GNSS Technology Developments in Point Position Fixing in Hungary

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Key words: GNSS technology, stop and go, RTK, Network RTK

SUMMARY

In the past decade the impact of GNSS hardware and software development and specially the ground based infrastructure improvement is favourable. As a consequence of this, the applied technology for geodetic position fixing is changing from static measurements to network RTK.

In this paper we present and describe the technological steps we went through in Hungary in the past years.

At the beginning of GPS era – because of the lack of GNSS infrastructure – we used the traditional horizontal points as reference, static measurements and postprocessing. After that the national GPS network had been established, we used it as a frame for connecting it to ETRS and the local Hungarian datum as well. Later, the traditional RTK dramatically reduced the time of measurement. The active GNSS network has already had the opportunity achieving positioning without own reference station.

In order to test the three realised concepts of network RTK, namely the VRS, FKP and MAC, we have done experimental measurements in the past months. Based on the first results, we may say, that furthermore significant effectiveness is expected by introducing this new technology.

We also investigated such favourable solutions where the classical GPS receivers were not equipped with RTK-capable hardware and software units. We came to the conclusion, the stop and go method with On-the-Fly initialisation is advisable because the observation time may be decreased down to some minutes. This method, of course, requires post-processing. Applying the newest technical developments, the Network RTK is desirable, because the observation time is very short, and there is possibility for real-time quality control in order to reach the cm level accuracy of GNSS based positioning.

We think so, our experiences in geodetic point position fixing technology may be useful for other colleagues across the professional world.

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1. THE GNSS PROVIDED OPPORTUNITIES

The GNSS comprises the basic system, the augmentation system and the user segment including the instrumentation and applied software as well (Fig. 1).

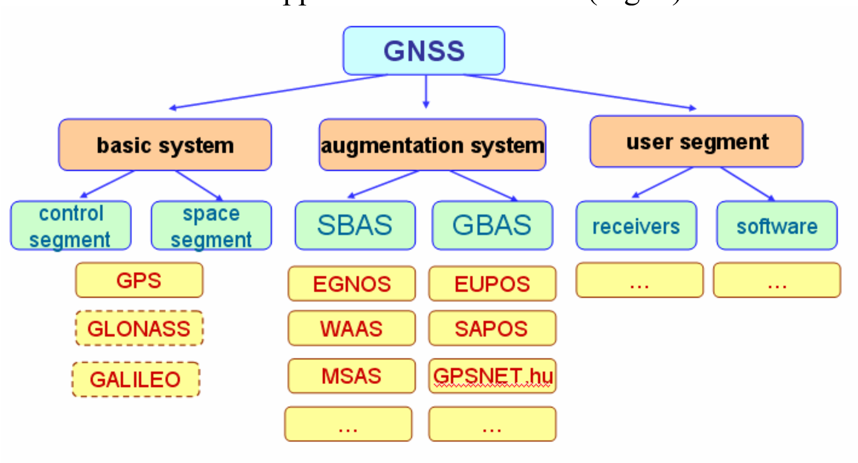

Fig. 1. The components of GNSS

Practically, if we speak about basic GNSS system, we mean the NAVSTAR GPS. It may be said, there have not been significant changes in the basic system since the full installation had been completed in 1993, even if the satellite segment developed and the network of tracking stations has been extended. In the meantime, the accuracy of position increased and the SA has been ceased. New frequency (L5) and code (L2c) are expected to give furthermore and significant developments in the future *(Rizos at al., 2005).*

The GLONASS is still not fully installed, although, it is being said officially, it will reach the level of full operation. However, it is not guaranteed, there will be large number of receivers which will be able to receive the signals from both type of systems.

The Galileo seems to be a great promise, but full operation is expected after 2010.

The development of GNSS infrastructure has brought fundamental changes in the GNSS based positioning. The satellite based Augmentation System (SBAS) has a big role in the increasing accuracy of code measurements and the extension of integrity. If phase corrections may be transmitted in the future, then the precise point positioning concept may be realised.
The development of ground tracking network (the GBAS) made a breakthrough in the positioning during the past decade. Different global civil services are being operated and national networks of permanent stations are being installed worldwide. The continuously operating reference stations (CORS) can be used for real-time or post-processing. If we use more stations simultaneously, the solution may be more effective.

The greatest changes occurred in the applied mathematical models and the developed software. At the beginning of 90s, the relative static observations needed at least an hour. New algorithms allowed decreased period of observations, usually between 10 and 20 minutes, depending on the number of frequency of receiver. The On-the-Fly initialisation increased the efficiency of kinematic observations creating the basic of the classical RTK technology.

Originally, own reference station was needed to achieve RTK measurement, nowadays the networking means the present and the future technological solution. One of the advantages of RTK-GPS is the rapidity, that is, the short-time initialisation and measurement. Furthermore advantage is the on-line quality control of positioning.

RTK receivers and total stations have been integrated to eliminate the unfavourable terrestrial circumstances. The leading manufacturers, first of all the Trimble and Leica, constructed such modular equipments which have same platform and software using common database and applying wireless communication between the receiver and the controller.

All in all, the efficiency of new instruments can be exploited, if we use a complete network of reference stations instead of an own reference receiver. This is called Network RTK having different concepts. These solutions will be introduced in the following chapters.

2. THE NETWORK RTK

The network RTK means the set of GNSS permanent stations being regionally harmonised and operated. In order to achieve a high-accurate and efficient real-time positioning, the processing centre collects and analyses the data of permanent stations modelling several factors having influence on the measurement accuracy. The extent of reference stations and the relating services may be local, countrywide or continental. The continuous operation must be guaranteed as well as the quality and integrity of data. At least, one processing centre is needed. The first-generation network RTK was realised in the developed countries at the beginning of 2000s.

2.1 VRS – Virtual Reference Station

In the concept of VRS, first the rover must transmit its approximate position to the processing centre. The centre generates corrected observations for the received provisional position and then transmits these corrected values to the rover. This is a bidirectional communication between the rover and the processing centre.

At first, this technology was applied by the Trimble and has been widespread later. The widespread use is due to the fact, there is no need for special hardware or software component in the rover, the data process is same as in the case of classical RTK. In the VRS concept, the observation data and the correction cannot be separated from each other, namely, the fictitious observation is generated for a particular rover.

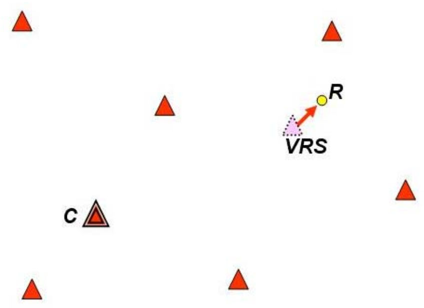

Fig.2. The VRS conception

In the original VRS concept, the correction was computed based on the actual position of rover. However, because of the moving rover, the resolution of phase ambiguity was a time consuming task and the capacity of rover did not allow the achievement of this operation without difficulties. Thus the position of reference station is fixed. However, this solution has also a drawback, namely, if the rover gets far from its original position, since the large distance changes may cause significant errors in the position. Because the rover does not sense the virtual reference, as an artificial object, therefore a reference being too close to the rover may cause furthermore disadvantage, because the rover does actually not use optimal processing, e.g. single-frequency solution instead of double-frequency one.

Because of the above written disadvantages, some software changes the rover-transmitted positions around 4…5 km. This is the Pseudo Reference Station (PRS). Such a solution is applied in the GNSMART software (Geo++), when the shifted position of rover is refreshed time after time according to the kinematic route.

To standardise the VRS concept a regular grid was proposed *(Townsend, 2000).* According to this, the corrected observations were generated at the node of this grid and not at the position of the rover. Finally, the rover interpolates the corrections based on the grid values.

2.2 Area Correction Parameter (FKP)

In the concept of FKP, the processing centre determines corrections to each permanent station. To model the distance dependent corrections, the parameters of an inclined plane are computed. This simple linear model has been very effective in the practice, but it may also be replaced with polynomial regression. The parameters of plane are computed for ionosphere-free and narrow-lane linear combinations at each satellite thereby the distance-dependent errors can be determined in the case of L1 and L2 frequency. The user must be aware of the closest permanent station and connected to it. Precisely saying, the user downloads the raw observations and the parameters of the inclined plane from the central server. In contrast to the VRS, this communication is unidirectional communication. The processing and the corrections are done by the rover based on the received correction parameters and the coordinate differences between the station and the rover.

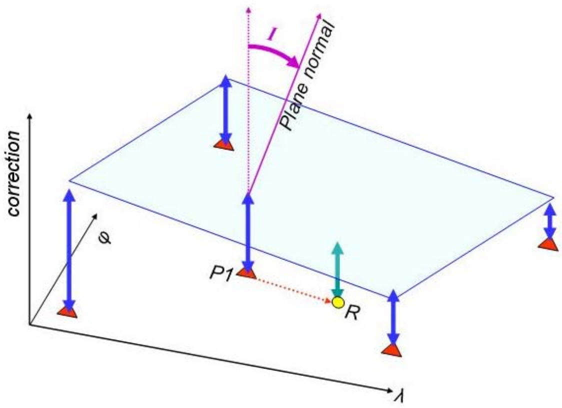

Fig.3. Symbolizing the FKP corrections.

The advantage of this method is the rover can always compute a motion-dependent individual correction. Disadvantage is the limited distance, because the distance between the station and rover must not exceed 100 km. Over this distance the correction parameters are not valid. The correction can be transmitted in RTCM 2.3 format through the message of number 59. The standardisation of this message was initiated by the German Geodetic Service, since this method was worked out in Germany at first. That is why the abbreviation of this concept is FKP (**F**lächen**k**orrektur**p**arameter- area correction parameter).

2.3 Compacted Raw Data and Corrections –MAC

The concept of the MAC (Master Auxiliary Concept) is to transmit the primary raw observation data and correction to the rover in compacted format separating the slowly and rapidly changing corrections *(Euler at al., 2001, Cranenbroeck, 2005).* This suggestion was submitted by the experts of Leica to the commission of RTCM SC104 in 2001. As a result of this, a provisional RTCM 3.0 standard was accepted in 2005. According to the concept, only the raw observation data and corrections of main station (master) are transmitted in original form, while in the case of the auxiliary stations, only the differences with respect to the master station. Since the amount of transmitted data is less, the transmitting time is much shorter and there is no need for wide bandwidth. Applying the differences, the rover can re-compute the raw data. Furthermore advantage is the user can select the appropriate model at the rover according to the requirements. Thus the user can carry out network adjustment (multiple-baseline positioning) or individual modelling *(Lachapelle, Alves, 2002).*

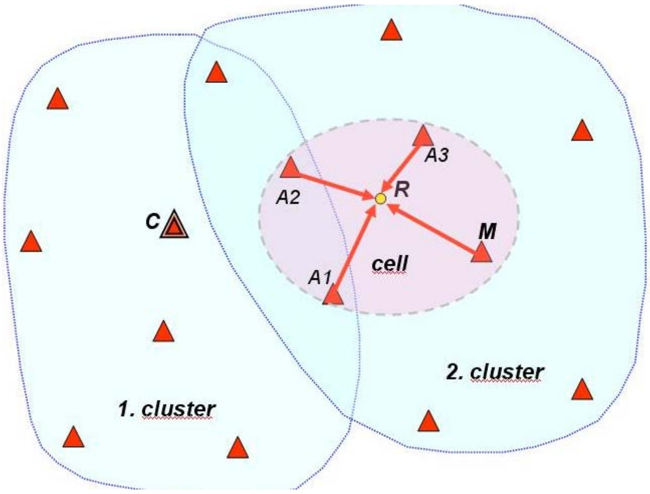

Fig.4. The MAC conception.

According to the MAC, the network can be classified as clusters and cells. In this case the network means the set of all stations of which corrections have to be computed by the centre. The cluster is such a subnetwork, that is uniquely computed and the baseline end-points have common ambiguity level. In a network, the clusters may cover each other having common points. The cell is the subset of a cluster that is used by a particular rover during the positioning. The master and the auxiliary stations are chosen within the cluster depending on the type of communication between the rover and the master.

In the case of bidirectional communication, the rover transmits its navigation coordinates to the centre where the cell stations and the master will be chosen. This is called Automatic Cell Corrections.

If there is only unidirectional communication, then the user can choose among the pre-defined cells selected provisionally by the software controlling operator. Here, the user must know the pre-defined cells and the actual one according to the rover position. This correction has been called as Single Cell Corrections in the instruments of Leica.

3. THE HUNGARIAN GNSS INFRASTRUCTURE

There are three different levels of the augmentation ground infrastructure. The first level is the so-called passive GPS network. This was established in 1991 creating a 24 points frame. This frame has been fixed to EUREF by 5 points, therefore its reference system is the ETRS89. Totally there are 1153 control points in the network with the average distance of 10 km that is called Hungarian National GPS Network (HGN). These points are identical with the points of the Hungarian Triangulation Network (HD72) and 350 points have levelled height as well. This allows achieving local transformation anywhere in the country with the standard error of 2…4 cm. The establishment of passive network was finished in 1997.

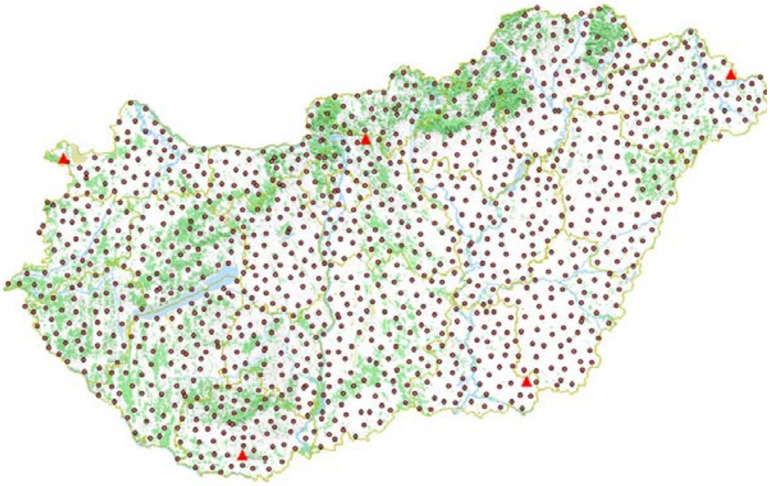

Fig.5. The 1153 points of Hungarian National GPS Network.

The second level of the infrastructure is the permanent network. In accordance with the plan there would be 12 permanent stations, but only 10 stations had been installed by the beginning of 2006. The average distance between the permanent stations is 100 km providing 50…60 km baseline solutions in the most unfavourable arrangement. The coordinates of the permanent stations are based on the Hungarian National GPS network. In the meantime, the project of EUPOS (European Position Determination System) was being launched to create a unified infrastructure in Eastern-Central Europe.

Within the range of this initiation a test network was realised around Budapest in 2005 in the cooperation of private companies and different institutes. The data collection and archiving is done by the software installed on the Ntrip server. RINEX files are stored hourly, furthermore six and twenty four hour’s period of time. More and more user downloads data to post-processing through the Internet. The greatest advantage of the second-level infrastructure is, there is no need for reference station set by the user.

The third level of the infrastructure is the real-time operated Network RTK service. The corrections are transmitted by the reference stations to the centre through TCP/IP port at each second.

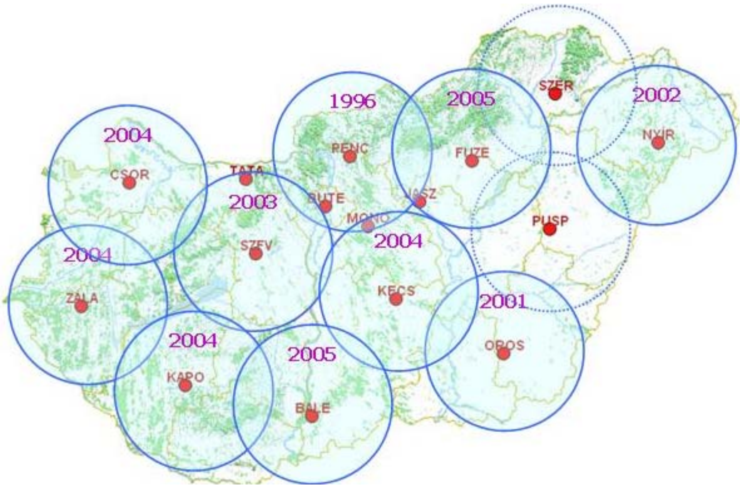

Fig.6. The 12 points of planned active GPS Network.

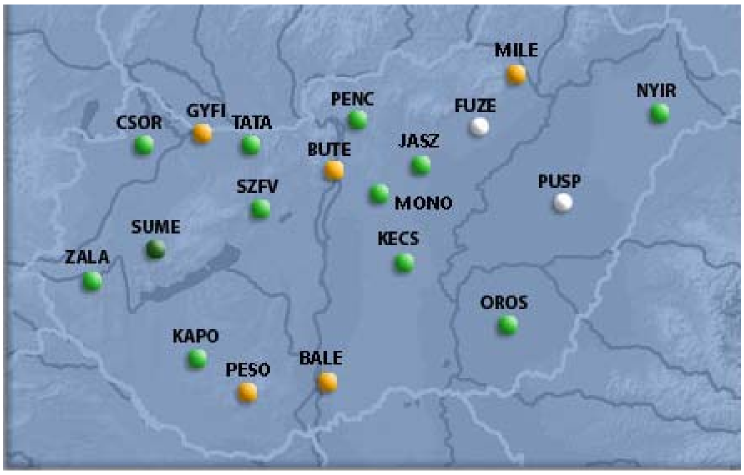

Fig.7.Operating stations in January 2006 (green and yellow). www.gpsnet.hu

The processing centre is installed and maintained by the Satellite Geodetic Observatory (SGO) of Penc. The first server was put on in April 2004. The SpiderNet and GNSMART software were installed during the summer of 2005 being able to compute the corrections of VRS, FKP and MAC. The task of NtripCaster is the multiplication of data in order to transmit them to number of users, who have themselves registered. There are two types of real-time services, namely, the availability only code or code and phase observations.

4. THE REVIEW OF GEODETIC FIXING TECHNOLOGIES

In Hungary, similarly to any countries across the world, the position fixing technologies formed from the static observations to the network RTK solutions gradually. The applied technology depends on the instrumentation and the processing mode. For this reason, several methods will be introduced in this chapter may be employed in geodetic position fixing.

a. Post-processing Because of the Lack of GNSS Infrastructure

As it is known, in this case the reference receivers are set up by the user at known HD72 stations, while the others at the points to be determined. Forward and inverse transformation parameters are computed between the HD72 and ETRS89 systems before the processing, employing the twenty four points reference frame of Hungary (the transformation error may exceed decimetre). Based on these parameters, the reference stations are transformed into ETRS89 in that the vector processing and network adjustment are carried out. As a result of this process, we transformed the ETRS89 coordinates into HD72 coordinates by reverse parameters. Applying this technology, the transform horizontal HD72 coordinates are correct relatively, but the "quasi" ETRS89 coordinates must not be used anymore. This principle was used at the beginning of GPS era.

b. Free Network Solution without GNSS Infrastructure

In this case an arbitrary reference station is set up where ground objects do not disturb the signal propagation. The coordinates of this station are primarily determined by single point positioning obtaining a free "GPS coordinate system". The rovers will be located at furthermore HD72 points, serving as a basis for ETRS89-HD72 transformation.

Similarly to the above written post-processing, the obtained ETRS89 coordinates are not true ETRS89 coordinates, but the local mapping coordinates will be relatively correct. Whether post-processing or RTK is used, this method may be successful even if the GNSS infrastructure is not exploited.

c. Post-Processing Based on the GPS Network

The coordinates of the National GPS Network are considered as fix points. The newly determined points are tied to this frame obtaining true ETRS89 coordinates. There is no need for bidirectional transformation parameter set since we just transform the ETRS coordinates into HD72 ones. One transformation parameter set does not ensure the cm level accuracy therefore local transformation parameter sets are computed.

d. Real-Time-Processing Based on Passive Reference Station

Here the reference station is chosen from the national GPS network where the reverence receiver is installed. After configuration, the rover receives the raw data generated by the reference receiver. The position can be determined after couple of seconds of time lag receiving phase corrections to reach the level of 1…2 cm in accuracy. It is desirable to set own local transformation parameter set in the controller.

e. Post-Processing Based on Permanent Reference Station

In this case the reference observations are provided by the permanent stations. The user just needs one receiver set at the points to be determined. Depending on the instrumentation and the software, short time static or kinematic observations are carried out. After the field works, the user download the observations of the permanent stations in RINEX format through the Internet and then the vector computations will be achieved.

f. Real-Time-Processing Based on Single Permanent Reference Station

This is the most common used method for control point positioning of detailed surveying, staking out and detail surveying alike. There is only one receiver operated by the user. The transformation is carried out similarly to section d.

g. Real-Time Processing Using Network RTK

The most conspicuous difference from the above written single permanent station solution is the user receives data from more permanent stations simultaneously. The range of distances between the rover and the permanent stations may be increased without deteriorating the accuracy of positioning. The processing centre has responsibility for transmitting corrections to the user who must possess the necessary hardware and software receiving the corrections (VRS, FKP or MAX).

5. EXPERIENCES OF SINGLE BASE POSTPROCESSING KINEMATIC TECHNOLOGY

The above presented methods have assumed the users had the appropriate hardware and software components. But what should the users do if they do not have any RTK receiver? Is there any method to substitute the RTK solution making the measurements more effective? Our definite answer, there are, namely the kinematic, stop and go observations with On-the-Fly initialisation employing the most up-to-date software.

For the sake of verification we present the results of some experimental measurements achieved nearby Szekesfehervar. In the test area, nine test points were measured employing stop and go method in five periods. The periods of measurements are denoted as roman numerals during the further discussions. Own reference receiver was set at an earlier monumented fix point (3001) nearby the test area, but furthermore permanents stations were also involved in the post processing. These were the following: SZFV (being 15 km from the test area), BUTE (43 km), PENC (80 km), KAPO (116 km), ZALA (141 km). The reference point and the test points had had known local mapping coordinates (HD72) from earlier terrestrial observations.

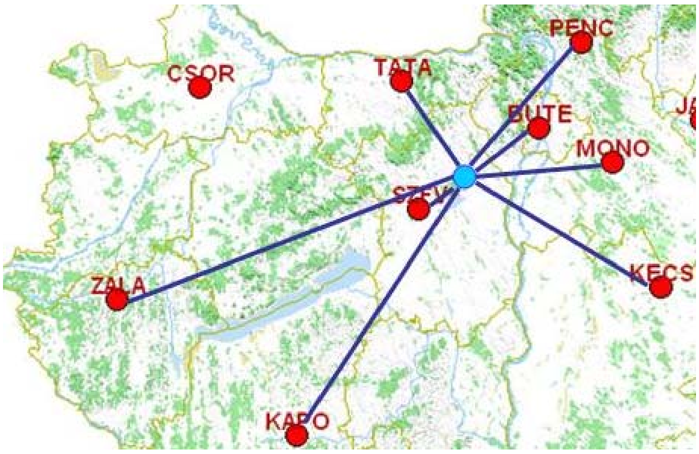

Fig.8. The used permanent stations in single base and Network RTK test.

During the first four periods, the rover was switched on continuously. The observations lasted 30 seconds at each point mounting the antenna on a pole with collapsible antenna tripod. In the case of the fifth period, the rover was transferred without power support simulating disturbed visibility of the sky. The rover was switched on directly before the occupation so the period of kinematic observation took 2…3 minutes. The satellite configuration was excellent during the observation since eight satellites were permanently observed. The instrumentation contained two Leica SR 520 sensor and the data were processed by Leica SKI Pro 2.0 and 3.0 software. The repeated observations were processed and analysed in different way to conclude the reachable accuracy and estimate the maximum length of baseline and the minimum number of epochs.

The points were computed based on single-baseline solution. After the process, we just accepted those vectors of which the phase ambiguity had been successfully resolved and then we transformed the coordinates of test points into HD72 system applying only one transformation parameter set. Finally, we computed the differences between the transformed and known HD72 coordinates and averaged the absolute values of residuals. The results are figured in Table 1. It can be seen, the discrepancies are proportional to the increasing length of baseline, but generally, they do not exceed 3 cm. The last two columns includes those discrepancies, that were computed omitting the reference station using only the data of station SZFV and BUTE. For the sake of interest, we present the results over 50 km long baseline, confirming that cm level of accuracy can be reached over long baseline as well.

Table 1. The averaged absolute residual of coordinates with respect to the known local coordinates. Unit is m.

Nr	**3001 nearest**		**SZFV**		**BUTE**		**adjusted**	
	dy	dx	dy	dx	dy	dx	dy	dx
I.	0,003	0,010	0,011	0,005	0,017	0,037	0,018	0,023
II.	0,006	0,009	0,015	0,025	0,008	0,036	0,008	0,029
III.	0,004	0,006	0,017	0,014	0,010	0,010	0,014	0,010
IV.	0,018	0,016	0,017	0,015	0,007	0,010	0,015	0,013
V.	0,020	0,017	0,013	0,016	0,005	0,021	0,012	0,016

Table 2. The averaged absolute residual of coordinates with respect to the known local coordinates. Unit is m.

Nr	PENC		KAPO		ZALA		adjusted	
	dy	dx	dy	dx	dy	dx	dy	dx
I.	0,024	0,026	0,005	0,029	0,005	0,029	0,007	0,023
II.	0,027	0,029	0,008	0,036	0,017	0,013	0,018	0,023
III.	0,034	0,025	0,026	0,049	0,005	0,041	0,026	0,026
IV.	0,033	0,033	0,006	0,024	0,008	0,019	0,013	0,022
V.	0,029	0,034	0,008	0,027	0,007	0,025	0,010	0,032
mean	0,029	0,029	0,011	0,033	0,008	0,025	0,015	0,025

The surprisingly accurate results are due to the Leica 3.0 software that has been available since 2004. Based on the tabulated values, it may be said, that precisely achieved kinematic observations can ensure 2 cm in accuracy up to 50 km baseline. The choice of optimal technology highly depends on the given circumstances, and finally, the right selection of the best solution is always the task of the surveyor. If this technology is used for the determination of control points, then we have to ensure furthermore checking observations during the field measurements.

6. EXPERIENCES WITH LEICA SMART STATION

The Leica SmartStation came out during the spring of 2005. One of its peculiarities is the so-called GPS free station function. This was tested in single baseline and network RTK mode according to section f and g. The observation lasted 30 seconds, however the phase ambiguity was resolved usually within ten seconds. We present only two typical tables of the results with respect to the single baseline and network solutions (Table 3 and Table 4).
Both table show, the actual standard errors (residuals) were smaller, than the instrument-displayed ones (RMS and CQ coordinate quality, the positional error). Horizontally the standard errors turned out between 1 and 2 cm, while the vertical standard errors exceed 2 cm that may be the consequence of the long baseline. The 9.7 cm vertical error at station SZFV is due to the phase centre eccentricity that was not accounted by the software. According to the expectations the network RTK was always better than the single baseline solution.

Table 3. Single-baseline coordinate residuals with respect to the permanent stations. Unit is metre.

Nadap known point, single base solution									
Permanent station	base [km]	Instrument displayed errors				Residuals at known points			
		RMS			CQ	East	North	linear	vertical
ref		σy	σx	σH		dy	dx	dl	dH
SZFV	17	0,014	0,016	0,032	**0,038**	-0,011	-0,007	**0,013**	**0,114**
TATA	42	0,014	0,017	0,033	**0,040**	-0,011	-0,003	**0,011**	**0,004**
BUTE	41	0,013	0,016	0,030	**0,036**	-0,020	0,006	**0,020**	**-0,011**
PENC	77	0,014	0,017	0,032	**0,039**	-0,022	0,004	**0,023**	**-0,015**
MONO	63	0,013	0,016	0,030	**0,036**	-0,010	-0,010	**0,014**	**-0,038**

SZFV	17	0,012	0,022	0,039	**0,047**	-0,009	0,005	**0,011**	**0,097**
TATA	42	0,011	0,022	0,042	**0,049**	-0,009	-0,007	**0,012**	**-0,062**
BUTE	41	0,011	0,023	0,049	**0,055**	-0,029	-0,018	**0,034**	**-0,048**
PENC	77	0,013	0,030	0,072	**0,079**	-0,013	-0,018	**0,023**	**-0,032**
MONO	63	0,011	0,028	0,071	**0,077**	-0,017	-0,007	**0,019**	**-0,033**

In this paper we assumed the data may be downloaded for real-time and post-processing applications as well employing a fully installed GNSS infrastructure. We also investigated such favourable solutions where the classical receivers were not equipped with RTK-capable hardware and software units. We came to the conclusion, the stop and go method is advisable with On-the-Fly initialisation because the observation time may be decreased down to 1…2 minutes. This method, of course, requires post-processing. Applying the newest technical developments, the Network RTK is desirable, because the observation time is very short, usually under 20 seconds, and there is possibility for real-time quality control in order to reach the cm level accuracy of GNSS based positioning.

Table 4. Network RTK coordinate residuals with respect to the permanent stations. Unit is metre.

Nadap known point, Network RTK solution									
Type of network concept	Seri-es	Instrument displayed errors				Residuals at known points			
		RMS			CQ	East	North	linear	vertical
		σy	σx	σH		dy	dx	dl	dH
SCI	10	0,015	0,019	0,035	**0,042**	-0,017	0,000	**0,017**	**0,007**
NEAREST	10	0,013	0,018	0,034	**0,040**	-0,007	0,003	**0,009**	**0,033**
FKP	10	0,014	0,026	0,041	**0,050**	0,000	0,000	**0,005**	**0,037**
VRS	10	0,019	0,026	0,058	**0,066**	-0,006	-0,001	**0,010**	**0,035**
IMAX	1	0,012	0,020	0,033	**0,041**	-0,010	0,000	**0,010**	**-0,018**
SCI	1	0,011	0,019	0,036	**0,042**	-0,017	-0,011	**0,020**	**-0,031**

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BIOGRAPHICAL NOTES

György Busics works as a lecturer at the Department of Geodesy at the Faculty of Geoinformatics, University of West Hungary. He graduated as a land surveyor engineer at the Technical University of Budapest in 1977. He worked as a field surveyor at the Cartographia Company. In 1981 he changed his work, since that he works as a teacher and research fellow at Székesfehérvár. His teaching and research field covers the GNSS technology, geodetic networks, quality management and supervising students. He obtained his Dr.techn. academic title at the TU Budapest, 1995. He is a member of Satellite Geodetic Sub-committee under Hungarian Academy of Sciences and fellow of Hungarian Society of Surveying, Cartography and Remote Sensing.

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