High-End and Low-Cost RTK GNSS in Machine Control and Precision Farming Applications

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SUMMARY

High accuracy real-time positioning of moving objects has been considered a standard task of engineering geodesy for 10 to 15 years. An absolute positioning accuracy of 1-3 cm is generally possible worldwide and is furthermore used in many areas of machine guidance (machine control and guidance), farming (precision farming), as well as for various special applications (e.g., railway trolley, mining, etc.). The cost of the measuring instruments required for the use of geodetic L1/L2 receivers with a local reference station amounts to approximately USD 30.000 to 50.000. Dual frequency RTK GNSS receivers are therefore not used in the mass market.

Affordable GPS/GNSS modules (hereafter referred to as GNSS) have already reached the mass market in various areas such as mobile phone, car navigation, leisure industry, etc. Kinematic real-time positioning applications at centimetre or decimetre level can also become a mass product. The costs for such systems must, however, lie under USD 1000 to 2000. The precise specification of the meaning of low-cost is determined by the given application.

Several university studies in geodesy focus on the approach of high accuracy positioning by means of single frequency receivers for static applications. [e.g. GLABSCH et. al. 2009, SCHWIEGER and GLÄSER 2005, ALKAN 2010, REALINI et. al. 2010, Korth and Hofmann 2011]. Procedures for real-time output of RTK GNSS positions based on L1 receivers do not yet exist. Although intelligent approaches have been developed that compute a trajectory in the post-processing mode **[**REALINI et. al., 2010**]**, there are only very few systems that enable real-time processing.

The approach to precise position determination by means of the computation of static raw data with single frequency receivers is currently being explored in a research project at the Beuth Hochschule für Technik Berlin - Applied of Applied Sciences and is being further developed for kinematic applications. This project is embedded in the European Social Fund. It is a follow-up project on the topic of static positioning with single frequency receivers [KORTH and HOFMANN, 2011].

ZUSAMMENFASSUNG

Die zentimetergenaue Echtzeitpositionierung von bewegten Objekten gehört seit etwa 10 bis 15 Jahre zur Standardaufgabe in der Ingenieurgeodäsie. Eine absolute Positionsgenauigkeit von 1-3 cm ist nahezu weltweit möglich und wird auch in vielen Bereichen der Baumaschinensteuerung (Machine Control and Guidance), der Landwirtschaft (Precision Farming) sowie in verschiedenen Sonderanwendungen (wie z.B. Gleismesswagen, Minenanwendugen, etc.) eingesetzt. Durch die Verwendung von geodätischen L1/L2-Empfängern mit einer lokalen Referenzstation müssen etwa 30.000 bis 50.000 USD für das Messinstrumentarium investiert werden. Deshalb stellen Anwendungen des RTK GNSS-Zweifrequenz-Empfängers keinen Massenmarkt dar.

Günstige GPS/GNSS-Module (in Zukunft nur noch als GNSS bezeichnet) haben jedoch den Massenmarkt in verschiedenen Gebieten wie Mobiltelefon, Autonavigation, Freizeitindustrie, etc. bereits eingenommen. Anwendungen kinematischer Echtzeitpositionierungen im Zentimeter- oder Dezimeterbereich können ebenfalls zu einem Massenprodukt werden. Hierfür müssen Systeme existieren, die unter 1.000 bis 2.000 USD liegen. Die genaue Spezifikation der Bedeutung Low-cost wird hierbei durch die jeweilige Anwendung gegeben.

In der Geodäsie existieren einige universitäre Arbeiten auf dem Ansatz der zentimetergenauen Positionierung mittels Einfrequenz-Empfänger für statische Anwendungen [z.B. GLABSCH et. al. 2009, SCHWIEGER and GLÄSER 2005, ALKAN 2010, REALINI et. al. 2010, Korth and Hofmann 2011]. Verfahren zur Echtzeitausgabe von RTK GNSS-Positionen, basierend auf L1-Empfänger, existieren bisher noch nicht. Es gibt zwar bereits intelligente Ansätze, die eine Trajektorie im Post-processing-Modus auswertet **[**REALINI et. al., 2010**]**, jedoch existieren zurzeit kaum Systeme die eine Echtzeitprozessierung ermöglichen.

Der Ansatz der genauen Positionsbestimmung mittels der Auswertung von statischen Rohdaten mit Einfrequenz-Empfängern wird gegenwärtig in einem Forschungsprojekt an der Beuth Hochschule für Technik Berlin aufgegriffen und für kinematische Anwendungen weiterentwickelt. Dieses Projekt ist eingebettet im Europäischen Sozialfonds. Es ist ein Nachfolgeprojekt zum Thema der statischen Positionierung mit Einfrequenz-Empfängern [KORTH and HOFMANN, 2011].

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1. STATE OF THE ART

As already mentioned in the introduction, various studies on the use of GNSS single frequency receivers have been available for several years. Hence, a raw data set is recorded over a specific observation period. Subsequently, these raw data are evaluated together with the reference data using a geodetic software. Depending on the additional components being used (GNSS antenna and ambient parameters like shading or multi-path effects), the results are often similar to conventional observations with geodetic receivers. Such L1 applications are frequently used for geodetic monitoring applications [GLABSCH et. al. 2009]. Moreover, Satellite Based Augmentations Systems (SBAS) such as Omnistar-HP/XP exist. The results of such procedures do not, however, suffice for numerous applications due to limited accuracy or rather because of the stability of the initialization and re-initialization. To date, only very few publications on kinematic real-time applications based on single frequency receivers exist next to [TAKASU and YAKASU, 2009].

Following components are needed for a low-cost approach:

- GNSS L1-Board (30 – 300 USD)
- GNSS L1-Antenna (30 – 300 USD)
- Reference Data (local L1- or L1/L2-Equipment, RTCM-Data e.g. via NTRIP)
- RTK GNSS-Software for the real-time Computation and Output incl. a Computer

Many products and solutions are available for the first three basic components. In this context, the real-time algorithm for carrier phase analysis plays a decisive role. Tomoji Takasu and Akio Yasuda have published an open source GNSS algorithm (http://gpspp.sakura.ne.jp/indexe.html) since 2006. The following versions exist in addition to the basic algorithm RTKLib (Version 2.4):

- RTKNAVI: Real-Time Positioning
- RTKPOST: Post-Processing Baseline Analysis
- RTKPLOT: Plot Raw Observation Data and Solutions
- RTKCONV: RINEX Converter for Raw Receiver Log
- ANTTool: Matlabtool to Verify the Antenna Phase Centre Offsets (Version. 1.3)

The RTKNAVI version uses the L1 receiver's carrier phase and thus enables the resolution of the phase ambiguities in real time with a simultaneous output of NMEA data. The following options are possible as I/O data:

- Serial (RS232C/USB), e.g. at the uBlox LEA 4T

(UBX RXM-RAW and RXM-SFRB Messages)
- TCP Server/Client
- NTRIP Server/Client
- Local File

Following GNSS L1-Boards are implemented in version 2.4:

- NovAtel OEM3
- NovAtel Super Star II
- Hemisphere Eclipse
- Hemisphere Crescent
- u-blox LEA-4T/5T
- SkyTraq S1315F

Additional OEM boards can be implemented in this open source software. In this research project, additional developments of the RTK GNSS algorithm will be explored in collaboration with the project partners. In addition to the GNSS receiver and the RTK GNSS algorithm, the quality of the antenna is decisive. A high quality GNSS antenna is capable of eliminating perturbations to a certain degree, such as multiphase. These geodetic antennas, however, cannot be considered low-cost antennas. Low-cost patch antennas such as e.g. *uBlox ANN-MS, AeroAntenna AT575, AntCom AG15A2-XS-3, MicroPlus 2335TB, Pioneer GPS-M1ZZ Ant or the Trimble Bullet III* lie in the range of approximately USD 30-300. The system illustrated in Figure 3 is capable of using various GNSS antennas. One major advantage in the use of single frequency receivers is the reduction of the antenna phase centre offsets problem. It is easier to determine the precise phase centre if there is only one wavelength. The L2 frequency is therefore usually used to define the elevation-dependent phase centre.

A simple quality comparison between a high-end (L1/L2) and low-cost (L1) GNSS receiver can be ideally verified under identical conditions with the following experiment.

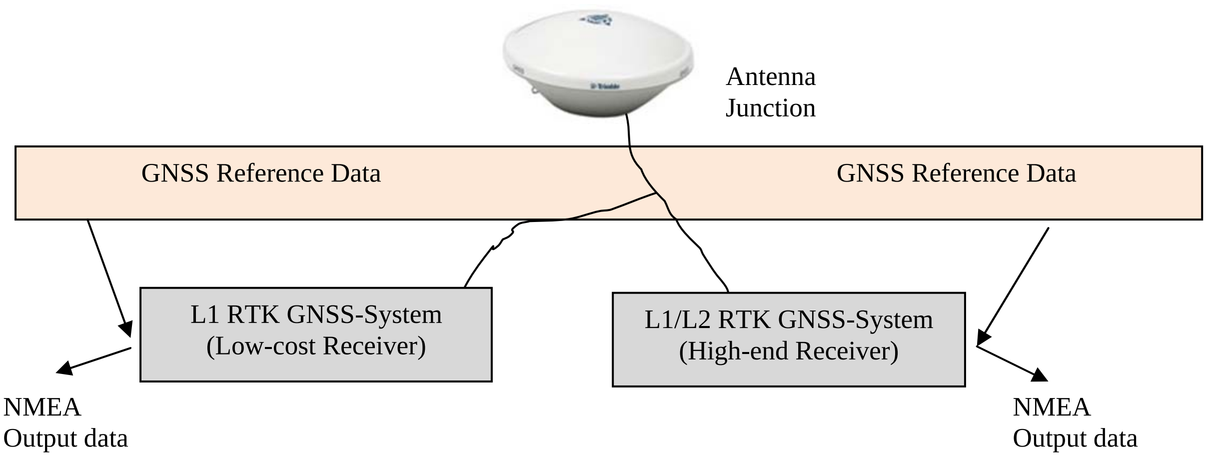

Fig. 1 – Verification of an L1 to an L1/L2 GNSS-Receiver in Real-time

This experiment must be analysed under a wide variety of conditions. The initial results reveal that a similar accuracy class can be achieved with single frequency RTK GNSS applications (see Fig. 4). For an accurate GNSS application, reference information must be transmitted to the rover. Geodetic receivers thus use local reference stations or reference services such as virtual reference station or the master auxiliary concept via NTRIP. The use of local L1 reference information is certainly the most cost-effective approach for low-cost RTK GNSS applications. For short base lines of several hundred metres to a few kilometres, the correction information suffices for high accuracy positioning. Atmospheric influence hardly plays a role for such short base lines. Initial results demonstrate the potential of this approach.

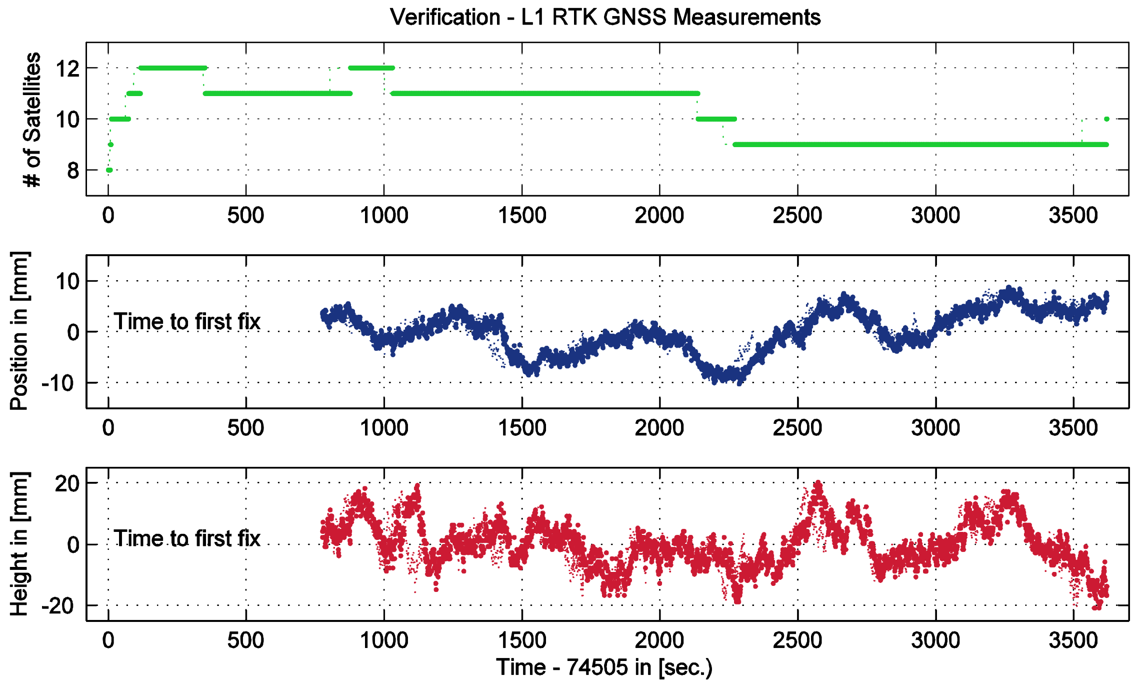

Fig. 2 – NMEA-Computation with very short baselines –
Reference and Rover are a uBlox LEA 4T Receiver

In addition to the measurement condition's determining factors such as shading and signal reflection, as well as the general influence of the atmosphere and satellite constellation on GNSS, the time to first fix (TTFF) and the stability of the carrier phase ambiguity resolution in real-time applications is decisive in the re-initialization. The ambient conditions parameters must be included in the verification (cf. Chapter 3).

2. APPROACH

The research project which addresses the topic "low-cost RTK GNSS" as a follow-up project of a static low-cost GNSS project is already able to provide real-time positions in the range of a few centimetres. A machine or moving object can thus already be navigated. The following system structure currently exists:

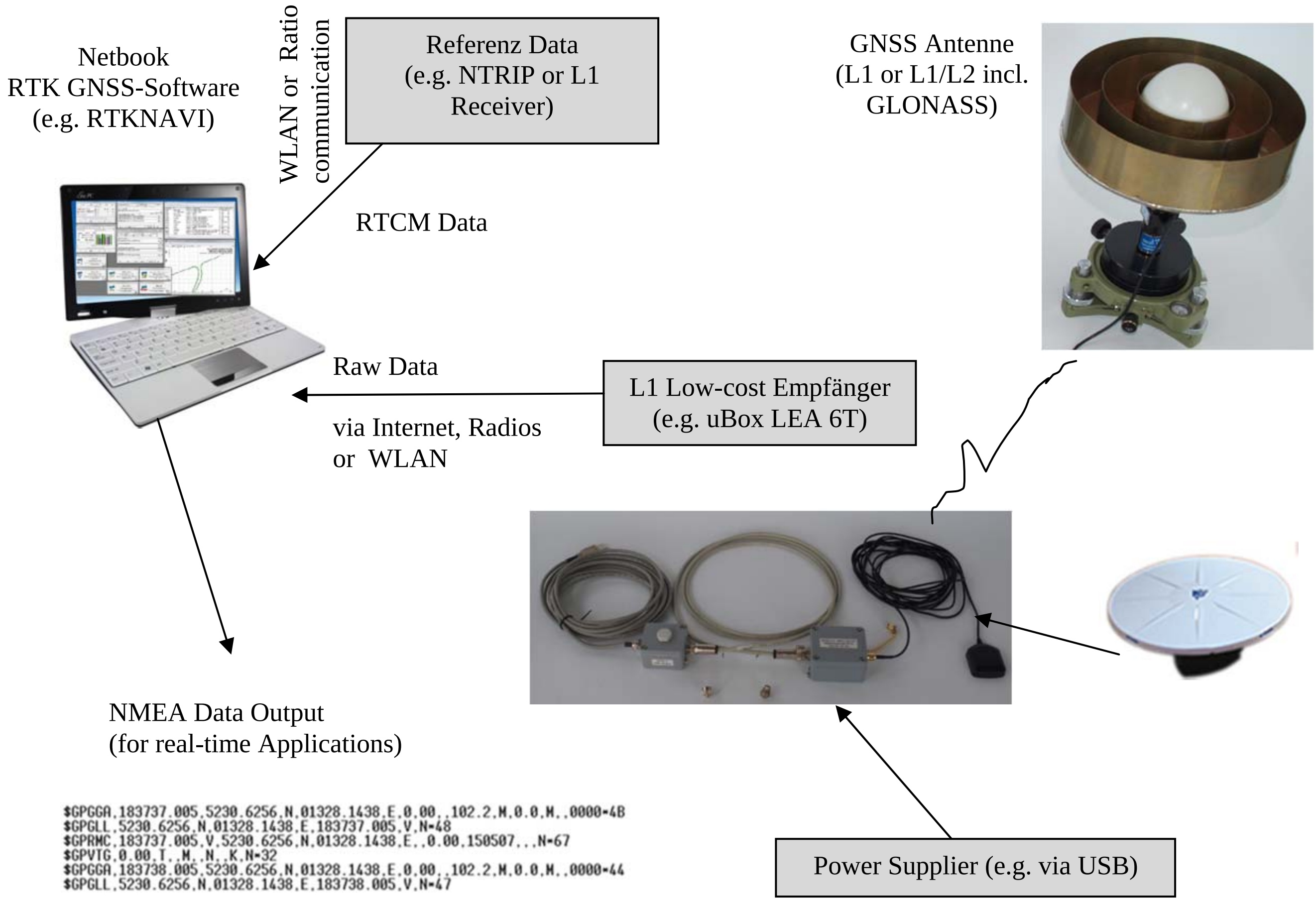

Fig. 3 – Modular Low-cost RTK GNSS System

Under ideal conditions, the system delivers a carrier phase solution within the centimetre range within few minutes. The first phase of the project deals with the evaluation of individual components. The result of the experimental set-up in Figure 1 thus illustrates the difference between a high-end solution using a geodetic receiver and a single frequency receiver (post-processed).

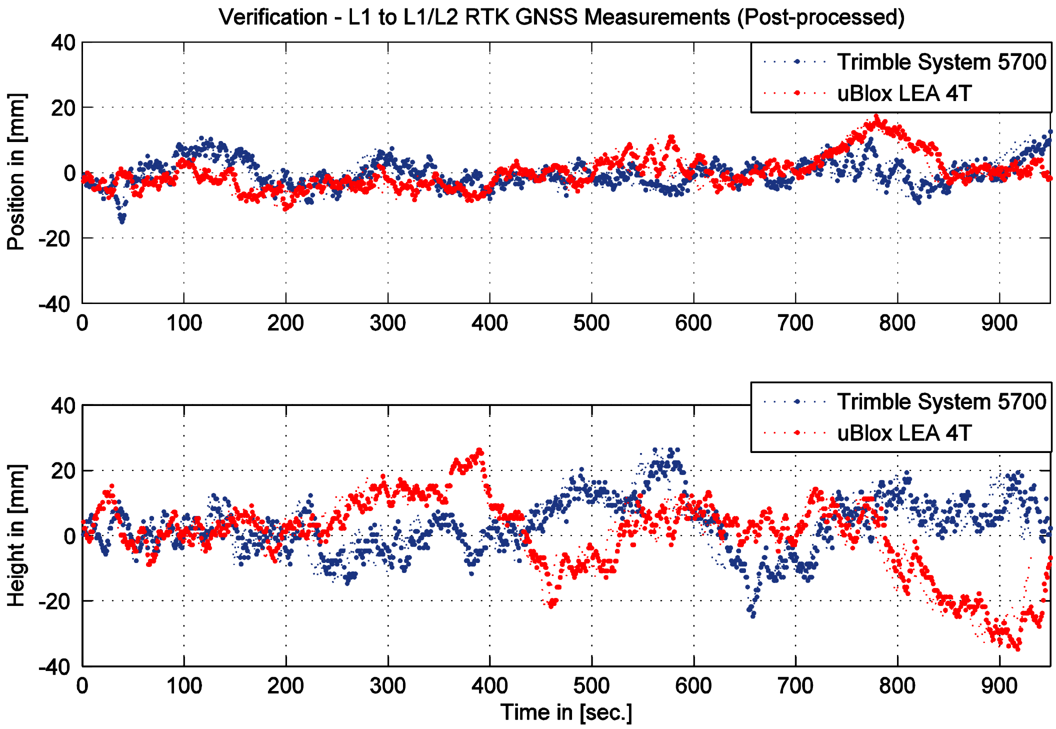

Fig. 4 – Verification of RTK GNSS High-end to Low-cost Measurements

A further test series will evaluate the temporal behaviour of latencies [Stempfhuber, 2004] and the initialization (TTFF) as well as the re-initialization. The ambient parameters are crucial in this regard. The L1 receivers' longer initialization period is frequently a result of the unsmoothed pseudorange solutions (e.g. in the uBlox LEA 4T modules used). The 3D space search thereby includes a lot more ambiguities and thus requires a longer initialization period.

Moreover, the optimization of low-cost GNSS antennas represents a crucial factor for such a system. In the previous research project [Korth and Hofmann 2011], a choke ring antenna was replicated on the basis of the Bullet III antenna (see Fig. 3 at the top right). Inspiration was derived from two sources, [Filippov et. al.] and the UNAVCO website http://facility.unavco.org/kb/questions/311/Choke+Ring+Antenna+Calibrations (US Patent 6278407). Under ideal conditions (no or little multipath), low-cost antennas do not differ considerably from geodetic antennas. Signal reflection is significantly worse when low-cost antennas are used in comparison with geodetic antennas. The GNSS signal is recorded via the signal reflection illustrated in Fig. 5 underneath the antenna. A ground plate does not really eliminate this problem. The signal glides across the ground plate and is inaccurately recorded at the centre of the antenna.

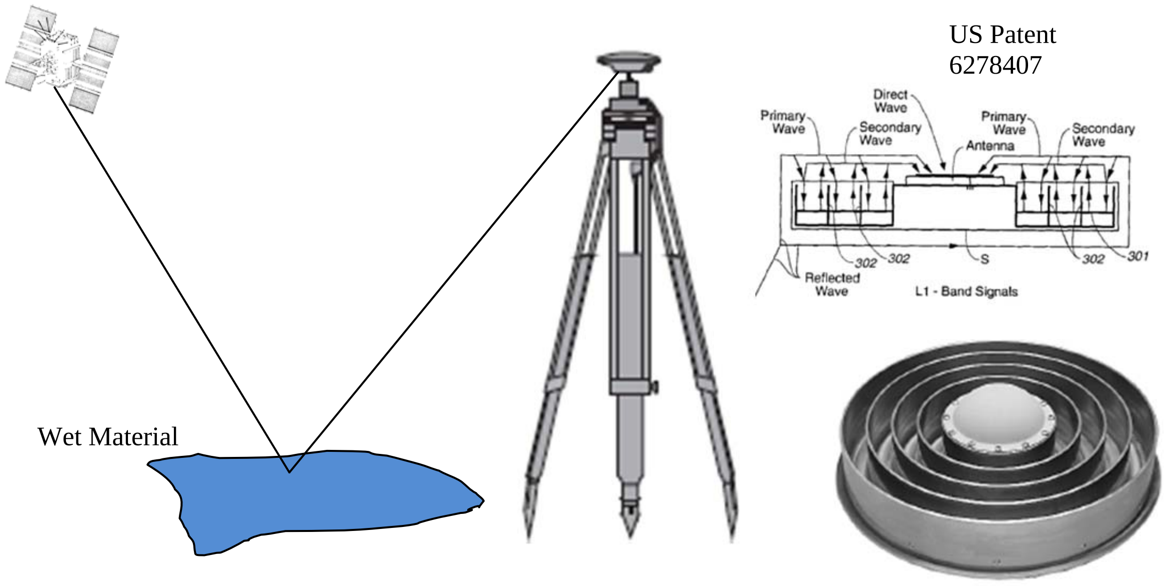

Fig. 5 GNSS-Multipath Problem

If, however, the base of the choke ring antenna is used (height of the antenna in accordance with the wavelength of the L1 signal or ½, respectively ¼ of this wavelength), these interference signals are eliminated in the antenna ring. Various antenna tests for evaluation purposes are currently being carried out and a student paper focuses on antenna calibrations.

3. PROJECT

This research project's primary objective is the development and optimization of the described approach. Many kinematic applications require a cost-effective GNSS solution for real-time positioning in the centimetre and decimetre range. One example is real-time monitoring of the use of rollers in the compression of street surfaces (see http://www.asphalt-fp7.eu/index.html). The main area of application, however, is the field of precision farming. A large-scale expansion of this technology can be achieved, since high-end GNSS applications are only being used to a limited extent. The following projects are suitable in this context:

- Future Farm (http://www.futurefarm.eu/)
- ICT AGRI (http://ict-agri.eu/)
- agriXchange (http://www.agrixchange.org/)
- Controlled Traffic Farming (http://www.controlledtrafficfarming.net)

Food security poses a major challenge worldwide. A further expansion of low-cost GNSS positioning can provide support for this demand at the global level through technical innovations.

4. OUTLOOK

The general tendency towards low-cost solutions for accurate real-time determination of a movement trajectory will further grow in the next few years. Many components already exist in this context. The linking of these subsystems makes preliminary applications possible. A commercial expansion will, however, take time. As a result of cost-effective internet lines, complex arithmetic problems can also be solved through so-called cloud computing on a stationary server. The costly hardware of mobile GNSS receivers is thus further reduced. The transfer of the reference information has for several years been based on such approaches. These services are also interesting for low-cost RTK GNSS applications, but are connected to permanent costs.

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