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(54) Benævnelse: **ONBOARD-ENHED OG FREMGANGSMÅDE TIL FUNKTIONSOVERVÅGNING I ET VEJGEBYRSYSTEM**

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Onboard unit and method for functional monitoring in a road toll system

The present invention relates to an onboard unit for a road toll system, comprising a satellite navigation receiver for continuously generating position fixes and associated quality measurement values from satellite raw data, a radio transceiver, and a processor connected to these components, which is configured to generate toll data from the position fixes and to send the toll data via the radio transceiver. The invention also relates to a method for function surveillance in a road toll system with the aid of such an onboard unit.

Onboard units (OBUs) based on satellite navigation systems (global navigation satellite systems, GNSS) can be "thick client" OBUs for example, which compare the generated position fixes with a digital road map stored in the onboard unit, in doing so determine road sections that are subject to a fee, calculate associated toll fees, and send this information as toll data via the radio transceiver, but can also be "thin client" OBUs, which directly send the position fixes as toll data to a central station, which calculates the toll fees on this basis. The functionality and efficiency of such GNSS OBUs is largely dependent on the quality of their satellite reception and the position fixes determined therefrom.

EP 1 696 207 A1 describes a method for classifying position fixes, wherein invalid position fixes are rejected or labelled on the basis of their quality, and, of those position fixes that have usable satellite raw data, only these raw data or metadata derived therefrom, but not the position fixes themselves, are used.

Whereas the billing of the toll fees is usually taken care of by the road operator or an authority, i.e. what is known as a "toll charger", the generation of toll data or the calculation of the toll fees is usually carried out in the form of a service by a "service provider"; the service provider must guarantee a certain efficiency, for example a certain level of toll levying over a toll route.

In order to measure the functionality and efficiency of a road toll system, fleets of test vehicles are currently used, which for example travel over given toll routes in a spot check manner so as to then compare the toll fees accruing in the central station of the toll charger with the spot check journeys. To reduce the staffing and organisational outlay, EP 2 665 044 alternatively proposes that the toll charger prompts individual onboard units liable to pay a toll fee to collect position-related data in a spot check manner and to send this as reference data directly to the central toll station of the toll charger, where the reference data is compared with the toll fees generated during operation by the service provider so as to measure the efficiency of the road toll system.

The objective of the invention is to create devices and methods for function surveillance in a road toll system which consequently enable an improvement of the efficiency of the road toll system and thus an increase of the level of toll levying.

This objective is achieved in accordance with a first aspect of the invention with an onboard unit of the type mentioned in the introduction, characterized by

an outage detector connected to the satellite navigation receiver, which outage detector is configured to respond to an absence of position fixes over a given minimum time span or to a drop in quality measurement values under a given minimum quality measurement, and

a recorder connected to the satellite navigation receiver and controlled by the outage detector, which recorder is configured to generate, when the outage detector responds, an error dataset with at least the last position fix before the response,

wherein the processor is configured to receive the error dataset from the recorder and to send it via the radio transceiver.

In accordance with a second aspect, the invention creates a method for function measurement in a road toll system with a central station and at least one vehicle-mounted onboard unit, which continuously generates position fixes and associated qual-

ity measurement values from satellite raw data and sends toll data based thereupon to the central station, comprising:
detecting an absence of position fixes over a given minimum time span or a drop in quality measurement values under a given minimum quality measurement in the onboard unit, and
in case of a detection, recording an error dataset with at least the last position fix before the detection in the onboard unit,
sending the error dataset from the onboard unit to the central station, and
evaluating the error dataset in the central station.
In accordance with the invention it is thus possible, for the first time, to make the quality of the GNSS position determination and coverage in the road toll system accessible to a central evaluation facility and to thus determine critical GNSS error locations in the road network in good time and to allocate these geographically on the basis of the last position fix. Instead of a mere spot check performance review, position determination errors of GNSS OBUs can be evaluated in the central station immediately or only with a short transmission time delay continuously and - with appropriate distribution of the OBUs - comprehensively covering a large area. As a result, different GNSS-induced errors in the road toll system, for example interfering signals, shadowing of the satellite signals, etc., and causes thereof, for example local or mobile interfering signal sources ("jammers") or geographical conditions, such as mountains or tunnels, can be determined. It is thus possible, for the first time, to introduce targeted measures at the error locations localized in each case by the last position fixes, in order to remedy the error, for example to erect stationary position transmitters, assisting beacons, satellite signal repeaters, or the like, or to identify and switch off interfering signal sources, etc.
It is particularly favourable when the error dataset generated by the onboard unit contains a time stamp of said last position fix. It is thus possible, from a plurality of error datasets of various onboard units or the same onboard unit, at different times of the day or year, to also determine time-dependent er-

rors and error causes, for example interfering signals that change over time or are periodic, unfavourable satellite constellations or shadowing of the satellite signals depending on weather events or by vegetation during growing seasons, etc. Furthermore, the movement of a mobile interfering signal source can be accurately tracked with the aid of traffic cameras and/or emergency vehicles, for example in order to identify "jammers", which deliberately transmit interfering signals so as to prevent correct toll levying.

So as to be able to even better delimit the geographical areas of the detected error, it is particularly advantageous when the error dataset also contains the first position fix generated after the response or detection has finished. Here, the error dataset preferably also contains a time stamp of said first position fix for the aforementioned reasons.

In a favourable embodiment of the invention the error dataset also contains at least one quality measurement value generated when the outage detector responds or during detection of the outage. Error causes can thus be determined even more precisely. When the quality measurement value contains, for example, the number of satellites used to generate the associated position fix or a DOP (dilution of precision) value of the associated position measurement value, an unfavourable satellite constellation - occurring randomly or locally frequently - could thus be identified. If the quality measurement value contains, for example, the respective signal levels of the satellites used for generation of the associated position measurement value and/or a signal/noise ratio of the satellite signals, then interfering signals or signal damping - for example as a result of local, possibly even movable interfering transmitters or as a result of weather events or shadowing by mountains or forests - can also be determined.

It goes without saying that an error dataset can contain not just one, but also a sequence of quality measurement values generated as the outage detector responds, and thus allows conclusions that are even more accurate, for example with regard to possible different error causes.

The error dataset also preferably contains satellite raw data received as the outage detector responds or during detection of the outage and/or sensor measurement values generated in a sensor element, whereby further basic principles for a subsequent determination of possible error causes are created.

It is particularly favourable when the outage detector contains a watchdog, which can be triggered anew by each generated position fix. This constitutes a particularly simple, reliable module for the outage detector.

In a further preferred embodiment of the method according to the invention, at least a second error dataset, generated and sent by a second onboard unit in the specified manner, is received and the error datasets of the at least two onboard units are validated against each other during evaluating. Changes over time of possible error causes can thus be taken into consideration more easily and individual errors or interferences of individual onboard units, for example as a result of incorrect arrangement in the vehicle, can be compensated for. At the same time, with an increasing number of available onboard units when evaluating the error datasets, the validity of said onboard units with regard to possible error causes also increases.

It is particularly favourable when, during evaluating, geographical interference and shadowing areas of the satellite reception are determined by comparing the error datasets with a digital map. A "map of GNSS errors" is thus generated, which can be compared with geographical conditions, such as high mountains, narrow valleys, tunnels, etc. In this way, natural error causes can be easily distinguished from technical errors causes, and measures for rectifying the errors can be undertaken.

The invention will be explained in greater detail hereinafter on the basis of an exemplary embodiment illustrated in the accompanying drawings. In the drawings:

Fig. 1 shows a schematic plan view of a road toll system with vehicle-mounted onboard units according to the invention;

Fig. 2 shows a block diagram of one of the onboard units from Fig. 1; and

Fig. 3 shows exemplary data and signal diagrams which occur in the onboard unit from Fig. 2 and as the method of the invention is being carried out.

Fig. 1 shows a road toll system 1, which is based on onboard units (OBUs) 2 which are carried by vehicles 3 in order to levy a toll or charge for their uses of certain locations in a network formed by roads 4. The use of a location can be, for example, travel in a certain segment of a road 4, travel beyond a border, residence in a certain geographical area, or the like, and can be billed for in any way, for example per road segment, distance travelled, time spent in an area (for example parking time), etc.

According to Fig. 2, each onboard unit 2 has a satellite navigation receiver 5 for this purpose, which continuously determines the position of the onboard unit 2 from satellite signals 6 of navigation satellites 7 (Fig. 1) of a global satellite navigation system (GNNS) and outputs this as position fixes p_1, p_2 ..., generally p_i, with associated quality measurement values q_1, q_2, ..., generally q_i.

Each quality measurement value q_i of a position fix p_i can contain different quality parameters, for example number, signal level and/or signal/noise ratio of the signals 6 of the navigation satellites 7 used to determine the particular position fix p_i, for example also in evaluated form of DOP (dilution of precision) values, as are made available by commercially conventional satellite navigation receivers 5 for each position fix p_i.

In addition to the position fixes p_i and quality measurement values thereof q_i, the satellite navigation receiver 5 can also output the "raw" satellite data forming the basis thereof, for example sections of the satellite signals 6, or can output processing data formed during the course of generation of the position fixes p_i, referred to hereinafter as "satellite raw data" r_i. The position fixes p_i, quality measurement values q_i, and satellite raw data r_i can be output here at separate outputs of the satellite navigation receiver 5, at a common output in multiplexing, or on a common bus in separate data packets.

The onboard unit 2 is also provided with a radio transceiver 8, for example in accordance with a 2G, 3G, 4G or 5G mobile radio standard such as GSM, UMTS or LTE, the ITS-G5 or WAVE standard for short-range radio communication, one of the IEEE 802.11 standards for WLAN communication, or the like, and a processor 9 connected to the satellite navigation receiver 5 and the radio transceiver 8.

One or more sensor elements 10, for example speed or acceleration sensors, can optionally also be provided, which can be arranged in the onboard unit 2 itself or - connected to the onboard unit 2 - in the vehicle 3 and generate sensor measurement values m_i, for example speed or acceleration measurement values or location measurement values approximated therefrom. A sensor element 10 of this type can also be formed by the radio transceiver 8, in which case the sensor measurement values m_i are metadata of the radio transceiver 8, for example radio cell or reception field strength data of a radio link 11 to a radio station 12, here a base station of a mobile network in which the radio transceiver 8 is located.

The processor 9 generates toll data M from the sequence $\{p_i\}$ of position fixes p_i so as to transmit this data with the aid of the radio transceiver 8 via the radio link 11 and the radio station 12 to a central station 13 of the road toll system 1.

The toll data M can be, for example, toll fees, which are generated by map-matching the position fix sequence $\{p_i\}$ with a digital map, stored in the onboard unit 2, of roads 4 or locations subject to a toll fee. Alternatively, the toll data M could also be the position fixes p_i themselves, which are sent individually or - filtered according to quality if desired - combined in a bundle at any or given moments in time, in accordance with given paths or simply with availability of a radio link 11 via the radio transceiver 8. In the latter case, map matching and fee calculation can be performed for example in the central station 13.

In accordance with Fig. 1, the vehicles 3 are travelling over their respective routes on the roads 4 through a geographical area 14 in which the satellite signals 6 received by the satellite navigation receivers 5 are disrupted or shadowed, such that

the quality measurement values q_i drop and/or the satellite navigation receivers 5 do not generate any position fixes p_i.

Fig. 3 shows, by way of example, time curves of the signals or data of an onboard unit 2. In accordance with this example the satellite navigation receiver 5 generates, at each of the moments t_1, t_2, ..., generally t_i, a position fix p_i (Fig. 3a) and an associated quality measurement value q_i (Fig. 3c) from the satellite raw data r_i (not illustrated). If the vehicle 3 travels through the specified geographical area 14, the satellite navigation receiver 5 does not generate any position fixes p_i over a period of time e, but generally still generates quality measurement values q_i.

In order to be able to sense and measure errors of the position determination of the onboard unit 2 and therefore the toll-levying function of the road toll system 1, for example as a result of signal interferences and/or shadowing of the satellite signals 6, the following components and methods are used.

The onboard unit 2 for this purpose has an outage detector 15 connected to the satellite navigation receiver 5, which outage detector responds and generates an output signal s (Fig. 3e), for example a logic "high" signal or a logic "1", when it either (a) detects the absence of position fixes p_i over a given minimum time span (δ) and/or (b) a drop in quality measurement values q_i under a given minimum quality measure Q_{min}.

In order to detect the event (a), the outage detector 15 can comprise a watchdog 16, for example in the form of a dead man's or retriggerable monostable multivibrator circuit, which is triggered anew by each new position fix p_i at its input for the minimum time span δ and thus outputs a detection signal d (Fig. 3b) at its (here: inverted) output when no new position fix p_i arrives within the specified minimum time span δ.

Alternatively or additionally to the watchdog 16, the outage detector 15 can have a comparator 17 for detection of the event (b), which comparator compares the incoming quality measurement values q_i with a minimum quality measure Q_{min} and, if the quality measurement values q_i drops under the minimum quality measure

Q_{min}, outputs an output signal c (Fig. 3d). Depending on the complexity of the quality measurement values q_i, it could be desirable for simplification of this comparison for the comparator 17 firstly to combine a quality measurement value q_i containing a plurality of parameters (dimensions) into a single global quality measure Q_i; alternatively, the minimum quality measure Q_{min} could comprise separate individual threshold values for a plurality of quality parameters contained in a quality measurement value q_i.

The output signals c of the watchdog 16 and d of the comparator 17 can be linked to the output signal s of the outage detector 15, for example by a simple OR circuit 18. Instead of the OR circuit 18, a complex evaluation logic, which for example also takes into consideration the time behaviour of the signals c and d, can also be provided. If the outage detector 15 contains only one of the components from the watchdog 16 or comparator 17, the circuit 18 is omitted and the output signal s coincides with the signal c or d.

The output signal s generated by the outage detector 15 controls a recorder 19, which, in the case of the specified events (a) and/or (b), generates an error dataset F and provides this for the processor 9 for transmission via the radio transceiver 8 to the central station 13. As shown symbolically in Fig. 2, the recorder 19 is, for example, a recording unit 20, which has a buffer memory 21 and which is connected to one or more outputs of the satellite navigation receiver 5.

As error dataset F, the recorder 19 in the simplest case records the last position fix p_m generated by the satellite navigation receiver 5 just before the response of the outage detector 15; see Fig. 3a. In addition, the recorder 19 can also add further data to the error dataset F depending on requirements, such that this error dataset can also contain - individually or in any combination:

- a time stamp t_m of the aforementioned last position fix p_m;
- the first position fix p_n generated directly after the responding of the outage detector 15 has finished, if desired also with associated time stamp t_n;

- the quality measurement values q_m and/or q_n generated with the specified last and/or first position measurement value p_m, p_n;
- one or more of the quality measurement values q_i generated during the responding of the outage detector 15, i.e. provided the recorder 19 is actuated (s = "1"), if desired also with associated time stamp t_i;
- the satellite raw data r_i received - or formed - with the specified last and/or first position measurement value p_m, p_n and/or during the responding of the outage detector 15 (s = "1"); and/or
- the sensor measurement values m_i generated approximately at the same time as the specified last and/or first position measurement value p_m, p_n and/or during the responding of the outage detector 15 (s = "1").

The recorder 19 can optionally pre-process the error dataset F, for example by eliminating redundant or irrelevant data, adding environmental data from the surroundings of the onboard unit 2 or internal state data of the onboard unit 2, data summary, etc., depending on the particular situation.

The received error datasets F are evaluated in the central station 13. This evaluation can be performed on the one hand individually, i.e. the error datasets F of an onboard unit 2 are considered individually, and on the other hand a plurality of error datasets F of different onboard units 2 can also be received, evaluated jointly, and validated, for example against one another.

When evaluating, the error datasets F are considered depending on the location of the position fixes specified therein p_m, p_n, $\{p_i\}$ and, when sensed, time stamps t_m, t_n, $\{t_i\}$, quality measurement values q_m, q_n, $\{q_i\}$, satellite raw data $\{r_i\}$ and/or sensor measurement values $\{m_i\}$ thereof and are analysed for possible error sources so as to prepare measures for remedying these. When evaluating, geographical interference and shadowing areas 14 of the satellite reception as well as, where applicable, the time dependency thereof can optionally be determined by a comparison of the error datasets F with a digital map. Permanent shadowing, for example by tunnels, can thus be identified and distinguished

from temporary shadowing, for example in narrow valleys, where a sufficient number of satellite signals 6 can, only sometimes, be received in the necessary strength, or from weather-induced signal attenuations, or shadowing, dependent on the time of year, in dense vegetation of fixed or movable interfering sources ("jammers"), and so on. Consequently, targeted measures for remedying errors can be introduced in order to increase the level of toll levying of the road toll system 1, for example stationary position transmitters or satellite signal repeaters can be erected, or interference sources can be eliminated or switched off, or deliberate transmission of interfering signals by jammers can be tracked and prosecuted.

The invention is not limited to the presented embodiments, but includes all variants and modifications that fall within the scope of the accompanying claims. The onboard unit 2, as a whole or individual components thereof, such as the outage detector 15, the recorder 19, or parts thereof, can thus be implemented, for example in the processor 9, both as hardware modules and as software objects.

ONBOARD-ENHED OG FREMGANGSMÅDE TIL FUNKTIONSOVERVÅGNING I ET VEJGEBYRSYSTEM

PATENTKRAV

1. Onboard-enhed til et vejgebyrsystem (1) med en satellitnavigationsmodtager (5) til fortløbende generering af positionsfikspunkter (p_i) og tilhørende kvalitetsmåleværdier (q_i) på basis af satellitrådata (r_i),
en radiotransceiver (8) og
en til disse komponenter (5, 8) koblet processor (9), der er konfigureret til på basis af positionsfikspunkterne (p_i) at generere gebyrdata (M) og sende dem via radiotransceiveren (8),
kendetegnet ved
en til satellitnavigationsmodtageren (5) koblet fejldetektor (15), der er konfigureret til at reagere ved en udeblivelse af positionsfikspunkter (p_i) over et bestemt mindstetidsrum (δ) eller et fald i kvalitetsmåleværdier (q_i) under et bestemt mindstekvalitetsmål (Q_{min}), og
en til satellitnavigationsmodtageren (5) koblet og af fejldetektoren (15) styret registrator (19), der er konfigureret til ved fejlmelding fra fejldetektoren (15) at generere en fejldatablok (F) med i det mindste det sidste positionsfikspunkt (p_m) før fejlmeldingen,
hvor processoren (9) er konfigureret til at modtage fejldatablokken (F) fra registratoren (19) og sende den via radiotransceiveren (8).

2. Onboard-enhed ifølge krav 1, **kendetegnet ved**, at fejldatablokken (F) også indeholder et tidsstempel (t_m) for det nævnte sidste positionsfikspunkt (p_m).

3. Onboard-enhed ifølge krav 1 eller 2, **kendetegnet ved**, at fejldatablokken (F) også indeholder det første efter fejlsituationens ophør genererede positionsfikspunkt (p_n).

4. Onboard-enhed ifølge krav 3, **kendetegnet ved**, at fejldatablokken (F) også indeholder et tidsstempel (t_n) for det nævnte første positionsfikspunkt (p_n).

5. Onboard-enhed ifølge ét af kravene 1 til 4, **kendetegnet ved**, at fejldatablokken (F) også indeholder mindst én under fejlsituationen genereret kvalitetsmåleværdi (q_i).

6. Onboard-enhed ifølge ét af kravene 1 til 5, **kendetegnet ved**, at fejldatablokken (F) også indeholder under fejlsituationen modtagne satellitrådata (r_i) og/eller i et sensorelement (10) genererede sensormåleværdier (m_i).

7. Onboard-enhed ifølge ét af kravene 1 til 6, **kendetegnet ved**, at fejldetektoren (15) indeholder en "vagthund" (16), der kan aktiveres på ny af hvert genereret positionsfikspunkt (p_i).

8. Fremgangsmåde til funktionsovervågning i et vejgebyrsystem (1) med en central (13) og i det mindste én køretøjsbåret onboard-enhed (2), som på basis af satellitrådata (r_i) fortløbende genererer positionsfikspunkter (p_i) og tilhørende kvalitetsmåleværdier (q_i) og sender derpå baserede gebyrdata (M) til centralen (13), omfattende:

detektering af en udeblivelse af positionsfikspunkter (p_i) over et bestemt mindstetidsrum (δ) eller et fald i kvalitetsmåleværdier (q_i) under et bestemt mindstekvalitetsmål (Q_{min}) i onboard-enheden (2),

i tilfælde af detekteringen registreres en fejldatablok (F) med i det mindste det sidste positionsfikspunkt (p_m) før detekteringen i onboard-enheden (2),

afsendelse af fejldatablokken (F) fra onboard-enheden (2) til centralen (13), og

analyse af fejldatablokken (F) i centralen (13).

9. Fremgangsmåde ifølge krav 8, **kendetegnet ved**, at fejldatablokken (F) også indeholder et tidsstempel (t_m) for det nævnte sidste positionsfikspunkt (p_m).

10. Fremgangsmåde ifølge krav 8 eller 9, **kendetegnet ved**, at fejldatablokken (F) også indeholder det første efter ophør af detekteringen genererede positionsfikspunkt (p_n).

11. Fremgangsmåde ifølge krav 10, **kendetegnet ved**, at fejldatablokken (F) også indeholder et tidsstempel (t_n) for det nævnte første positionsfikspunkt (p_n).

12. Fremgangsmåde ifølge ét af kravene 8 til 11, **kendetegnet ved**, at fejldatablokken (F) også indeholder i det mindste én under detekteringen genereret kvalitetsmåleværdi (q_i).

13. Fremgangsmåde ifølge ét af kravene 8 til 12, **kendetegnet ved**, at fejldatablokken (F) også indeholder under detekteringen modtagne satellitrådata (r_i) og/eller i et sensorelement (10) frembragte sensormåleværdier (m_i).

14. Fremgangsmåde ifølge ét af kravene 8 til 13, **kendetegnet ved**, at der i centralen (13) modtages mindst én anden af en anden onboard-enhed (2) på den nævnte måde frembragt og sendt fejldatablok (F), og fejldatablokkene (F) fra de mindst to onboard-enheder (2) valideres ved vurdering af dem mod hinanden.

15. Fremgangsmåde ifølge ét af kravene 8 til 14, **kendetegnet ved**, at der ved analyse gennem en sammenligning af fejldatablokkene (F) med et digitalt landkort bestemmes geografiske forstyrrelses- og skyggeområder (14) i satellitmodtagelsen.