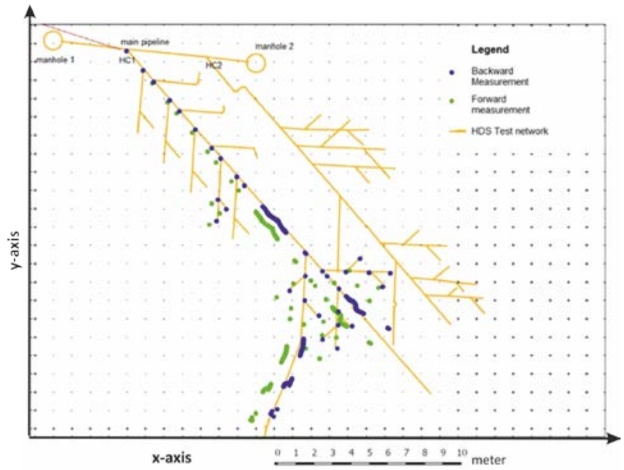

Figure 5. KEB HDS test network (in yellow colour)

The two manholes are connected by a straight main sewer pipe. The main pipe has two house connections (HC1 and HC2) which are composed of different types of pipe sections (straight and curved). The whole network as well as all the connection points along the main pipe and within the house connections have been surveyed (i.e. have known 3D coordinates). Therefore the network provides a frame of reference for analyzing the accuracy of the defined measurement strategy. The longest house connection is about 25 meters.

B. *Results*

As already mentioned in Chapter III, the practical tests have shown that the forward measurement has its limitations concerning the accuracy of the measurements especially the orientation measurements because of the unprofitable conditions. The path of motions of the backward measurement is however very reliable, continuous and accurate. For this reason, the measurements of the backward observation are used to improve the measurements of the forward observation. Figure 6 shows a snapshot of the results of the measurement strategy.

The blue colour depicts the backward measurement and the green colour is the forward measurement. The two red circles highlight some challenging sections (S-curved) of the network. The backward measurement rests almost exactly over the test pipe while the forward measurement deviates with about 0.5 meters to 1.0 meter in the circled sections. Hence at the end of 25 meters the deviation well exceeds the required accuracy. To conclude the backward measurements always meet the required specification in position. Therefore the forward observation is preferentially used for building up the initial topology of the network.

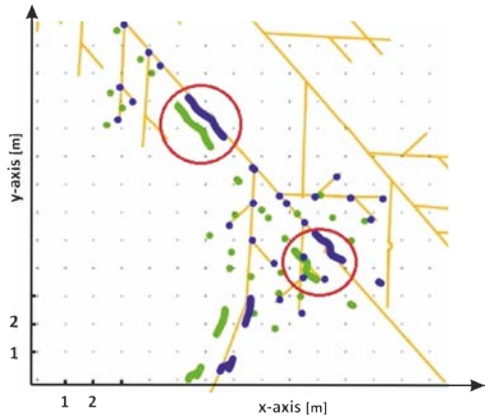

Figure 6. Example of measurement results

V. Short Summary

The measurement strategy described in this paper is very promising. With this strategy the geoASYS system is able to achieve the currently required specification. In future the system will be tested for longer networks of 50-100 meters with many branches and/or complex structures. Sensor technology and developed algorithms will be further optimized in order to improve accuracy and reliability in both planimetric position and height for complex and extended networks.

ACKNOWLEDGEMENT

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References

[1] F.W. Günthert, Ursachen von Schäden in Abwasserkanälen, Wasser und Abfall Nr. 5, 1999

[2] W. Reinhardt, H. Heister, A. Bauerm geoASYS – ein System zur Dokumentation des Verlaufes von Grundstücksentässerungsanalgen, in gwf Wasser|Abwasser, February / March 2009, pp. 190-196

[3] F.W. Günthert, W. Reinhardt, H. Heister, Inspektion- und Sanierungsstrategie für nicht öffentliche Grundstücks-entwässerungsanlagen, research initiative "Zukunft Bau", federal office for civil engineering and comprehensive regional planing, unpublished

[4] Heister, H. Reinhardt, W. Günthert, F.W., Cvaci, D.: 3D-Dokumentation von Anschlußkanälen und Grundstücksentwässerungsanlagen. KA Abwasser, Abfall, 2007, pp 584 - 588

[5] MTi and MTx User Manual and Technical Documentation, XSens, October 2010