Hungarian Association of Agricultural Informatics
European Federation for Information Technology in Agriculture, Food and the Environment

Journal of Agricultural Informatics. Vol. 11, No. 1
journal.magisz.org

Technical characteristics of global navigation satellite systems and their role in precision agriculture

Róbert Barna[1], Katalin Tóth[2], Mónika Zita Nagy[3], Kristóf Solymosi[4]

INFO
Received 24-06-2020
Accepted 15-07-2020
Available on-line 17-07-2020
Responsible Editor: L. Várallyai

Keywords:
GNSS, GPS, Galileo, measuring, Precision Agriculture.

ABSTRACT

Originally developed for military applications, Global Navigation Satellite Systems (GNSS) have become a part of our daily lives. It is also essential in modern agricultural production. For example, precision crop production and precision livestock farming work with a lot of position (stationary or dynamic) data provided by navigation systems. The first global navigation system was called Global Positioning System (GPS). Since then, a number of similar independent systems have been developed because of the fact that the service can be restricted or even disabled due to an event. Modern terrestrial navigation devices measure their position across multiple GNSS systems, thus increasing accuracy.
In this article we will illustrate the general operational features with an example of the oldest navigation system, the NAVSTAR GPS of the USA. In addition, we present the main features of Galileo, the system set up by the European Union, which is expected to be fully operational in 2020. We present the market situation for GNSS systems and illustrate its use through some precision farming applications.
We conducted in-depth interviews to learn about farmers' knowledge and motivations about GNSS technology and precision farming. All those who are not yet or only partially precision farmers want to switch to full precision farming in the long run. Respondents have all heard of Galileo, but their knowledge is partial. Users are waiting for Galileo to be fully operational.

1. Introduction

The development of positioning based on satellites, now commonplace, is linked to the military industry. The technology, primarily designed for military navigation, has become available in civilian life, where it is used to retrieve data with a variety of accuracy requirements.

The best known of these systems are the US NAVSTAR GPS (Global Positioning System for Navigation Satellite Timing and Ranging, simply GPS) and the Russian GLONASS (GLObal NAvigation Satellite System). (Detrekői and Szabó, 2002) Since both systems are operated by the army, it can become inaccessible to users at any time. To eliminate dependence, Japan has developed the QZSS (Quasi-Zenith Satellite System) and India has developed IRNSS (Indian Regional Navigation Satellite System).

The Chinese BDS (BeiDou Navigation Satellite System) was built in 3 phases. Initially, the regional BeiDou-1 system (2000-2007) was used in China and neighboring countries, and then the

[1] Róbert Barna
Kaposvár University, Faculty of Economic Science, Institute of Methodology
barna.robert@ke.hu
[2] Katalin Tóth
Kaposvár University, Faculty of Economic Science, Institute of Regional and Agricultural Economics
toth.katalin@ke.hu
[3] Mónika Zita Nagy
Kaposvár University, Faculty of Economic Science, Institute of Methodology
nagy.monika@ke.hu
[4] Kristóf Solymosi
Kaposvár University, Doctoral School in Animal Science
solymosi.kristof@ke.hu

BeiDou-2 system, also known as Compass satellite system (2007-2015), became available in the Asia-Pacific region. The third BeiDou-3, still under development, already provided a global service at the end of 2018.

The Galileo navigation system, developed by the European Union, is fully civilian, and is expected to be completely operational at the end of this decade.

More and more similar systems are emerging in the world – these are collectively called the Global Navigation Satellite System (GNSS). (Károly, 2018a; 2018b)

2. Principle of satellite positioning

To determine our position, we first calculate the time delay of the electromagnetic wave from three visible and known satellites to the receiver. From this, the distance of each satellite can be calculated by knowing the propagation speed (speed of light) of the signal. Then we can determine our position based on the principle of triangulation (Figure 1). The locations of points at a given distance from a point are on a spherical surface. We can form three spheres so that the three measured satellites give the center of the spheres and the calculated distance is the radius. These three spheres intersect at two points, but the coordinates of one of them would be so extreme that it could be immediately ruled out (either inside the Earth or somewhere in space). (Belényesi et al., 2008)

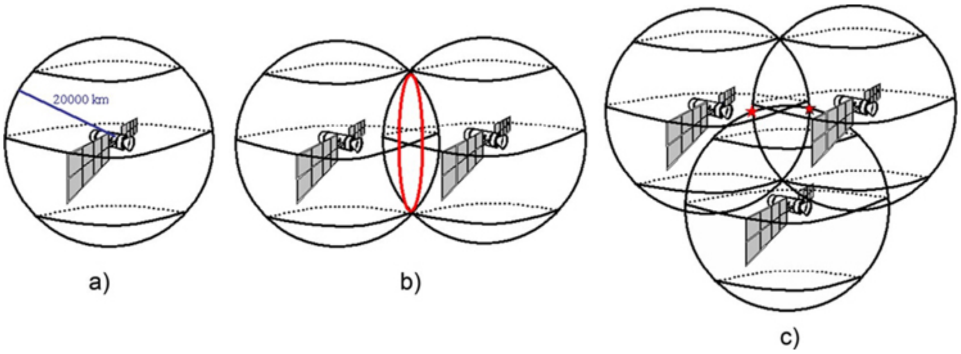

Figure 1. Distance from a: 1 satellite, b: 2 satellites, c: 3 satellites (Belényesi et al., 2008, 57. p.)

There are three segments to satellite positioning: the satellite system (Space Segment), the ground segment with control system (Control Segment) and the receivers of users (User's Segment) (Figure 2). (Busznyák, 2011)

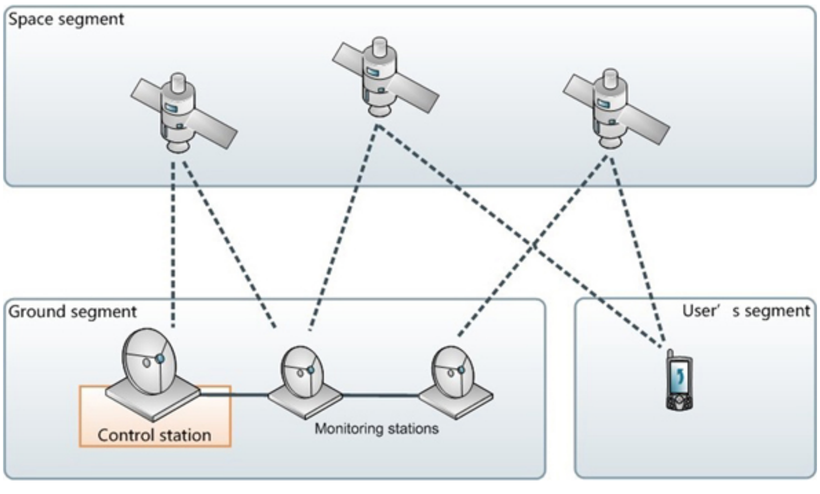

Figure 2. Parts of satellite positioning (http://access.feld.cvut.cz/storage/201102071036_Fig1.jpg)

2.1. Space Segment

The GPS system officially became fully operational in 1995 (FOC: Full Operation Capability) when 24 Block IIA type satellite were in orbit (Figure 3). The system has 24 artificial moons orbiting at approximately 20200 km in orbit. The orbits are designed so that users can always see at least 5-8 satellites from anywhere on Earth. (Busics, 2010a)

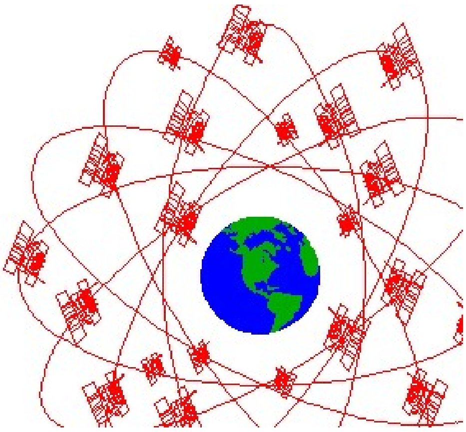

Figure 3. The 6 orbits of GPS satellites (http://www.agt.bme.hu/tutor_h/terinfor/gif/35afig96.gif)

The GPS satellites transmitted the data needed for measurement at two frequencies (L1, L2). The freely available C / A (Coarse / Acquisition) code was broadcast only on the L1 carrier signal, while the P (Precision) code was transmitted to military users by the L1 and L2. Each of the signals contains the data (D-Data) required for the measurement. Navigation data such as the current position of the satellites or the clock correction data.

As a result of modernization, GPS satellites are currently transmitting eight signals at three frequencies. (GPS.GOV, 2017a)

2.2. Control Segment

The Operational Control Segment (OCS) is made up of a global network of ground facilities that is monitoring GPS satellites plus their transmissions, perform assessments, and send commands back to the satellites. The ground control stations continuously measure and improve the parameters of the satellites and, if necessary, make orbital changes (Figure 4). (GPS.GOV, 2018)

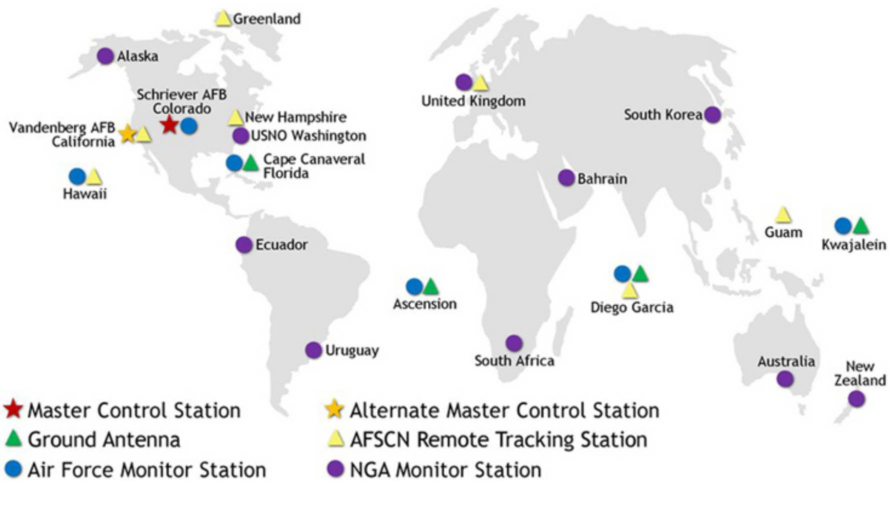

Figure 4. GPS Control Segment (https://www.gps.gov/multimedia/images/GPS-control-segment-map.pdf)

2.3. User's Segment

GPS receivers are responsible for determining their own current position, using the hardware needed for measurements and the software needed for evaluation. Receivers can be divided into three groups: navigation receivers, GIS receivers and geodesic receivers (Figure 5).

navigation recievers GIS recievers geodetic recievers

Figure 5. The three basic types of GPS receivers in User's Segment

Navigation receivers are the most common and cheapest devices used for absolute positioning and navigation. Tangible receivers have an accuracy of around 10 meters. Receivers for GIS data collection are more expensive devices, their accuracy is measured in meters, but it is possible to achieve accuracy under 1m. The devices consist of a data acquisition (control) unit and an antenna. Geodetic receivers carry out phase measurements, so their accuracy is in the order of mm. Geodetic receivers achieve accuracy of 5 mm in relative upright (static) measurement and cm when in motion (kinematic measurement). (Busics, 2010b)

3. The measurement

Distance measurement is not directly possible for obvious reasons, but distance can be calculated. If we know the propagation speed of the signal and we can measure the time it takes to travel from satellite to receiver, then the speed and time gives the path. The speed of the signal is known (speed of light, c), so measuring the time is the task to be solved. Accuracy of timing is essential as a millisecond error causes a 300 km error. Because of this, the satellites run several (3-4) atomic clocks. The distance can be obtained in two ways, code measurement or phase measurement.

3.1. Code measurement principle

The satellite broadcast signal indicates which satellite was broadcasting at that time. Code measurement can be performed only if the GPS receiver is familiar with the code generation algorithm. The receiver also generates a copy of the code sent from the satellite, the so called replica code and begins to measure the time until the satellite receives the same "patterned" signal. When the incoming code overlaps the replica code, the timing stops (Figure 6), and the distance can be calculated. (Ádám et al., 2012)

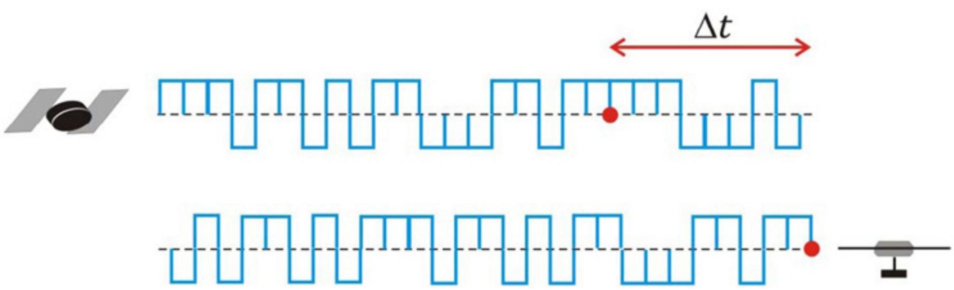

Figure 6. Code measurement principle (Ádám et al., 2012, p. 39.)

If the receiver's clock were perfect, the three measurements would result in our actual location. However, satellite clocks are accurate, but not the receivers' ones, thus ue to an inaccurate receiver clock, all measurements have the same error. The receiver's clock error can be eliminated by taking another measurement, so each receiver must see at least four satellites. (Belényesi et al., 2008)

The theoretical accuracy of the code measurement is 3 meters for civilian and 0.3 meters for military purposes. (Ádám et al., 2012)

3.2. Phase measurement principle

In phase measurement we can measure the phase position $\Delta\varphi$ (t) of the carrier wave with the codes. The distance to be measured consists of two parts: the unknown integer product of N over the periods ($N \times \lambda$) and the residual distance that can be determined by phase measurement ($\Delta\varphi / 2\pi \times \lambda$). (Busics, 2010c)

It is sufficient to determine the number of complete cycles (N) at the time of the first measurement. If the receiver does not move and follows the satellite while continuously measuring the phase, then the value of N can be calculated from the results of four consecutive measurements. The receiver records the number of complete cycles received after the start of the measurement (n). The distance can then be calculated as $N\lambda + n\lambda + (\Delta\varphi / 2\pi)\,\lambda$ (Figure 7).

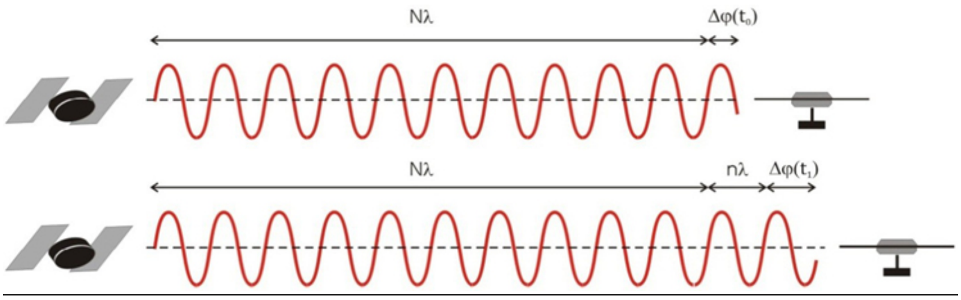

Figure 7. Performing phase measurement at times t0 and t1 (Ádám et al., 2012, p. 41.)

For phase measurement, the measurement is – in principle – accurate to 2 mm for each carrier wave. Therefore, geodetic data is collected by this method, phase measurement. (Busics, 2010c)

3.3. Result of measurement

GPS receivers provide horizontal (Λ, Φ) and elevation (h) coordinates in the WGS-84 reference system. In case of another projection system, the measurement results have to be converted (transformed) into Unified National Projection (EPSG: 23700) system coordinates, which is used in Hungary. (Sárközy, n.a.)

The accuracy of the results is affected by many factors:

- satellite orbit and clock errors,
- the delay caused by the ionosphere,
- the delay caused by the troposphere,
- multipath propagation caused by surface objects,
- cycle jumps due to an object placed between the satellite and the receiver,
- error due to antenna phase center deviation,
- receiver clock error,
- adverse satellite geometry,
- errors due to covering of terrain, trees, buildings. (Belényesi et al., 2008)

Due to the delay in the ionosphere, the satellite measures the distance of the satellite longer than it actually is, and, if not corrected, would result in large positioning errors. This delay is proportional to the signal frequency, the lower frequency signals suffer more delay than the higher frequencies.

Therefore, by measuring at two different frequencies for the same satellite, the ionospheric delay error can be reduced. (Ádám et al., 2012)

To ensure accuracy of measurements, the GPS satellites themselves transmit correction parameters in the navigation message. This can be complemented by SBAS (Satellite Based Augmentation System) and GBAS (Ground Based Augmentation System). The SBAS service transmits reference data and distance corrections from satellites in the geostationary orbit to the receiver. EGNOS (European Geostationary Navigation Overlay Service) is available free of charge in Europe. EGNOS uses terrestrial GNSS measurements at reference stations with well-known coordinates in Europe. The stations transmit all measurement errors to a central computer hub, where the necessary corrections are calculated. They are transmitted to the three satellites located above the Equator so that, in principle, they are always visible from anywhere in Europe.

Apart from EGNOS, there are three globally owned, civilian-supervised, global-scale SBAS systems: WAAS (Broad Extension System) in North America, MSAS (Multifunctional Satellite Based Extension System) in Japan and GAGAN (GPS and Geo-Enhanced Navigation System) in India. (Busics, 2010d)

Another way to correct accuracy measurements is Precise Point Positioning (PPP). PPP is provided by the International Global Navigation Satellite System (ISS) network service. IGS is a worldwide system of civil GNSS reference stations, data centers and analysis centers independent of GNSS core system operators. It aims to "provide high-quality, high-precision GNSS data and products that can be used as a standard to support earth science research, multidisciplinary applications and education". IGS is an active global network, but most services are not available in real time.

During PPP, longer period measurements with the GNSS receiver are processed afterwards, which does not use the on-board orbit data of the given system, but the precise orbit data provided by the IGS, post-determined clock parameters and atmospheric models.

The trajectory, clock, and atmospheric models provided by the active IGS network have improved over time, which is why the PPP method also provides increasingly accurate results. (Busics, 2010d)

Relative positioning has been developed to eliminate the most common measurement errors. In this case, simultaneous measurements are made at a reference point of known coordinate and at one (or more) unknown points. At the reference point, the difference between the measured and known coordinates, ΔX, ΔY and ΔZ, can be calculated. These coordinate differences are transmitted by the reference station to other receivers via a real-time communication channel (radio, GSM telephone, mobile Internet), which corrects their own coordinates. It is important that all receivers detect the same satellites at the same time.

Customers can stay in one place during measurement (static measurement) or move one or more of the customers (kinematic measurement). (Ádám et al., 2012)

In relative positioning, at least two receivers are required for simultaneous measurement, a base station at a known location and a rover station also at a known position. If the measurement is real-time, then the proper communication conditions for data traffic must be ensured. If the user provides them himself, he does not depend on others to operate the equipment (autonomous measurement). For service-based metering, they can use a built-in active network instead of their own autonomous system that provides them with the necessary correction data for a fee. (Busics, 2010e)

Real-time kinematic measurement is called DGPS (Differential GPS) positioning, and phase measurement is called RTK (Real-time Kinematic) positioning. Both methods require the calculation of correction data and their transmission to the customer via a fast communication channel. At least four satellites are required for DGPS and five for RTK. RTK can be based on one or more bases. A base system consists of a reference station and a rover, which is installed at a known position (Ádám et al., 2012). In case of autonomous measurement, the base is temporary, it is only working at the time of measurement. On the other hand, in the case of service-based measurement, the base is permanent (for example one of the base points of GNSSnet.hu). With the case of RTK measurement, corrections calculated from data measured by several coordinated permanent bases are provided to the customers by a single control panel. (Busics, 2010e)

3.4. GNSSnet.hu

Its statutory definition follows as a system of Hungarian active GNSS networks maintained by the central governmental organization for surveying and GIS and services based on it (VM, 2013). From its name it relies not only on the GPS network but also on other navigation systems (GLONASS, Galileo). For even coverage of the country, the stations were located at distances of about 60-70 km. A total of 35 stations in Hungary have been built, with 19 stations from the neighboring countries helping to ensure full coverage of the border areas (Figure 8).

The GNSS Service Center provides real-time GNSS correction services and post-processing off data. The Differential GNSS (DGNSS) service provides accuracy of under one meter for GIS, navigation and hobby applications. They provide RTK and grid RTK corrections for geodetic and precision agricultural purposes. (KGO, 2019)

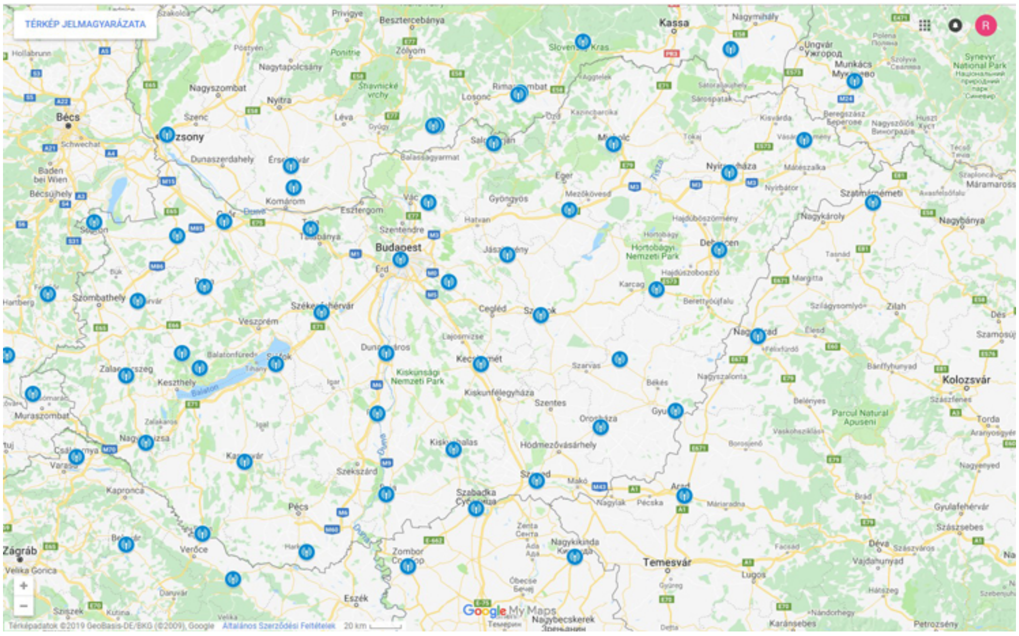

Figure 8. GNSSnet.hu base points (http://www.sgo-penc.hu/geo_halozatok.php)

4. Modernisation of GPS satellites

The space segment of GPS is continuously undergoing development. In 1995, the fully deployed system contained 24 units of Block IIA (2nd generation, “Advanced”) satellites. The satellite generations since then have been released in chronological order: Block IIR (“Replenishment”), Block IIR-M (“Modernized”), Block IIF (“Follow-on”), GPS III, and GPS IIIF (“Follow-on”) (GPS.GOV, 2018).

Eight Block IIR-M satellites launched between September 2005 and 2010 are already broadcasting the new civil code L2C. Because the L2C signal is transmitted by satellites at a higher power than the L1 signal, it provides better reception indoors and under the canopy of trees. Since the effect of the ionosphere is a function of frequency, receiving the same signal at two frequencies can significantly reduce the ionospheric effect. Until then, this option was only available for military use. Also, these satellites were the first to broadcast the new hard-to-crack and obfuscated M code (M: Military). A complete satellite system will ensure full functionality by 2020. (GPS.GOV 2017b)

From May 2010 to February 2016, 12 Block II-F satellites were launched. These included new, more accurate atomic clocks, a more easily reprogrammed computer system, and the new L5 frequency (1176.45 MHz). (Busics, 2010a)

Combining L5 with L1 C / A improves accuracy through ionospheric correction. The use of three GPS frequencies (L5, L1 C / A and L2C) allows for sub-meter accuracy without supplementary services (SBAS, GBAS). The L5 has not yet been fully commissioned, so its use is limited. (GPS.GOV, 2017b)

The first Block IIIA satellite was launched on December 23, 2018, followed by nine more. The biggest novelty is the newer civilian signal L1C, which has moved to the L1 frequency, where the L1 C / A signal is still available.

L1C was originally developed jointly by the US and the European Union for GPS and Galileo as a common civilian signal, but L1C-like signals were also accepted by the Japanese, Chinese and Indian GNSS systems.

The satellite is currently in test phase only. (GPS.GOV, 2017b)

L1C is the fourth civilian GPS signal. It was designed to enable the operability between GPS and international satellite navigation systems, thus it will improve GPS reception (e.g. for cars, mobile phones) in cities and other challenging environments.

Japan's Quasi-Zenith Satellite System (QZSS), the Indian Regional Navigation Satellite System (IRNSS), and China's BeiDou system also use L1C-like signals for operability through borders. (Xu and Xu, 2016)

As a result of the upgrade, the GPS satellites will transmit eight signals (four civilian and four military signals) at three frequencies. (GPS.GOV, 2017a)

5. Galileo navigation system

Europe’s own global navigation system, Galileo functions with each Galileo satellite transmiing 10 different navigation signals, allowing Galileo to offer four different services. Signals may include navigation data (data channels) and non-data carriers (pilot channels). The data channels contain code that identifies the given satellite from where the signal came. Long codes allow for the interpretation of very weak signals such as those that can be received inside a building (of course it needs more time). On the other side, it takes less time to receive shorter codes, but the receiver can mix signals from two satellites more easily. Differentiating between two codes in the receiver is inversely proportional to the length of each code.

Galileo provides alternative codes with different characteristics for different needs (an indoor, stationary user requires a long code, while an outdoor, fast-moving car needs rather short codes). In addition, many codes allow estimation of the ionospheric delay error in the receiver. This is the reason why Galileo services are usually implemented in pairs of signals. (ESA, 2018)

Galileo offers four global services when fully operational:

- Open Service (OS): Open and free positioning and timing service on smartphones or car navigation systems. After full operation, the measurement accuracy for a single frequency measurement is 7.7 m horizontally, 12.6 m vertically, 1.8 m horizontally and 2.9 m vertically for two frequency measurements;
- High Accuracy Service (HAS): An additional code is added to the OS in a different frequency band to achieve accuracy close to cm. HAS allows you to develop professional or commercial applications. The HAS signal can be encrypted to control access. Galileo's high precision service is a redrafting of the former Galileo Commercial Service (CS);
- Public Regulated Service (PRS): A service limited to government-authorized users (Civil Defense, Fire Department, Customs and Police) for sensitive applications. They require a level of service availability in national emergencies or crises such as terrorist attacks;
- Search and Rescue Service (SAR, formerly Safety of Life - SOL): Europe's contribution to COSPAS-SARSAT, an international satellite-based search and rescue alarm system. As a result, the search time after triggering the alarm is reduced from three hours to only ten minutes at sea or in the mountains. In addition, the position of the alarm will be determined within 5 km instead of the current 10 km (GSA, 2019).

The Galileo system expected to be fully operational in 2020. (GSA, n.d.)

6. GNSS in agriculture market

The global precision agriculture market will grow with a CAGR (Compounded Annual Growth Rate) of 12% through 2020, while the total market value will be about $5.5 billion until then (Dressler et al., 2015).

This increase is reflected in the agricultural penetration of GNSS-based solutions. The global annual delivery of a GNSS device by 2025 is expected to be more than tripled, and the penetration of a GNSS device is expected to increase by more than 50%. By generating revenue controlled by autonomous flight, but with an expected fast price drop, high-precision applications will become easier to access. Variable Rate Applications' revenue will be near to €900 million in 2025, as more efficient business models are better established. This growth is primarily due to the rapid deployment of sophisticated agricultural applications in both the developing world (India, China and the Smart Pacific) and the most developed areas (US, Europe and Australia). (GSA, 2018)

The most technologically advanced region in the world is North America followed by Asia. In addition, the former is the most developed in Precision Agriculture (PA) (More about PA see Chapter 7). Furthermore, according to expectations, PA market will be doubled in North America between 2015 and 2025 (GSA, 2017).

With the average farms being large and highly mechanized, and also having to have high costs of labor, US farmers have been great adopters of precision agriculture applications. Services such as soil sampling with GPS and guidance systems are examples the most popular ones among farmers. WAAS (Wide Area Augmentation System) has a significant penetration (approx. 70%), while RTK solutions offered by public, commercial or public and commercial partnerships, are preferred for more advanced uses (Holland et al., 2013).

In Europe, Western and Eastern countries are moving at different speeds and maturity levels to adopt GNSS-based solutions. In Western Europe, an advanced precision agricultural sector boasts increased production and mechanization, mainly due to increased cost-effective management. For example, in the Netherlands, GNSS is well adopted and 65% of farmers use its technology in their cultivation in 2016. (Michalopoulos, 2016)

Eastern Europe, however, starts at a lower level but also grows at a greater pace, driven by the need for increased output, the RTK, DGNSS and EGNOS will have market penetration rates of 25%, 8.5% and 67% respectively (VVA Market Research, 2012).

Additional emphasis should be placed on users' expectations of EGNSS (European GNSS), especially in relation to the new opportunities opened by Galileo HAS and SAS, dual frequency receivers (or even multi-frequency ones such as PPP - Precise Point Positioning). This would allow the realization of the potential of E-GNSS (GNSS based on EGNOS correction) in the technology-driven era of agriculture.

Increased and sustainable agricultural production, addressing main social and economic challenges (global population growth, increased food demand, increasing middle-class' higher calorie intake), relies on GNSS-enabled solutions in a number of ways. GNSS user needs, closely linked to growing and emerging market trends, are:

- Enhancements in high-precision solutions (multiple constellation, multiple frequencies, Galileo High-Precision Service (HAS), coupled with increased availability of low-cost equipment (e.g. EGNOS-enabled devices and more affordable GNSS RTK solutions);
- A combination of GNSS with other technologies such as Remote Sensing, proximal sensor, IoT and Robotics, drones, Integrated Farm Management Solutions and Big Data Analytics.

In this regard E-GNSS solutions could be significant in the usage of GNSS by farmers and applied in a variety of applications (GSA, 2018).

„The introduction of the Galileo GNSS, offering technological innovations and new business concepts compared to traditional GNSS, will benefit the application of GNSS in the agricultural community in various application areas." (Lokers et al., 2007)

7. Usage of GNSS in precision agriculture

Precision Agriculture (PA) is the application of the "right treatment in the right place at the right time". Relying on the utilization of various technologies - dominantly on precise positioning through GNSS, it enables in-depth, site-specific management of agricultural production (Figure 9). Precision agriculture applications are steadily rising over the past few decades with the help of low-cost and high-accuracy GNSS solutions. It has been driven by the need for improved crop yield by optimizing inputs. Thus, farmers have been able to minimize soil compaction, reduce the use of fuel, pesticide and fertilizers, and increase productivity by precisely guiding their farming equipment and accurately applying different inputs tailored to their fields. Other significant benefits include the reduction of environmental impacts and, of course, increased worker safety.

There is great diversity of applications in agriculture for GNSS, mainly: Guidance systems, Variable Rate Applications, Site-Specific Data Analysis applications and tracking/delineation. Each of these application groups has its own GNSS performance requirements.

The most widespread and well-adopted PA solutions are the accurate and precise steering of tractors and other farming equipment. Methods such as machinery guidance, automatic steering and controlled traffic farming (CTF) enable machinery to move along tracks on the field, minimizing overlaps, being faster and allowing extended work periods. Equally important are Variable Rate Technology applications that allow the efficient utilization of nutrients and chemical products in different areas of the field, and more importantly precise seeding and planting. In the future, new applications are coming to existence such as field levelling and drainage, implement guidance, grassland-related operations (where EGNOS could have an advantage), and machine telematics. (GSA, 2018)

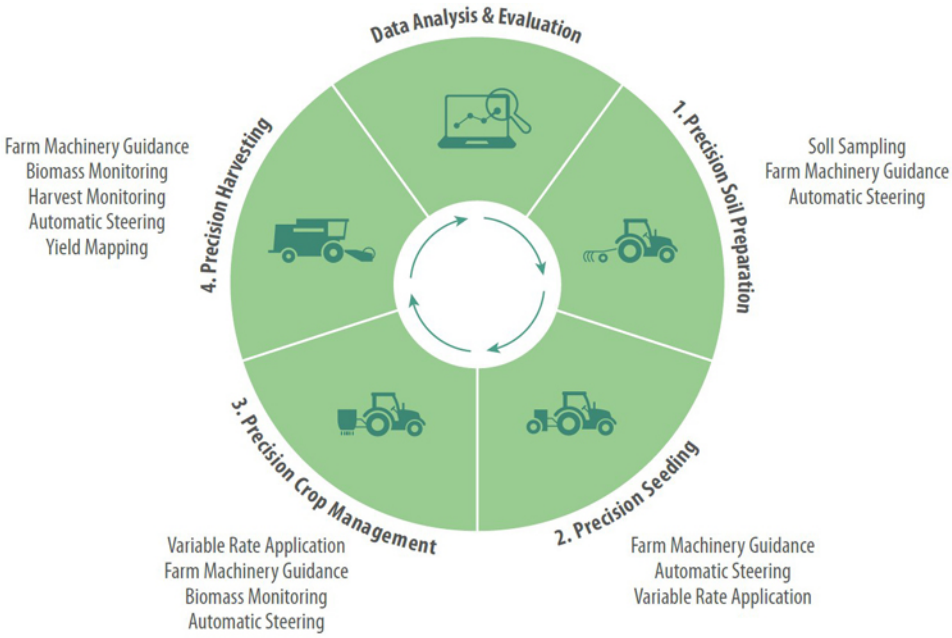

Figure 9. Overview of GNSS-supported precision agriculture activities along the crop cycle (GSA 2018, p. 23.)

Farm Machinery Guidance systems have field operations such as spraying, fertilizing, planting and harvesting (Figure 10). They utilize corrected GNSS signals, aiding farmers in driving on the planned path. By reducing overlaps and skips between adjacent track lines on the field, guidance systems enable increased driving accuracy, improve in-field efficiency, and allow working at night or under low-visibility conditions. GNSS-based guidance relies either on a prior pass or on a fixed line. For prior pass guidance, the driver starts by manually steering the machinery on a path along the field. Once the pass is recorded, all subsequent passes across the field are carried out at a given distance from that particular pass. This distance is typically the swath width of the equipment. The prior pass method is god for adapting to the shape of the field. On the other hand, in fixed-line guidance, the first path is carried out along the so-called AB line connecting two predefined points. As with the prior pass guidance, all subsequent passes are defined by a given offset distance - typically the swath width - multiplied by an integer. Contrary to the prior pass guidance, each subsequent pass is dependant on the AB line, the offset distance and the respective integer. (Heege, 2013)

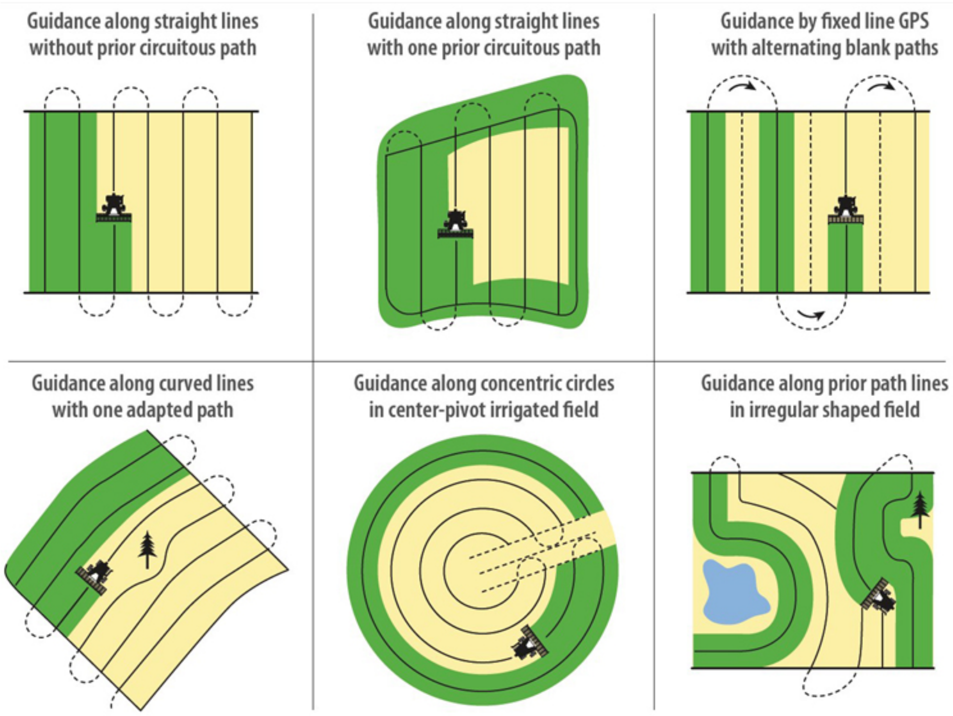

Figure 10. Examples of various In-field driving patterns (GSA 2018, p. 25.)

Whether referring to manual or autonomous guidance, farmers' requirements are focused mainly on GNSS receiver performance. The farm machinery guidance solutions should offer a pass-to-pass accuracy of 10-30 cm ensured through SBAS or DGNSS. Automatic steering solutions, as well as advanced machinery guidance (i.e. planters, weeders), require cm-level (2.5-10 cm) accuracy ensured via RTK solutions. For activities where the farmer returns to an exact location at a different time (e.g. strip tillage) high-repeatability is also necessary, meaning smaller effects from GNSS drift. RTK has essentially no impact from GNSS drift, whereas DGNSS (Differential GNSS) and SBAS can drift in a range from 50-150 cm. Apart from accuracy requirements, availability and continuity in the reception of GNSS signals (especially to mitigate operating environment and multi-path impacts) are very important factors. (Mullenix et al, 2010)

With regard to GNSS accuracy, requirements vary depending on the specific farming process (Figure 11). Thus, activities such as spreading, spraying and harvesting of bulk crops require sub-meter to decimeter accuracy provided by SBAS/DGNSS. However, demanding activities such as seeding, planting and weeding require cm-level accuracy provided by RTK. Furthermore, GNSS-based solutions should provide automatic controlling capabilities (i.e. turning the spreaders on and off depending on the exact site). (GSA, 2018)

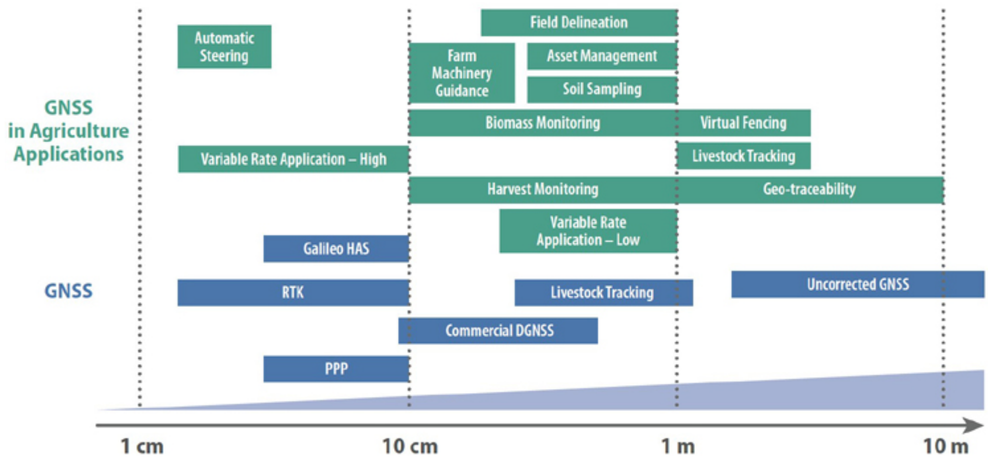

Figure 11. Positioning accuracy requirements per GNSS application and technology (GSA 218, p. 36.)

8. Galileo awareness among Hungarian farmers

In order to assess the awareness of Galileo GNSS system, we conducted qualitative research and conducted structured in-depth interviews. In-depth interviews were conducted in April 2020 in the form of an informal interview, in person or by telephone, with four agricultural specialists from Somogy County, who had decision-making power and/or insight in the field of enterprises (Table 1). We did not strive for representativeness in the survey, but it was important that the respondents really had an insight into how the businesses work. We looked for farms of a size where efficient precision farming can (or could) be carried out efficiently. Based on personal acquaintance, we selected the respondents, who were fully or partially precision farmers and also traditional farmers. Partly precision farmers use certain precision elements - line guide and RTK-based automatic steering, section control. In the long run, they want to introduce the full range of technology into currently not yet fully precision farming businesses.

Table 1. Background variables

No.	Economic form, start of operation	Interviewee	Area size, ha	Management mode
I.	Co. Ltd., 2007	owner, machine operator, 44 years old	510	traditional farming
II.	Ltd., 1994	owner, 38 years old	350	partly precision farming
III.	Ltd., 2013	founder of company, 65 years	310	full precision farming
IV.	Co. Ltd., 2001	agronomist, 36 years old	2700	partly precision farming

In addition to basic management data, the in-depth interview questions focused on the familiarity with the Galileo system and the associated views of farmers. In addition, in the case of precision or semi-precision farms, we were also interested in how the information from the obtained data is utilized by the given economy.

The answers on knowledge of satellite systems show that they are basically familiar with the technology, they know GPS and Glonass, but the RTK, Trimble and Ag Leader systems too.

All of the in-depth interviewees had heard of Galileo, they knew it was a European development, one of them called it the “European GNSS system”.

They differed on the impact that the introduction of Galileo would have on accuracy, speed and cost. There were those who said that using the Galileo system would increase both speed and accuracy and reduce costs, while others believed that Galileo would not bring anything improvement over the past. According to one of them, it may improve the accuracy of the return, but this does not substantially affect precision farming, it has no effect on speed, but he could not judge its impact on costs. The remaining respondent could not judge the impact of the introduction of Galileo.

Respondents use other commercial software in addition to the factory software added to the machines, but some also use open source software, QGIS.

The fully precision farm is equipped with all the tools currently on the market: autopilot, automatic steering, active implement control, automatic turn table's end, automatic section control, active charge control, variable dose application, machine communication, remote monitoring. The data obtained by them are analyzed by experts, and the following application plans are prepared based on the information extracted from them. In addition to the experts' analyzes, Agrovir and SMS software are used to perform their own analyzes. They, since they built their farm on American GPS, do not want to switch to Galileo.

Overall, regardless of whether they are traditional, precision or 'mixed', all in-depth interviewees have heard of the Galileo system. The owner of the traditional farm was the most positive about the evaluation of the system, the farmers applying the elements of precision farming cannot yet clearly judge the speed, accuracy and contribution of the system to the costs.

Conclusion

The use of GNSS in agriculture will become inevitable. Precision management requires a great deal of satellite navigation support, furthermore continuous development of available GNSS systems contributes to increasing accuracy. It is particularly important in Europe for more accurate navigation to be made available by making full use of the Galileo system.

Users are waiting for the Full Operational Galileo. It would be useful to carry out more in-depth economic studies in this area and it would be worthwhile to describe in detail the technical characteristics and accuracy of Galileo in order to switch to its use, thus becoming independent of the US, Russian and Chinese systems.

Acknowledgements

The work is supported by the EFOP - 3.6.3 – VEKOP – 16 – 2017 - 00005 project. The project is co-financed by the European Union and the European Social Fund.

References

Ádám J., Rózsa Sz., & Takács B. 2012 'GNSS elmélete és alkalmazása' Oktatási segédlet. Budapesti Műszaki és Gazdaságtudományi Egyetem, Építőmérnöki Kar. Földmérő és Térinformatikai mérnök mesterszak. (Online) Available at: https://edu.epito.bme.hu/local/coursepublicity/mod/resource/view.php?id=57066 (Accessed: 17 October, 2019)

Belényesi M., Kristóf D., & Skutai J. 2008 'Térinformatika elméleti jegyzet' Egyetemi jegyzet. Skutai J. (ed.). Gödöllő: Szent István Egyetem, Mezőgazdaság- és Környezettudományi Kar, Környezet- és Tájgazdálkodási Intézet

Busics, Gy. 2010a 'Műholdas helymeghatározás 2. - GNSS alaprendszerek - Az amerikai GPS' (Online) Available at: https://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_MHM2/ch01s02.html#id489165 (Accessed: 7 December, 2019)

Busics, Gy. 2010b 'Geodéziai hálózatok 4. - A GNSS alapjai - A NAVSTAR GPS részei' (Online) Available at: https://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_GEH4/ch01s04.html (Accessed: 23 November, 2019)

Busics, Gy. 2010c 'Geodéziai hálózatok 4. - GPS-jelek, adatok, hibaforrások' (Online) Available at: https://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_GEH4/ch01s05.html (Accessed: 23 November, 2019)

Busics Gy. 2010d 'Műholdas helymeghatározás 7. - Aktív GNSS hálózatok és szolgáltatásaik - További, műholdas alapú kiegészítő GNSS rendszerek' (Online) Available at: https://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_MHM7/ch01s05.html (Accessed: 10 October, 2019)

Busics, Gy. 2010e 'Műholdas helymeghatározás 1. - A GNSS-ről általában - A GNSS technológiákról' (Online) Available at: https://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_MHM1/ch01s05.html (Accessed: 4 December, 2019)

Busics, Gy. 2010f 'Műholdas helymeghatározás 3. - Matematikai modellek - GNSS hibaforrások és hatásuk' (Online) Available at: https://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_MHM3/ch01s03.html (Accessed: 9 October, 2019)

Busznyák J. 2011 'Az informatika ágazati alkalmazásai - 4. fejezet: Globális helymeghatározás eszközeinek agrár-felhasználása' Debreceni Egyetem, Nyugat-Magyarországi Egyetem, Pannon Egyetem. (Online) Available at: http://www.tankonyvtar.hu/hu/tartalom/tamop425/0010_1A_Book_20_Az_informatika_agazati_alkalmazasai/ch04.html (Accessed: 21 October, 2019)

Dressler N, Gundermann S, Keese S, Aulbur W, Zhang J, Amichi S, Marinoni A, Nagashima S, & Cherkin E 2015 'Business opportunities in precision farming: Will big data feed the world in the future?' München: Roland Berger Strategy Consultants GmbH, 181. p. doi: 10.1007/978-3-658-20905-6, (Online) Available at: https://www.rolandberger.com/publications/publication_pdf/roland_berger_business_opportunities_in_precision_farming_20150803.pdf (Accessed: 19 December, 2019)

ESA (European Space Agency) 2018 'Galileo Open Service (OS)' (Online) Available at: https://gssc.esa.int/navipedia/index.php/Galileo_Open_Service_(OS)#cite_note-ESA_GALILEO-3 (Accessed: 15 September, 2019)

GPS.GOV (Official U.S. government information about the Global Positioning System (GPS) and related topics) 2017a 'GPS Modernization' (Online) Available at: https://www.gps.gov/systems/gps/modernization/ (Accessed: 13 September, 2019)

GPS.GOV (Official U.S. government information about the Global Positioning System (GPS) and related topics) 2017b 'GPS Modernization, New Civil Signals' (Online) Available at: https://www.gps.gov/systems/gps/modernization/civilsignals/ (Accessed: 13 September, 2019)

GPS.GOV (Official U.S. government information about the Global Positioning System (GPS) and related topics) 2018 'Control Segment' (Online) Available at: https://www.gps.gov/systems/gps/control/ (Accessed: 13 September, 2019)

GPS.GOV (Official U.S. government information about the Global Positioning System (GPS) and related topics) 2019 'Space Segment, Current and Future Satellite Generations' (Online) Available at: https://www.gps.gov/systems/gps/space/#generations (Accessed: 13 September, 2019)

GSA (European GNSS Agency) 2017 'GNSS Market Report, Issue 5.' (Online) Available at: (https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf (Accessed: 17 October, 2019) doi: 10.2878/0426,

GSA (European GNSS Agency) n.d. 'Programme' (Online) Available at: https://www.gsc-europa.eu/galileo/programme (Accessed: 14 November, 2019)

GSA (European GNSS Agency) 2018 'Report on Agriculture User Needs and Requirements - Outcome of the European GNSS' User Consultation Platform' (Online) Available at: https://www.gsc-europa.eu/sites/default/files/sites/all/files/Report_on_User_Needs_and_Requirements_Agriculture.pdf (Accessed: 14 November, 2019)

GSA (European GNSS Agency) 2019 'Galileo Services' (Online) Available at: https://www.gsa.europa.eu/galileo/services (Accessed: 13 January, 2020)

Heege H.J. 2013 'Precision in Crop Farming Site Specific Concepts and Sensing Methods: Applications and Results' Dordrecht: Springer, 356. p. doi: 10.1007/978-94-007-6760-7

Holland J.K., Erickson B., &Widma D.A. 2013 '2013 Precision Agricultral Services Dealership Survey Results' (Online) Available at: https://agribusiness.purdue.edu/wp-content/uploads/2019/08/rs-11-2013-holland-erickson-widmar-d-croplife.pdf (Accessed: 19 January, 2020)

Károly, K. 2018a 'Applications of Global Navigation Satellite Systems in Military and Civilian Fleet and Force Tracking Systems (1.). Globális műholdas navigációs rendszerek alkalmazási lehetőségei katonai és polgári célú flotta- és erőkövetési rendszerekben (1.)' *Honvédségi Szemle* Vol. 146. No. 1. HU ISSN 2060-1506, pp. 83-97.

Károly, K. 2018b 'Applications of Global Navigation Satellite Systems in Military and Civilian Fleet and Force Tracking Systems (2.). Globális műholdas navigációs rendszerek alkalmazási lehetőségei katonai és polgári célú flotta- és erőkövetési rendszerekben (2.)' *Honvédségi Szemle* Vol. 146. No. 2. HU ISSN 2060-1506, pp. 77-88.

KGO (Kozmikus Geodéziai Obszervatórium) 2019 'Szolgáltatások' (Online) Available at: http://www.sgo-penc.hu/szolgaltatasok.php (Accessed: 23 October, 2019)

Lokers, R.M., van der Wal, T., & Turecki, T. 2007 'Galileo improves farming' *Proceedings of the 6th Conference of the European Federation for Information Technology in Agriculture, Food and Environment* (ed.). (Online) Available at: https://www.informatique-agricole.org/download/efita-conference/Congres_EFITA_2007/monday/1400/business_theme-dss_applications/fieldfact_efitawcca2007_25042007_20070425164015.pdf (Accessed: 3 May, 2020)

Michalopoulos, S. 2016 'Europe entering the era of 'precision agriculture' (Online) Available at: https://www.euractiv.com/section/science-policymaking/news/europe-entering-the-era-of-precision-agriculture/ (Accessed: 16 October, 2019)

Mullenix, D., Fulton, J., Brooke, A., & Winstead A. 2010 'Explanation of GPS/GNSS Drift' *Precision Agriculture Series Timely Information Agriculture, Natural Resources & Forestry*, (Online) Available at: https://sites.aces.edu/group/crops/precisionag/Publications/Timely Information/GPS-GNSS_Drift.pdf (Accessed: 14 May, 2020)

Sárközy, F. n.d. 'Térinformatikai elméleti oktatóanyag' (Online) Available at: http://bme-geod.agt.bme.hu/tutor_h/terinfor/tbev.htm (Accessed: 29 September, 2019)

Xu, G., & Xu, Y. 2016 'GPS: Theory, Algorithms and Applications' 3rd edition. Berlin Heidelberg: Springer-Verlag, doi: 10.1007/978-3-662-50367-6, 489 p.

VVA Market Research 2012 'GNSS in Agriculture' (Online) Available at: http://www.vva.it/content/Upload/GNSSinAgriculture.pdf (Accessed: 19 November, 2019)

VM 2013 'A vidékfejlesztési miniszter 15/2013. (III. 11.) VM rendelete, 1. § 18.' (Online) Available at: https://www.gnssnet.hu/pdf/MK_13_041_15-2013.pdf (Accessed: 23 April, 2020)