Determining the guidance system accuracy with the support of a large GNSS dataset

V. Rataj, J. Galambošová, M. Vašek

Department of Machines and Production Systems, Faculty of Engineering, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

Abstract

Rataj V., Galambošová J., Vašek M., 2013. **Determining the guidance system accuracy with the support of a large GNSS dataset**. Res. Agr. Eng., *59* (Special Issue): S65–S70.

Several methods are used presently to assess the accuracy of machinery guidance systems. However, these offer a limited number of records and are time and cost consuming. As the machinery is often equipped with a monitoring system for the management purposes, these data can be used. The aim of this work was to develop and verify a method to determine the accuracy of the machinery guidance systems based on a large dataset obtained from the machinery monitoring system. The proposed method uses the transformation of global navigation satellite systems (GNSS) data into a rectangular coordinate system SJTSK (National projection system – Krovak projection). Based on the geometry principle, the ideal line can be determined, and afterwards, the off-track error of each actual position can be calculated. After the verification of this method, it can be concluded that it brings benefits in terms of further use of the data from the monitoring systems, the estimation of the error based on a robust dataset, elimination of subjective and measurement method errors, as well as spatial localisation of the off-track errors at the field.

Keywords: off-track error; geometry; rectangular coordinate system SJTSK

The machinery movement in the field is an important parameter of the machinery use efficiency. The research into this topic has been conducted for many years by many authors from many aspects. Among the first published results on the field traffic are those by Pavlov et al. (1973) and Ondřej et al. (1989). The problem of the machinery movement is connected with the technical level of tractors and implements. Because of the kinematics of modern tractors, it is necessary nowadays to study and model the machinery movement. Several authors deal with the aspects of machinery movement itself including the kinematics (Backman et al. 2012; Rovira-Más 2012). The issue of the machinery movement within a defined space, described by the shape and the area of a field, has been solved by Hameed et al. (2010). Besides the movement of machinery for the field operations, those of machinery for service operations such as e.g. field transport have been analysed (Bochtis et al. 2010a).

The analyses of the machinery movement, optimal direction of movement, algorithms and mathematical models of machinery field traffic were conducted by Bochtis et al. (2007, 2010a, b), Oksanen and Visala (2007), Bochtis and Vougioukas (2008), Yakusshev and Yakusshev (2008), Spekken and Bruin (2011) and others.

Supported by the European Union, research project under the title: ITEPAg – Application of information technologies to increase the environmental and economical efficiency of production agro-system. ITMS 26220220014.

The machinery guidance in the field is provided by guidance systems with sufficient accuracy. There are many of these. Optical or laser guidance systems can be used under specific conditions. The examples are the guidance based on the crop height, implement guidance during intra-row field operations (Slaughter et al. 1999). Nowadays, machinery guidance is based mostly on the signal from global navigation satellite systems (GNSS). This is efficient for wide implements during soil preparation, fertilisation, or crop protection (Nozdrovický et al. 2008; Trimble GPS 2012).

The use of these systems affects the work quality and overall economic efficiency of the machinery use (Grisso et al. 2004; Galambošová, Rataj 2010).

The economic effect and optimal return on investment are directly connected with the work quality. The criteria of the work quality when using the GNSS guidance systems are the accuracy of GNSS guidance and its transmission to the movement control. This issue is covered in world standards (ASABE 2007) as well as scientific papers (Gan-Mor et al. 2007; Gavric et al. 2011; Williams et al. 2012).

The data on machinery movement (traffic) in the field can be used for other analyses as well, e.g. the machinery management assessment (Taylor et al. 2002), soil compaction assessment (Kroulík et al. 2011) etc. The exact data, which are saved, can be used for traceability assurance as well (Cascone et al. 2010).

The aim of this work was to propose and verify a method for determining the accuracy of the machinery movement based on datasets obtained from the machinery monitoring system.

MATERIAL AND METHODS

The proposed methodology enables to determine the accuracy of the machinery movement based on large datasets from the machinery monitoring system. The monitoring system is primarily used for the machinery management purposes. The monitoring system consists of a GNSS antenna (AgGPS; Trimble Navigation Ltd., Sunnyvale, USA) and a GPRS modem (RTKMD; FONS s.r.o., Františkovy Lázně, Czech Republic), which sends the data to the server. The data exported from the system (in its extended use) are gathered with a frequency of one record per six seconds. The data contain the information on GNSS coordinates with real time kinematics (RTK) precision as the system is connected to the machinery guidance system Trimble Autopilot (Trimble Navigation Ltd., Sunnyvale, USA) (Fig. 1). The calculation of the error is based on the geometry principle.

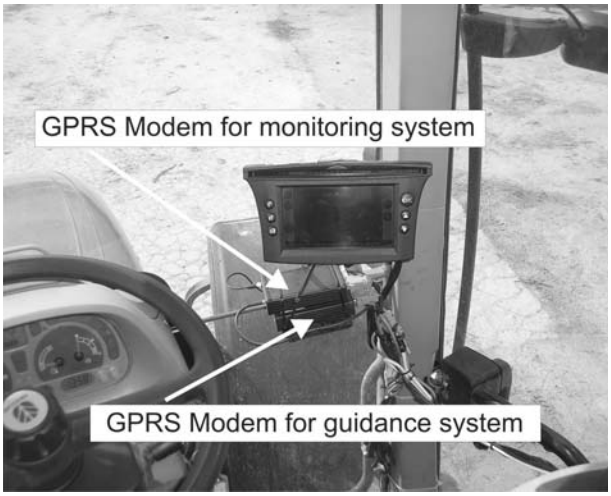

Fig. 1. Machinery monitoring system and machinery guidance system

The verification of the proposed method was conducted during field operations. The machinery guidance was provided by Trimble Autopilot with RTK accuracy (Trimble GPS 2012). The AB line mode of the guidance system was selected. The accuracy was calculated as the distance of the machinery real position from the AB line.

RESULTS AND DISCUSSION

Based on the trajectory of the selected traffic line (AB line), the positions of the starting point K(x_K; y_K) as well as the last point L(x_L; y_L) can be obtained. The coordinates of this AB line give the "ideal line", which can be described by the linear dependence $y = A + Bx$ (Fig. 2). The measured error can be, based on the ASABE standard, defined as an "off-track error" and is equal to the perpendicular deviation from the actual travel course. The proposed method uses the transformation of GNSS data into a rectangular coordinate system SJTSK, which is a national coordinate system used mainly in the Czech and Slovak Republics as introduced by Krovak (Tuček 1998; Huml, Michal 2006).

The real implement working width can be determined as the following (Fig. 3):

$$Bp = Bk - \Delta B$$

where:

Bk – construction width of the implement (m)

ΔB – overlaps – value set in the guidance system (m)

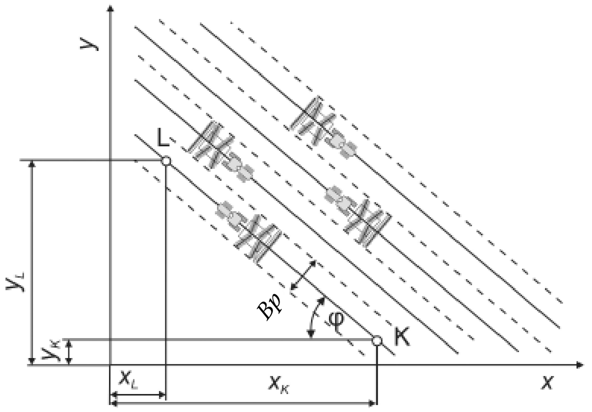

Fig. 2. Basic scheme of machinery movement
$K(x_K, y_K)$, $L(x_L, y_L)$ – position of the tractor and its coordinates; φ – angle of the traffic line; *Bp* – implement width

The efficiency of using the implement width during the field operation is commonly calculated as $\beta = Bp/Bk$, where β is the ratio of the effectively used implement (*Bp*) width to the implement width (*Bk*) (Pavlov et al. 1973; Ondřej et al. 1989).

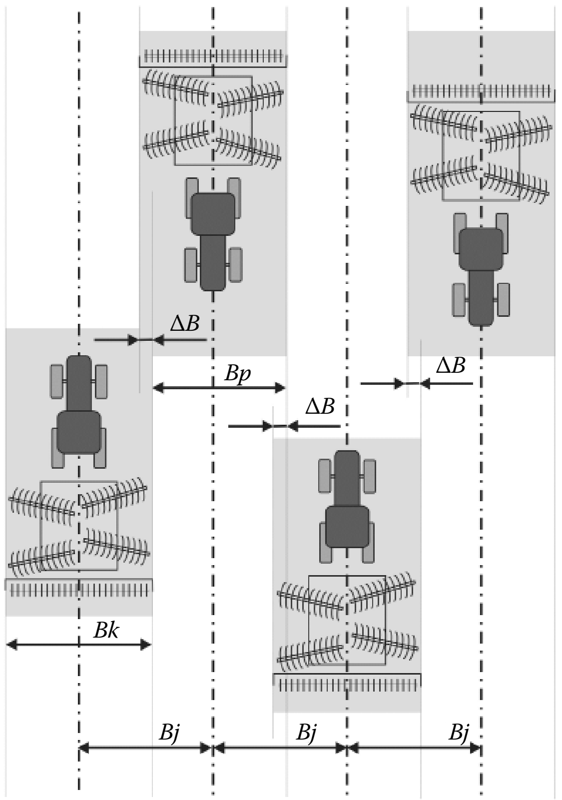

Fig. 3. The real working width of the machine during field operation
Bk – implement width; *Bp* – effectively used implement width; *Bj* – perpendicular distance of guidance lines; Δ*B* – overlaps

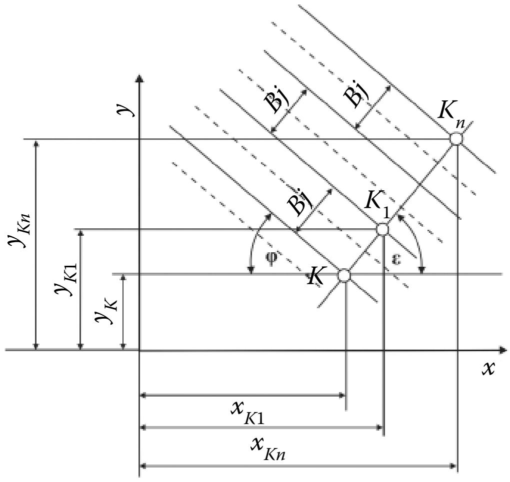

Fig. 4. Determining the starting and terminating points
Bj – perpendicular distance of guidance lines; $K(x, y)$, $K_1(x_1, y_1)$, $K_n(x_n, y_n)$ – starting points of guidance lines and their coordinates; φ – angle of the traffic line, $\varepsilon = 180 - (90 + \varphi)$

The guidance system uses for the guidance of machinery "*n*" lines (K_{1-n} L_{1-n}) of a perpendicular distance (*Bj*) from the ideal line. The distance (*Bj*) is equal to the implement working width (*Bk*). This line should be the trajectory of the machinery centre line during the field operation. However, due to the errors of GNSS as well as technical or terrain influences, off-track errors are present.

Several methods are used to determine the error: physical measurement with a measuring tape,

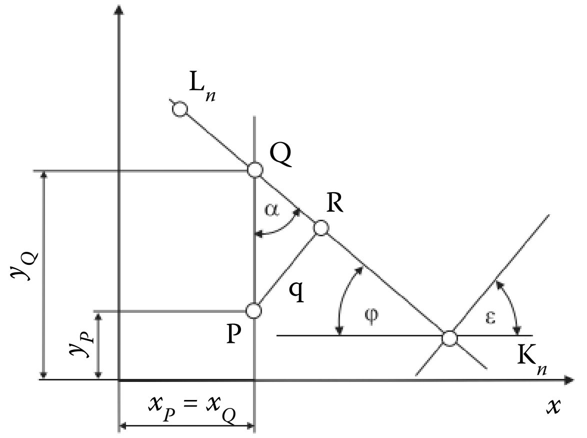

Fig. 5. Estimation of off-track error of a selected position
K_n starting point of line"*n*"
L_n – terminating point of line "*n*", $P(x_P, y_P)$ – selected position from a dataset with its coordinates, R – position of the point "P" on the ideal line, Q – vertex of the triangle PQR, q – off-track error

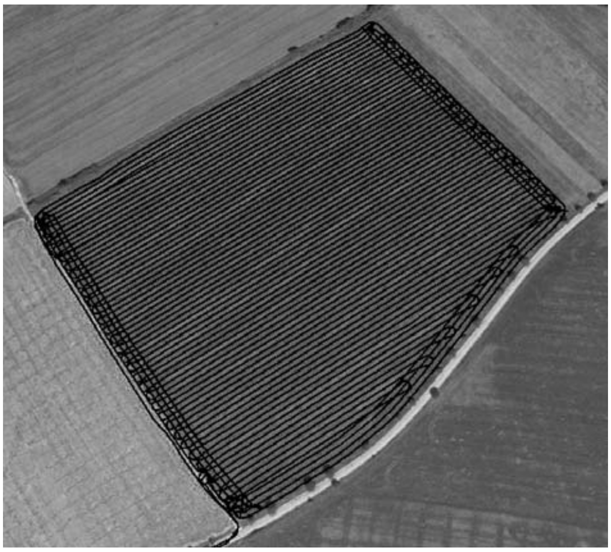

Fig. 6. Recorded data for the assessed field operation

measurement with a laser distance meter (Macák, Žitňák 2010), and measurement with a handheld GNSS receiver. Compared to that, the extended use of the machinery monitoring data provides the data in the structure: latitude, longitude, time, and date in large datasets. The transformation of these data into the rectangular coordinate system enables its geometric processing. The starting and ending points have to be determined (Fig. 4).

The coordinates of the points K_1L_1 to K_nL_n can be estimated by angles φ and ε:

$$\tan\varphi = \frac{y_L - y_K}{x_K - x_L} \qquad \varepsilon = 180 - (90 + \varphi)$$

The coordinates of the ideal or previous lines are the base for the estimation.

Table 1. Basic statistics of off-track error

Mean (m)	0.002
Standard deviation (m)	0.058
Minimum (m)	0.216
Maximum (m)	0.184
Number of records	867

The coordinates of the first line points can be estimated as follows:

$$x_{K1} = x_K + B_j \times \cos\varepsilon$$

$$y_{K1} = y_K + B_j \times \sin\varepsilon$$

$$x_{L1} = x_L + B_j \times \cos\varepsilon$$

$$y_{L1} = y_L + B_j \times \sin\varepsilon$$

As mentioned above, when using the machinery monitoring systems in an extended mode, the actual position of the machine can be recorded. For example, the point $P(x_P, y_P)$ should lie on the line K_nL_n (Fig. 5). The error is the perpendicular to the line K_nL_n. The solution proceeds from the triangle PRQ.

The angle α can be determined as: α = 90 – φ; the error can be estimated as: $q = r \times \sin\alpha$.

The line segment $PQ = y_Q - y_P$ and the coordinate y_Q can be determined as the linear function:

$$y_Q = A + B \times x_P$$

where:

A – vertical intercept

B – line gradient

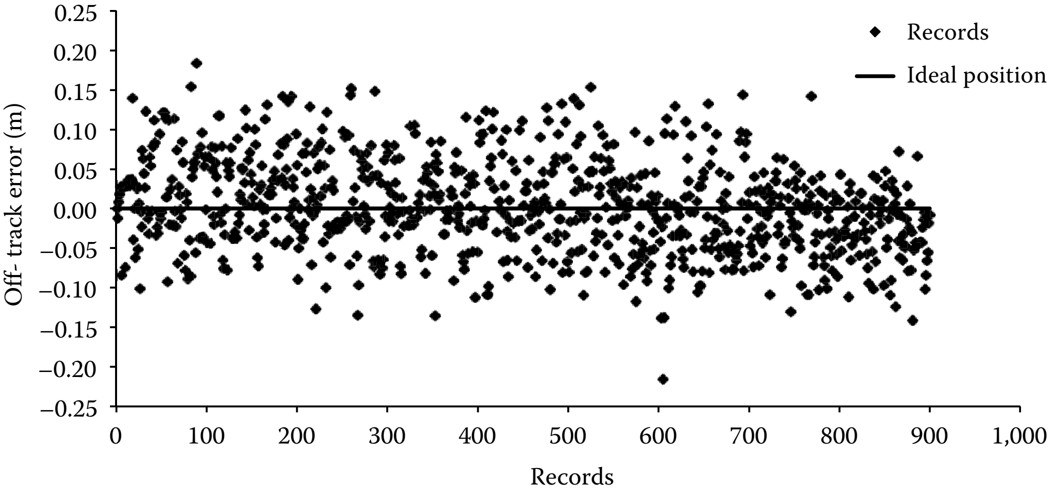

Fig. 7. Distribution of off-track errors

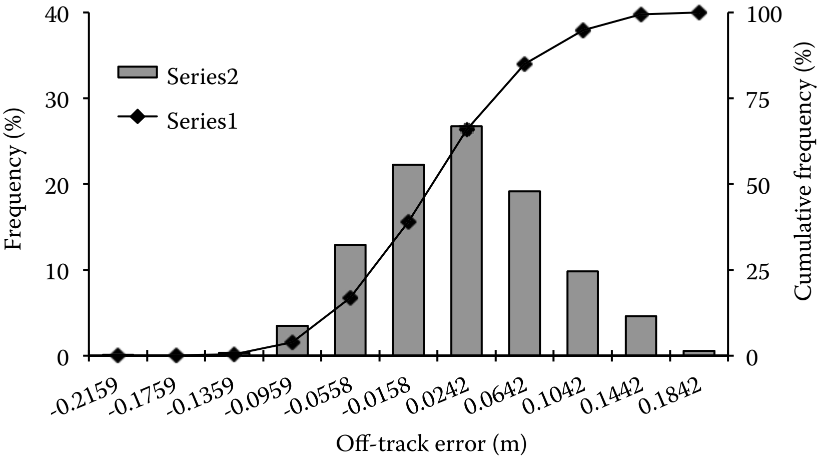

Fig. 8. Histogram of off-track errors

The methodology was evaluated for several field operations, which were monitored with the support of the on-line monitoring system. One example is described below. For the purposes of this paper, the data from a drilling field operation were used. The tractor NewHolland T6070 (New Holland Agriculture, New Holland, USA) with the guidance system Trimble Autopilot with RTK system together with the drilling machine Lemken Solitaire 9 (Lemken GmbH & Co. KG, Alpen, Germany) were assessed. The implement width (*Bk*) was 6 m. The overlapping width (ΔB) was set up at 0.2 m. The tracks of the machinery were recorded. For the evaluation, 45 tracks were used (867 monitoring points) (Fig. 6).

The errors distribution is shown in Fig. 7. The basic statistics is given in Table 1.

Based on the data distribution, it can be concluded that the errors from –0.016 to 0.024 m (Fig. 8) are the most frequent.

As shown in the example, the data obtained for the purposes of machinery monitoring can to be used for the movement accuracy determination. Also, the errors which exceed the acceptable range can be later identified, localised, and their source can be analysed. In the case of the machinery assessed, the errors were present at headlands, while the machinery was turning.

CONCLUSION

The proposed methodology is based on using large data sets obtained from the extended use of the machinery monitoring system. The evaluation of off-track errors with the proposed methodology provides reliable information on the accuracy compared to the traditional physical measurement methods. The method brings benefits in terms of:

- further use of the data coming from the monitoring systems,
- obtaining a robust dataset,
- elimination of subjective errors, errors of the measurement method,
- spatial localisation of off-track errors at the field.

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Received for publication July 16, 2012
Accepted after corrections January 31, 2013

Corresponding author:

Ing. Jana Galambošová, Ph.D., Slovak University of Agriculture in Nitra, Faculty of Engineering,
Department of Machines and Production Systems, Tr. A. Hlinku 2, 949 78 Nitra, Slovak Republic
phone: + 421 376 414 344, e-mail: jana.galambosova@uniag.sk