Lantmäteriet
Lantmäteriverket - National Land Survey
S - 801 82 GÄVLE · SWEDEN

Tekniska skrifter - Professional Papers LMV-RAPPORT 1990:8

ISSN 0280-5731

THE SWEDISH EXPERIENCE WITH THE ISS ULISS 30 RESULTS FROM TESTS AND PILOT PROJECTS

L'EXPERIENCE SUEDOISE AVEC L'ISS ULISS 30
RESULTATS DES TESTS ET PROJETS PILOTES

DIE SCHWEDISCHEN ERFAHRUNGEN MIT ISS ULISS 30
RESULTAT DER TEST UND PILOT PROJEKTMESSUNGEN

By

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FIG - XIX INTERNATIONAL CONGRESS
HELSINKI, FINLAND, 1990

Lantmäteriet
Lantmäteriverket

ISSN 0280-5731

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1. RÉSUMÉ

Au cours des dernières années le National Land Survey of Sweden (NLS) s'est fortement intéressé à la technique inertielle (ISS) afin d'étudier ses possibilités d'utilisation dans son processus de production. Une étude comparative des divers systèmes existants; FERRANTI, LITTON, et SAGEM courant 1987/88, résulta dans l'achat du système ULISS 30 de SAGEM (FRANCE).

Un certain nombre de tests et projets pilotes ont été effectués depuis et nous voulons ici faire part de notre expérience et des résultats obtenus.

SUMMARY

During the last years great attention has been paid at the National Land Survey (NLS) of Sweden to study the possibilities of using Inertial Surveying Systems (ISS) for production needs. Comparative studies of different existing ISS: FERRANTI, LITTON, and SAGEM during 1987/88 resulted in the purchase of the ULISS 30 from SAGEM in 1989. (FRANCE)

Different tests and pilot projects have been carried out and this document will report on our experiences and results.

ZUSAMMENFASSUNG

Unter den letzten Jahren hat sich das National Land Survey von Schweden (NLS) sehr an Inertial Survey Systems (ISS) intressiert, dieses besonders für die Anwendungsmöglichkeiten in eigener Produktion.

Deshalb sind während den Jahren 1987/88 verschiedene ISS Systeme ausprobiert worden von: FERRANTI, LITTON und SAGEM.

Dieses resultierte 1989 im Kauf eines ULISS 30 der Firma SAGEM (Frankreich) welches in verschiedenen Testmessungen und Pilotprojekte eingesetzt worden ist. Dieser Bericht wird von unserer Erfahrungen und Resultaten informieren.

Figure 1.

The ISS system mounted in a cross-country vehicle. The COMPAQ 386 computer and the control and display unit is in the driving-cab, the ULISS 30 is on the back seat and a Geotronics 440 LR EDM instrument is mounted on a tripod through the skylight.

2. INTRODUCTION

During the last years databases of all types has been established at an increasing pace. Without doubt this has been in response to the expanding need for information and above all to optimise the process of production.

The NLS, in fact the largest producer of maps and coordinates in Sweden is establishing digital data bases in the national coordinate system in order to satisfy the needs of modern cartography and other demands from society. In order to reach this goal the NLS embarked on a mission to find the best ways of obtaining the coordinates for a large number of points, with an appropriate accuracy, whilst keeping the costs to a minimum.

The modern techniques of inertial surveying (INS) and the Global Positioning System (GPS) very quickly showed to be able to respond to these requirements; using them together and in conjunction with classical surveying techniques.

A comparative study of several existing ISS which were currently available: Ferranti (Fils 3 and Pads Mk 2), Litton (Las II), and Sagem (ULISS 30) was carried out. The study was intended to evaluate these systems in terms of technical ability, software provided, and financial constraints so that a choice for a purchase could be made.

Since June 1989 the NLS owns an INS system from SAGEM type ULISS 30 mounted in a terrain vehicle. The complete system also included a total station type GEOTRONICS 440 LR, a portable computer COMPAQ 386 and a printer.

From the date of its delivery this equipment has undergone various tests. The first tests were delivery tests to ensure that the equipment conformed to the technical specifications of the manufacturer. Secondly these tests were useful to familiarise the operators with the equipment. During this test period minor adjustments of the software to conform to our requirements was made.

After that the ULISS 30 has been tested and used in several pilot projects specifically designed to show the ability of the INS to carry out the topographic surveys which eventually will constitute its everyday work. These tests were conceived to find the optimal use of the INS either on its own or in combination with classical surveying techniques or GPS.

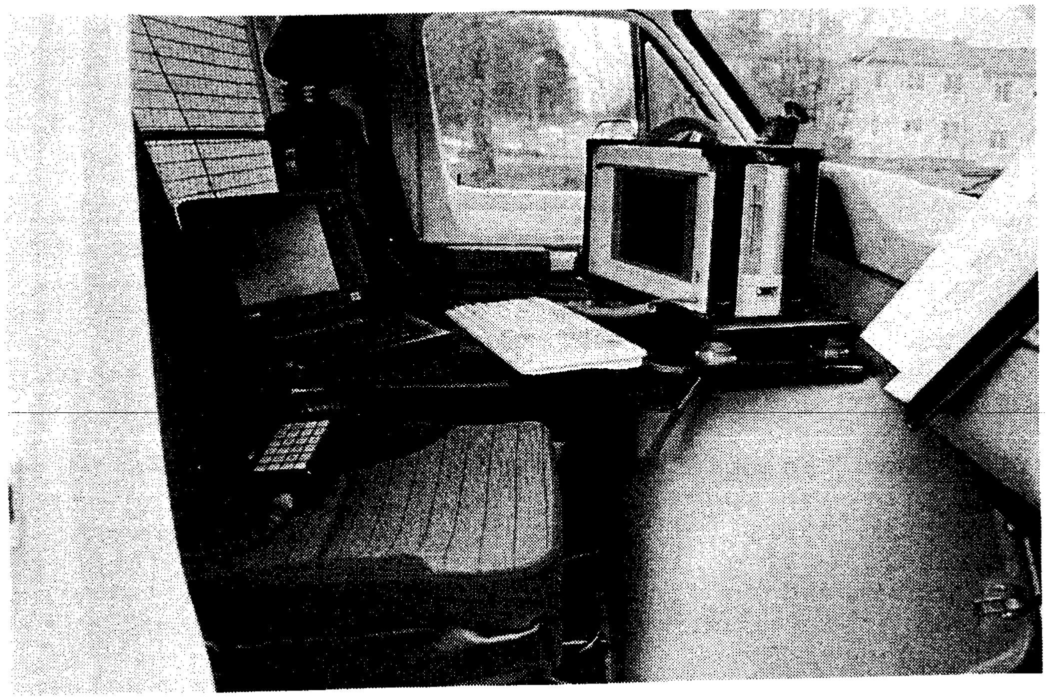
3. THE INERTIAL SYSTEMS STUDIED

Our study of existing ISS was concentrated on the systems giving the highest precision while at the same time being the best adapted to topographical surveys. Table 1 gives an insight into the most important characteristics; note that the Honeywell GEOSPIN was not available for sale at that time.

Table 1

Name: Type:	LITTON (USA) LassII	FERRANTI (UK) Fils III	SAGEM (FR) ULISS 30
Platform	Local level	local level	local level
Gyros Accelerometers	2 floated 1 dry +2 floated	3 floated 3 floated	2 drytuned 3 dry
Dimensions weight	78x66x50 cm 95 kg	59x47x37 cm 63 kg	55x45x30 cm 50 kg
Power supply:N warm-up	960 W 2340 W	250 W 7-1500 W	280 W 700 W
Real time soft-ware	Kalman filter	Polynomial curve fit	Kalman filter
Data dumps	Only at ZUPTs	Every 10 sec.	User programmable
Data storage	Tape	Tape	PC-harddisc
Access raw data	No	Yes	Yes possible
Prepared forGPS for tot.station	No	No	Yes Yes, "harmonized"

Figure 2.



The computer with control and display unit is mounted in the driving-cab.

The technical comparison of the various systems brought us to the following conclusions:

- from the point of view of precision the LASS II and the ULISS 30 gave equally good results (of the order of one decimetre), that of FILS III being less accurate (several decimetres).

- regarding from the field operations point of view the new concepts behind the ULISS 30 proved to be the best suited for topographic surveying. LASS II lacked flexibility, weighed too much, consumed too much electricity, as well as took too long time to initialise. All of these factors serve to complicate its use on the ground.

- regarding the technical specifications the ULISS 30 offers the greatest range of possibilities: connection to a printer and PC as well as the harmonisation of the total station with the ISS and the future possibility of combining GPS with the ISS.

- the conditions imposed by Litton regarding any after-sales service (stocks of spare parts, delay in repairs) were totally unacceptable.

- the strict conditions applied by Litton and Ferranti regarding usage in a third country strongly decreased the possibility for us to work there.

- from the financial standpoint Ferranti was the cheapest, Litton and Sagem were about equivalent.

In conclusion the ULISS 30 seemed to be the most promising of the possible studied candidates.

4 THE ULISS 30 EQUIPMENT

This system stems from a close collaboration between the NLS and SAGEM regarding the technical specifications, its operational possibilities and above all its adaption to specific surveying needs (both for the equipment and the software).

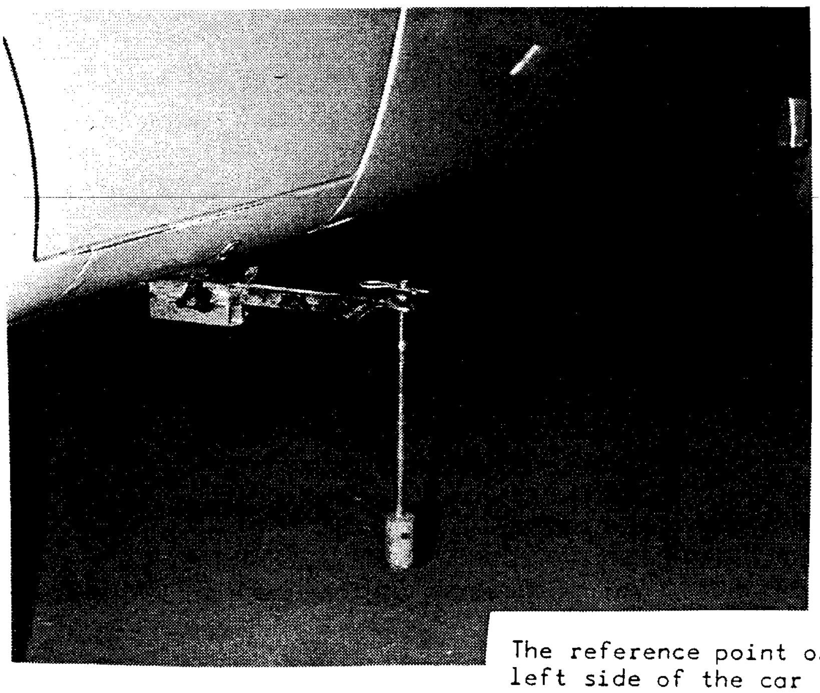
The complete system (inertial platform, command unit, microcomputer, electronic total station, printer and navigation unit) is mounted in an all terrain vehicle (Dodge Ram 4x4) which has been specially customised and includes an openable roof (see on page 2).

The ISS-system ULISS 30 is an autonomous navigation system which, when placed in a vehicle, is able to measure its displacements in an orientated 3D reference coordinate system. In fact the system computes in real time the coordinates of the platform inside the ISS system.

Figure 3.

The total station GEOTRONICS 440 LR instalated over the platform in position for offset measurements.

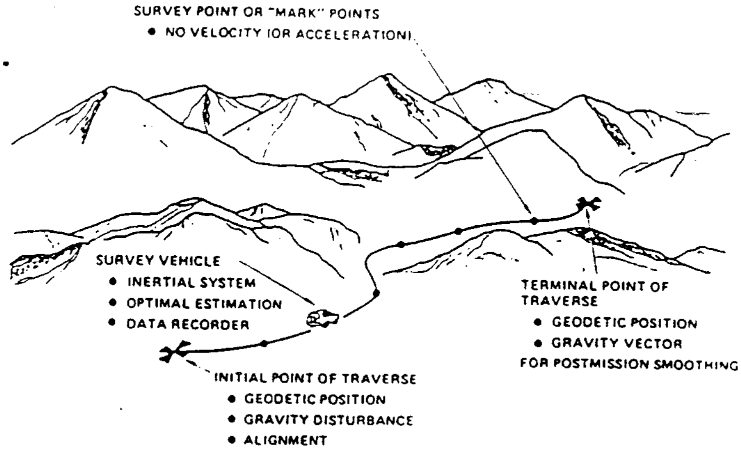
Figure 4.



The reference point on the left side of the car (mecanical plomb).
This point is used for direct survey over the marks

SCENARIO FOR AN INERTIAL SURVEY
SINGLE TRAVERSE

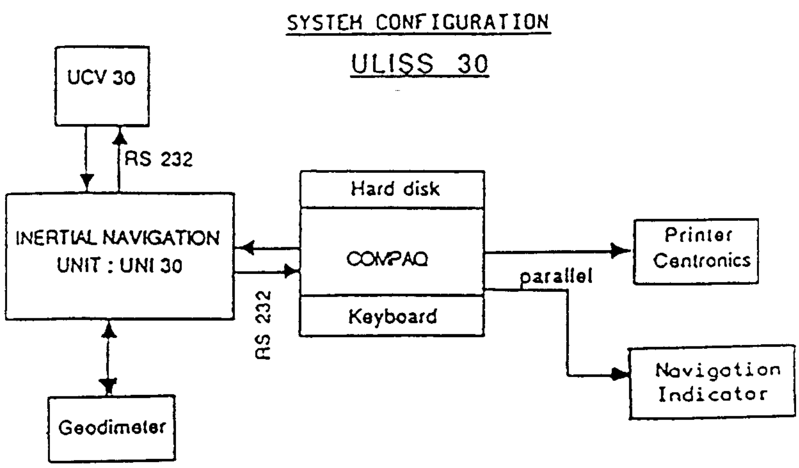
Figure 5.



Consequently in topographic surveys it is necessary to relate the "survey points" (either being set-out or picked up) relative to the platform. This can be done in either one of two ways. First using reference points on the sides of the vehicle which can be accurately placed over the ground point, or, if the latter is inaccessible, using the electronic total station.

The total station is mounted upon a tripod within the vehicle and fixed over the inertial platform. The observations to the survey points are made through the open roof. Also because the total station is harmonised with the ISS-system the coordinates for the survey points can be directly translated into the ISS system coordinates. All necessary calculations are done automatically.

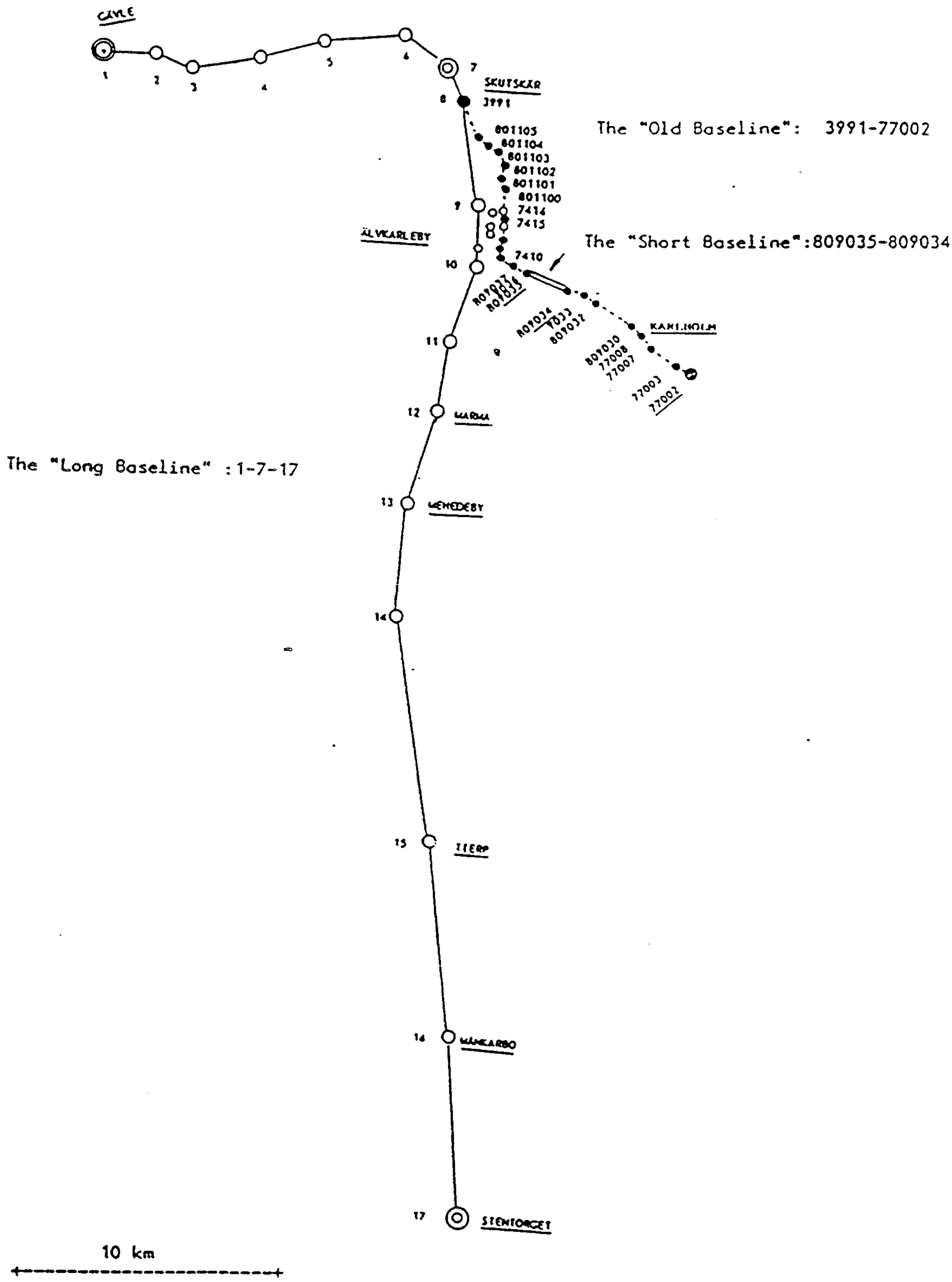
The reference points fixed on the vehicle can be used in two ways. The prefered method is to drive the car so that the reference mark is placed directly over the ground survey point. However if this is not possible, the eccentric measurements to one of the reference points on the vehicle can be made either by using rectangular or polar methods (coordinates).



This diagram shows the main components of the ULISS 30 system.

Figure 6.

THE CALIBRATION BASELINES AROUND GÄVLE



The special "geodetic" software package enables us to perform several types of geodetic/topographic works including network densification, setting out, point coordinates determination, trajectory surveys, navigation, etc.

5. FIELD TESTS ON BASELINES

The surveys already carried out with the ULISS 30 fall into one of two categories. The first were by delivery tests on different calibration baselines in the region of Gävle. The second consisted of several tests in the form of pilot projects distributed over the whole country of Sweden and in Denmark.

In total three calibration baselines have been measured, each having a different objective (see figure 6).

The "Long Baseline" with a total length of 73 km is L-shaped and composed of two branches, one in an east-west direction (15 km) the other being north-south (58 km). This baseline is relatively flat with a total altitude difference of only 43 m. There are 17 points determined by GPS with a density of between 2 and 10 km.

The "Old Baseline" is composed of 2 branches (NS = 10 km, SE = 15 km) with a density of 1 to 3 km. This line is basically flat.

The "Short Baseline" is only 2,3 km and perfectly straight. Intermediate points exist on this baseline at a spacing of every 10 m up to 100 m, then every 50 m up to 500 m and subsequently at every 100 m. The maximum height difference is only 9 m.

Table 2.

The "Short Baseline": 1989-10-04

final coordinates and comparison errors in meter
(derived from adjusted parameters - also for fixed points)

dist(km)	northing	easting	height	dx	dy	dh
0.0	6715622.71	1594349.93	29.93	0.00	0.00	0.00
0.8	6715858.68	1593616.41	24.22	-0.03	0.05	-0.09
0.9	6715889.38	1593521.23	22.77	-0.01	0.04	-0.08
1.0	6715920.06	1593426.04	21.92	-0.03	0.03	-0.06
1.1	6715950.75	1593330.83	21.29	-0.02	0.00	-0.07
1.2	6715981.38	1593235.63	20.94	0.00	0.00	-0.07
1.3	6716012.08	1593140.44	20.39	-0.01	0.00	-0.06
1.4	6716042.79	1593045.26	20.15	0.00	0.01	-0.04
1.5	6716073.49	1592950.06	20.35	0.00	-0.01	-0.07
1.6	6716104.17	1592854.87	21.18	-0.01	-0.03	-0.03
1.7	6716134.89	1592759.68	22.05	0.02	-0.08	-0.03
1.9	6716196.31	1592569.40	23.33	0.00	-0.02	-0.03
2.0	6716227.05	1592474.20	23.48	0.03	-0.09	-0.03
2.1	6716257.70	1592379.04	23.64	0.00	-0.03	0.00
2.2	6716288.42	1592283.81	23.67	-0.01	-0.04	0.00
2.3	6716318.19	1592188.38	23.18	0.00	0.00	0.00
r.m.s. error for 14 comparison stations:				0.02	0.04	0.05

This table shows the variations between the coordinates (True minus ISS) at every comparison point

Table 3.

Lengdt in km	Nber of known points , at distances	Comparison points	Root Mean Square for the "d" = True minus ISS determinated coordinates (mean values) RMS dX(cm)	RMS dY(cm)	RMS dH(cm)
Short BL 2,3 km	2 0 -2,3km	16	2 cm	4 cm	3 cm
Old BL 38 km	4 0-15-23-38km	19	11	12	9
	3 0-15- -38km	20	40	21	14
	3 0- -23-38km	20	32	29	9
Long BL 73 km	4 0-15-32-73km	14	30	31	12
	3 0-15- -73km	15	36	29	15

RESULTS FROM THE BASELINES

Some RMS values for ISS surveys along the calibration baselines (True coordinates minus ISS) .Differences between mean values.

A fourth baseline has been established for altimetry test. This "Altimetry Baseline" (around 25 km) is greatly undulating, with a maximum height difference of 175 m. This baseline is part of the first order levelling network, with points of known height every kilometre, with altitude variations being as much as 80 m/km. The gravity variations are important and have been determinated on 10 of this basepoints. Test on this baseline will be carried out later.

Several repeated trips (in both directions) were carried out on this baselines in order to familiarise ourselves with the equipment, to test the performances of the system with regards to the technical specifications, to calibrate the system, and finally to learn more about the technical possibilities of the INS. At the same time this tests served to test the software package and allowed us to make certain improvements both in operational and logistic procedures. Tables nr 2 and 3 shows some results obained with ULISS on this baselines.

The ISS coordinates are the average of twice measured points and were adjusted in the post processing using two or more known points.

6. PILOT PROJECTS

ISS is a relatively unique technique which has not previously been used in Sweden for surveying. Consequently there is a lack of experience and no Survey Regulations governing its use. There is little information available in the literature relating to field techniques.

At the system evaluation stage it was clear that it would have considerable potential as a technique for creating road databases and for documentation of the opto-cable networks which are being established by the Swedish Telecommunications Administration. Other areas for which the technique had potential were cadastral surveying and forestry in relatively remote areas.

To develop ISS working methods and to investigate applications main pilot projects were designed and carried out in three specific areas of survey works namely: control networks, road networks and survey of cables.

6.1 Control networks

There are several cadastral and mapping activities for which lower accuracy of the order of 10 cm, and with connections to the national triangulation, is acceptable.

Different types of network surveys were carried out according to the current works in progress, for example:

- densification of already existing network and connection to the national datum using inertial polygonal surveys
- connection of several isolated local networks into a common network by ISS traversing
- establishment of local network for cadastral purposes with connection to the national datum.

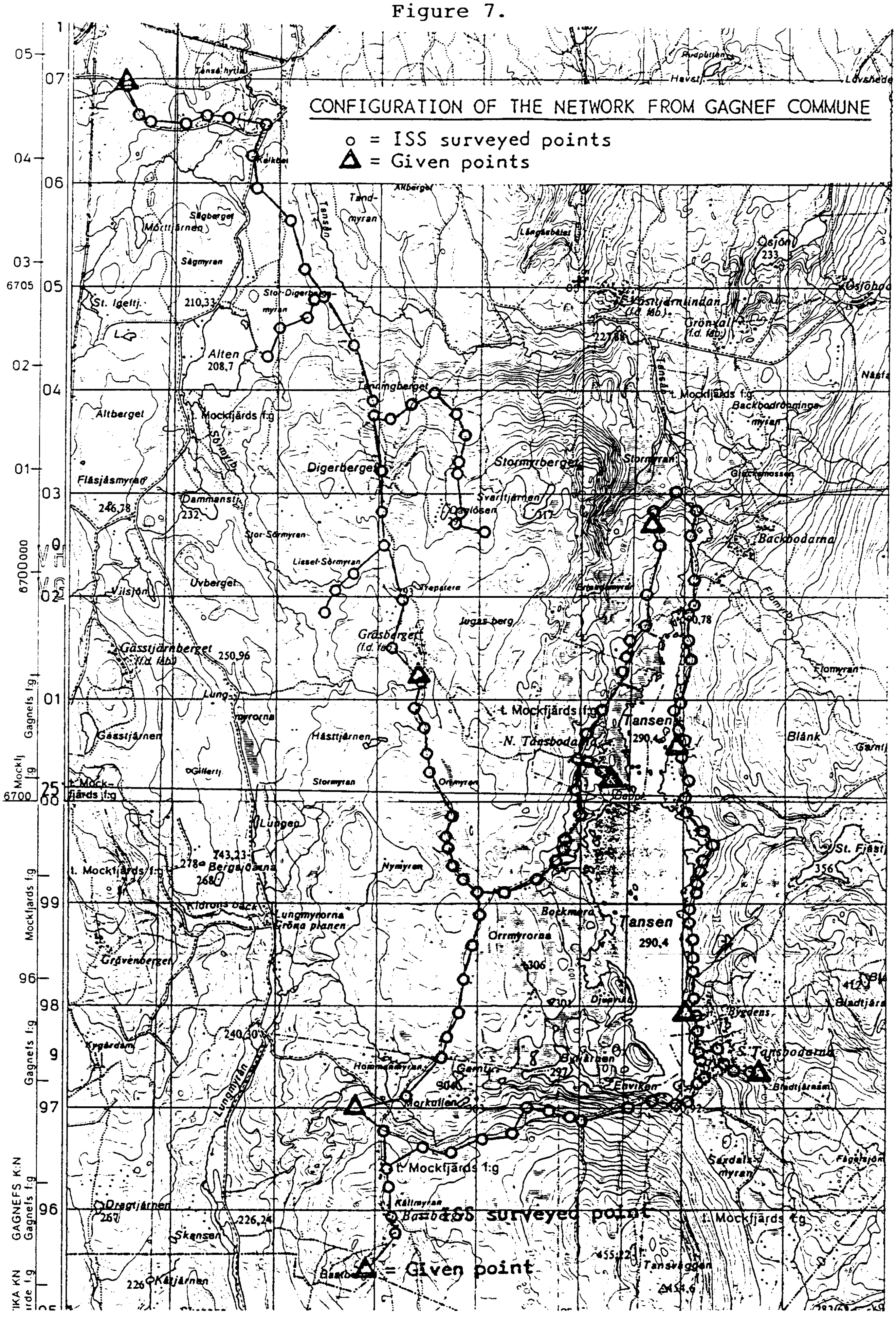
Several pilot control networks of this type were established. Here follows some exampel.

Falu Commune.

Fifty eight survey control points and ten boundary beacons were measured to densify three older networks and the area between them and finally to connect the block to the national network. A traverse with a total length of 25 km was measured along public roads. The distance between points varied between 100 and 500 m. The work took 2 days.

Several of the old points were included in this ISS-survey and remeasured, this gives a good control of the precision of the ISS measurements.

Figure 7.


CONFIGURATION OF THE NETWORK FROM GAGNEF COMMUNE
o = ISS surveyed points
△ = Given points
ISS surveyed point
△ = Given point

Gagnef Commune.

A network was established to support a land consolidation project around the Tansen Lake in Southern Mockfjaerd. This is a forested area with very broken terrain in which the roads are narrow and lined with dense bush vegetation. For classical traversing a great amount of line-cutting would have been necessary; and connections to the national network, through a breakdown network would have required towers and additional clearing of forest. The use of GPS methods would also have been difficult because of the dense and high tree cover.

The ISS measurement programme included the remeasurement of a number of existing traverse points and the connection of the network to the national coordinate system. In all, 30 km of traversing were carried out and coordinates were determined for 129 points. The traverse points, which were established beside the roads, were connected to the ISS reference point in the vehicle using an on-board total station. The work took 2,5 days to complete. The distance between the points varied between 100 and 300 m and they were established so that a free line of sight was available between pairs of points. In figure 7 the configuration of this network is shown.

Several survey points have been measured twice in order to control the repetability of the ISS. Control of distances between ISS (determinated) points have also been made with total station.

6.2 The road networks

The measurements of road networks consists of determinating the trajectory of the roads including the position of monuments (bridges, cross roads, etc) by determination of the coordinates of all those points, and furthermore to store these details and information into the "national road database".

This survey was carried out in the mountainous north west area of the country, where the road network is sparse, and where the cost for a photogrmmetric survey is too high. About 3000 km have to be surveyed in this project, only 1300 km were surveyed 1989. In order to tie the survey to the national network around one hundred GPS points were necessary.

The precision requirement of 2 m was easely obtained with the special inertial mode of "vectorised trajectory" when using known points every 20 - 30 km. During the survey position coordinates are given six time every second, after "vectorisation" 95 % of non interesting points are rejected, this reduce considerably the volume of records.

The dayly production average was about 50 km (double run).

Table 4.

COMPARISON BETWEEN TWO ISS SURVEYING OF THE SAME POINTS

dX ,dY, dH are the differences between the coordinates of the first minus the second measurement (GAGNEF 1989)

X	Y	H	dX (m)	dY (m)	dH (m)
6696804.73	1453031.45	319.90	0.00	0.12	-0.02
6697548.78	1456129.11	295.12	0.08	-0.08	-0.03
6697759.67	1456115.38	297.07	0.01	-0.08	-0.09
6697908.44	1456102.09	295.63	0.05	-0.05	-0.10
6697519.44	1453619.10	307.44	0.14	-0.06	0.02
6697953.01	1453797.76	314.85	0.09	-0.04	0.08
6698606.97	1453940.07	318.56	-0.04	0.06	0.24*
6698902.97	1454016.44	317.86	-0.05	0.07	0.13
		RMS :	5cm	7cm	8cm

(0.24 *=error in reflector height)

Table 5.

RESULTS FROM PILOT PROJECTS

Tipical RMS values obtained for ISS surveys (True minus ISS coordinates) with different distances between given points.

Lengdt in km	Nber of known points , at distances	Comparison points	Root Mean Square for the "d" = True minus ISS determinated coordinates (mean values) RMS dX(cm)	RMS dY(cm)	RMS dH(cm)
3,6 km	2 (endpoints)	7	5 cm	2 cm	8 cm
4,7 km	2 (endpoints)	10	7	5	9
6,6 km	2 (endpoints)	11	10	7	10
10,5 km FALUN	2 (endpoints)	13	8	11	6
10,9 km FALUN	2 (endpoints)	19	8	6	10

6.3 The cable surveys (type opto-cables)

The survey of cables was carried out on behalf of the Swedish Telecommunication Company with two purposes. Firstly to be able to map the cables on maps of different scales, secondly to be able to locate the cables if needed for maintenace or repair, or other purposes.

Several distinct types of survey were carried out:

- The measurement of traverses or pairs of points along the cable ditches. The points were connected to the national coordinate system. In one of the projects, 100 points were established over a distance of 45 km. These points were than used as set-up points for detail measurements with a total station.

- Detail measurements along cables. In this project 925 points were established over a distance of 20,5 km. Most of the points could be established without any additional detail measurements. Where detail measurements were needed they were done using the on-board total station.

- Pilot projects similar to that above but including simultaneous measurements of the position of the edges of the road, existing cables and other objects of interest. In two such projects in excess of 1470 points were measured along a distance of 10,5 km.

In all of the projects carried out for the Telecommunications Administration the required accuracy was 10-20 cm.

In the majority of this surveys the connection to the national network has been done directly by using either existing points from the survey area or by using new determinated points etablished with help of GPS.

7. RESULTS

The tables nr 3-6 shows the results obtained with ULISS 30 on the various tasks: calibration baselines and pilot projects. The values given for the RMS are calculated from the differences between the ISS determinated coordinates and those already known by other techniques, classical or by GPS.

The ISS coordinates are the average of twice measured survey points and were adjusted in the post processing using two or more known points.

Table 6.

COMPARISON CLASSICAL MINUS INS COORDINATES (Mariestad)

Pnr	Km	x	y	h	dx m	dy m	dh m
14220	0.0	6530297.76	26519.39	51.67			
14299	0.5	6529759.65	26459.48	54.48	0.00	0.02	0.09
14300	0.8	6529802.74	26676.03	63.12	-0.02	-0.04	0.10
195	1.3	6530038.65	27137.83	68.08	-0.04	-0.01	-0.17
14301	1.4	6530098.05	27235.83	69.34	0.05	0.01	0.10
196	1.6	6529987.03	27426.40	66.30	0.06	0.01	0.07
197	1.8	6529911.77	27547.87	67.81	0.09	0.00	0.11
198	1.9	6529876.10	27690.54	71.56	-0.01	0.00	0.08
218	3.6	6528811.10	28538.64	74.70			
				RMS	=0,05	0,02	0.10

The experiences gained so far allows us to conclude as follows:

- In order to increase the production results and the accuracy it is necessary to prepare carefully the ISS surveys. Prereconnaissance and marking of the points to be surveyed are recommanded prior the ISS mission.

- If the density of the survey points is to large it is recommanded to make the measurements in two different stapes: first measurement of a number of basic points strategicly distributed along the traverse (primary network), and secondly measurement of all details) between this basic points. (This is commun fact by cables surveys.)

- The use of the "harmonized" total station facilitate higly the field operations.

- The operators of ISS have to be trained and familiar with both equipment, software and the problems encountered in classical geodetic surveys

- The accuracy of the ISS surveyed points is influenced and depending on:

  * the length of the mission (less an tree bours)
  * the distance between known points
  * the number of known points in the traverse (2 or more)
  * the straight of the lines between known points ("knees" are decreasing the accuracy)
  * the number of points which are surveyed twice or more
  * the speed, time needed for execution of the mission
  * the precalibrations and alignements quality
  * the software used for the post processing

- The following accuracies are possible with ULISS 30 as long as double measurements (forward and backward) or more are made and the lines are straight. For distances less than :

2 km	accuracy	+/- 5 cm
10 km	-"-	+/- 10 cm
50 km	-"-	+/- 50 cm

The internal accuracy between ISS surveyed points is high. Comparisons with distances measured by total station shows that the differences up to 300 m were about +/- 2 to 3 cm. (Exampels in Gagnef commune.)

8. CONCLUSIONS

The ISS technique has proved to be flexible and very efficient for the type of surveys mentioned above if a appropriate methodology is used for each different type of survey.

Well planned ISS missions give high production results and are time-saving compared to classical land survey techniques. ISS makes possible to increase the productivity by a factor 3 to 5.

The cost can be reduced to about 50 persent compared to the conventional techniques specially in forested areas, where the existing networks are defficient and decimeter accuracy is acceptable (large scale projects).

It is possible to achieve decimeter accuracy as long as double measurements are made and the distances between known points are less than 10 km.

However there is a great deal to be done in order to improve the post processing models of the raw inertial datas. Software problems exist and are critical for the results.

ISS are basically "interpolation-systems" and required known points (3-D) at the ends of the traverses. This is a handicap which hopefully will be eliminated in the next years when the efforts to develop a "hybridation" between ISS and GPS will be successfull. This "hybrid system" will allow a total autonomy of work with centimetric accuracies and would be sufficient for most types of geodetic surveys.

To day ISS can be used successfully in combination with GPS or conventional survey techniques, for many large scale or smaller projects. We are looking forward to the comming generation of integrated ISS/GPS systems.

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