(19) DANMARK

(10) DK 2017 70011 A1

(12) PATENTANSØGNING

Patent- og
Varemærkestyrelsen

(51) Int.Cl.: *G 01 S 11/02 (2010.01)* *F 03 D 17/00 (2016.01)*

(21) Ansøgningsnummer: **PA 2017 70011**

(22) Indleveringsdato: **2017-01-09**

(24) Løbedag: **2017-01-09**

(41) Alm. tilgængelig: **2018-05-22**

(71) Ansøger: **KK WIND SOLUTIONS A/S, Bøgildvej 3, 7430 Ikast, Danmark**

(72) Opfinder: **Chris Damgaard, Gilmosevænget 15, 7400 Herning, Danmark**
Per Mølhave Christiansen, Nygade 4, 7430 Ikast, Danmark

(74) Fuldmægtig: **Patentgruppen A/S, Arosgården, Åboulevarden 31, 4., 8000 Århus C, Danmark**

(54) Benævnelse: **ESTABLISHING A DISTANCE ON WIND TURBINE BLADE**

(56) Fremdragne publikationer:
US 2015/0029053 A1
US 9140772 B1
US 6803851 B1

(57) Sammendrag:
The invention relates to an apparatus integrated in a wind turbine blade for establishing the distance X between a root antenna and a tip antenna, the apparatus comprising: a root antenna mounted at a root portion of the blade, a tip antenna mounted at the tip portion of the blade, a signal transmitter connected to one of the tip or root antennas, a signal receiver connected to the other of the tip or root antennas, and a data processing unit configured to control transmittal of a radio signal via the signal transmitter and processing of the radio signal received by the signal receiver, wherein the data processing unit, signal transmitter and signal receiver are located inside the wind turbine blade, wherein the processing of the radio signal results in determining a peak value of the received signal, and wherein the distance X is established based on the determined peak value.

Fortsættes ...

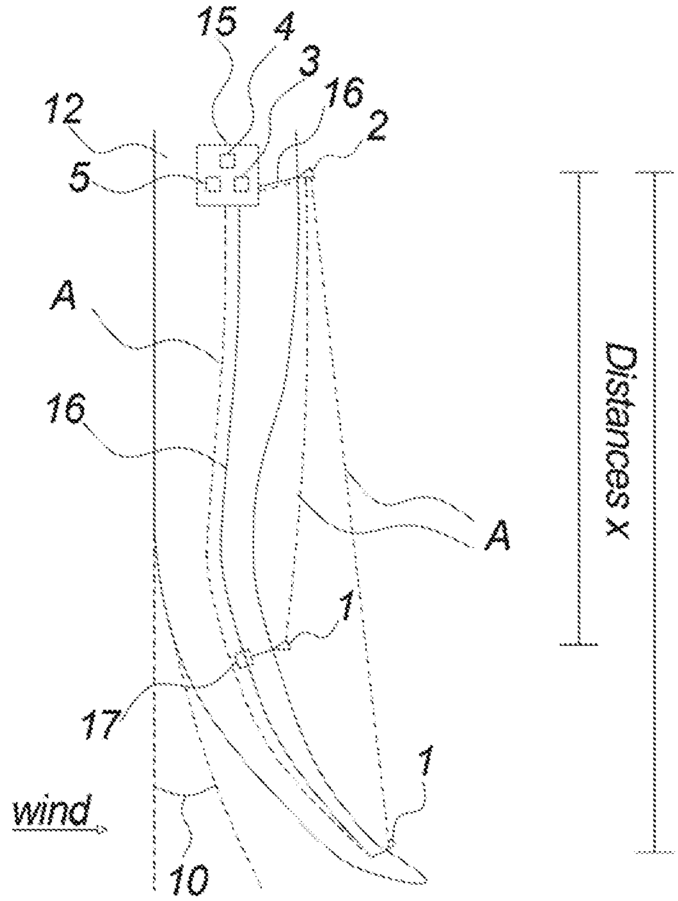

Fig. 2

ESTABLISHING A DISTANCE ON WIND TURBINE BLADE

Field of the invention

The invention relates to an apparatus and a method for determining the distance between a tip and a root antenna of a wind turbine blade.

Background of the invention

Development of blades of modern wind turbines is going towards longer and thus more flexible blades. Longer blades will increase deflection of the blades, a deflection which in a worst-case scenario could lead to a collision of a blade with the wind turbine tower.

To avoid the risk of such collision the control of wind turbine must balance (aggressive) control to increase power production and (Non aggressive) control to avoid blade / tower collision.

It is known to provide input to the wind turbine controller to perform this balanced control in many ways. Prior art describe to use different types of sensors positioned on the blades, tower and / or nacelle, blade modal profile, laser or video based monitoring systems etc. to provide input to the wind turbine controller which can be used in the control to avoid blade / tower collision.

WO2014027032 describes a blade deflection monitoring system wherein wireless communication between blade mounted tip and root communication devices is used to monitor the position of the tip of a blade. WO2015035270 describes how to determine the distance between a first antenna and a second antenna based on using the time delay between a signal transmitted and received from a first and a second antenna respectively. It is mentioned to compare templates of the expected received time signal with the actual received time signal to determine the time delays.

The robustness of known sensors / monitoring systems is of the outmost importance for the owner of a wind turbine in that failure of such system may lead crash down of the wind turbine.

Brief description of the invention

Therefore, the present invention relates to a method of determine the distance X between a first antenna and a second antenna, the method comprising the steps of: by a signal transmitter, transmitting an air born signal A between a first antenna to a second antenna, by a signal receiver, receiving the air born signal A from the first or second antenna, by at least one data processor at a time T, sampling the received air born signal A thereby obtaining a sampled received air born signal B, and correlating the sampled received air born signal B with a reference signal C, thereby obtaining a correlated signal D, establish the distance X as the raw distance Xr at time T between the first antenna and the second antenna 2 based on the peak value 7D of the correlated signal D.

The air borne signal is received as an analog signal and e.g. every 10ms the received radio signal is sampled with a GHz frequency resulting in e.g. around 100 samples points. The sample frequency determines the number of sample points based on which a distance between a set of first and second antennas is established. A set of antennas could be a tip antenna and a root antenna communicating. The ratio between when the radio signal should be sampled can be determined by the wind turbine controller, both this and the sample frequency can be varied to fit the individual wind turbine control.

Accordingly, a first set of sample points defined by the sample frequency is evaluated as described above to obtain a raw distance representing the distance X at time T. Then at time T+1, after e.g. 10ms (configurable) the radio signal is again sampled leading to at a second set of sample points. A raw distance Xr at time T+1 can then be determined based on the second set of sample points.

The air born signal is preferably a radio signal. Hence a reference in this document to a radio signal is a reference to an air born signal.

The raw distance Xr is the so-called raw distance which at times, may be determined based on an outlier. Therefore, the distance Xr cannot be 100% trusted but if averaged would be sufficient for determining an approximated average distance between antennas.

According to an embodiment of the invention, the method further comprising the steps of: calculating a difference Δ between the raw distance Xr at time T and a smoothed distance $Xs_{(T-1)}$ wherein the smoothed distance $Xs_{(T-1)}$ is the distance X at time T – 1 storing the difference Δ in a data storage together with a plurality of previously determined differences Δ, calculating a median value of the plurality of differences Δ of the data storage, establishing a residual as the median value if the absolute difference between the difference Δ and the median value exceeds a difference threshold, otherwise the residual is established as the difference Δ, and establishing the distance X at time T as the smoothed distance $Xs_{(T-1)}$ of the signal D at time T – 1 plus the residual if the residual exceeds a residual threshold, otherwise the distance X at time T is established based on the peak value 7D found within the sample window 6 centered at the smoothed distance $Xs_{(T-1)}$ of the signal D at time T – 1.

These additional steps are advantageous in that hereby the raw distance Xr is verified or corrected if needed. Hence the smoothed distance Xs can be closer to 100% trusted than the raw distance Xr leading to the possibility of using the smoothed distance e.g. in pitch control of the wind turbine. Hence, the additional steps are a way of verifying the raw distance Xr is in fact the distance X between a set of tip and root antennas.

When a difference Δ at a given time T is determined it is stored in a data storage such as an array with e.g. with room for e.g. 400 peak values. This is advantageous in that an average of the least 400 differences Δ is then used to determine the distance X. Thereby, a single or even maybe 100 outlier values does not influence the result significantly.

As mentioned the peak value representing the distance X is found in the set of sample points within the sample window or as the previously smoothed distance Xs plus the residual. In the latter situation, i.e. when the residual is above the residual threshold the raw distance Xr is considered an outlier and discharged. Instead the distance X is determined based on the previously established smoothed distance Xs plus the residual and thereby the distance X is changed more radically than possible in the first situation.

According to an embodiment of the invention, the difference threshold is between 1 and 10, preferably between 1 and 6 most preferably between 1 and 5. The difference threshold is advantages in that it defines the limit for the value of the residual as either the difference Δ (if the difference Δ is less than the difference threshold) or the median value (if the difference Δ is higher than the difference threshold). Thereby is indirectly also made a limit for the change of the distance X for time T to T+1.

According to an embodiment of the invention, the residual threshold is between 1 and 10, preferably between 1 and 6 most preferably between 1 and 5. The residual threshold is advantages in that it defines the limit for when the distance X should be determined based on the peak of the sampled received signal (if the residual is less than the residual threshold) or a previous smoothed distance Xs plus the residual (if the residual is higher than the residual threshold). Thereby is indirectly also made a limit for the change of the distance X for time T to T+1.

According to an embodiment of the invention, the distance X is established periodically with a frequency between 1Hz and 500Hz, preferably between 25Hz and 250Hz and most preferably between 75Hz and 125Hz. As with the size of sample window, sample frequency, etc. the frequency with which the distance X is determined may vary from wind turbine to wind turbine. The distance X should be determined sufficiently often that the wind turbine controller can use it e.g. in the pitch control of the blade. Hence, updating the distance X with a frequency of 100Hz has turned out to be sufficient for most wind turbine controllers

According to an embodiment of the invention, the location in or out of the rotor plane of the blade is determined based on distances X from a plurality of sets of first antennas and second antennas. This is advantages in that the data processor then based on the different distances obtained between the sets of antennas is able to determine the deflection of the blade out of the idling rotor plane. the deflection can be made based on mathematic principle such as trigonometry. A set of antennas can be any combinations of first and second antennas.

According to an embodiment of the invention, the first antenna is a tip antenna and the second antenna is a root antenna. One set of tip and root antennas can be made of any combinations of these types of antennas hence a tip antenna can be part as many sets as the number of root antennas. In the same way, the root antennas can be part of as many sets as the number of tip antennas. By obtaining distance X between blade root and each of the location of the tip antennas, then when combined and processed a location of the tip in / out of the neutral rotor plan can be determined. Here the neutral rotor plan is the rotor plane in which the blades are rotating when very low or no force from wind is acting upon them e.g. during idling.

According to an embodiment of the invention, the first and second antennas are located at the blade. The first and second antennas are also referred to as tip (firsts) and root (second) antenna. At the blade should be understood as integrated (typically the tip antenna) or attached (typically the root antenna) to the blade. Preferably in a way where line of sight is present between at least one root and one tip antenna at least ¾ of the time of one revolution of the blade in the rotor plane.

According to an embodiment of the invention, the at least one antenna of the second antennas is located at the root of the blade and at least two antennas of the first antennas are located at the outer half of the blade. It is advantageous to have more than one (e.g. 3) tip antennas located at the blade from the middle of the blade and towards the tip of the blade. The tip antennas may be located in the blade preferably in plane with the outer shell of the blade. The signal A can be sent from tip antenna to root antenna but could also be send from the root antenna to the tip antenna.

According to an embodiment of the invention, the center of the sample window 6 is varied from time T-1 to a subsequent time T. It is very advantageous at time T to let the sample window be centered around the peak value established at time T-1 if this peak value was used to determine the distance X at time T-1. In this way when the peak value changes and thereby the distance X the sample window 6 is changing with it. Thereby the balance between capturing the correct peak value and the likelihood of confusing this peak with an outlier peak is maintained constant.

According to an embodiment of the invention, the sample window covers less sample points than the number of sample points of the sampled received air born signal B, preferably less than 100 sample points, most preferably less than 50 sample points.

As mentioned the peak value representing the distance X is found in the sample points within the sample window if it has been determined that the residual is less than the residual threshold. Therefore, the extent of the sample window should be large enough to capture changed in distance X, but at the same time short so that the likelihood of peak values from outliers occurring in the radio signal is not found within the sample window.

According to an embodiment of the invention, the data storage is an array facilitating storage of at least 200 difference Δ values. The difference Δ can be stored in any kind of data storage e.g. based on vectors, RAM, etc. The use of an array (or any data storage) is that it helps filtering out outliers, hence the size of the array should be balanced. Too long array make it slow to track the correct peak when e.g. the wind turbine come into an operation point where the two antennas can see each other. Too small array make it more sensitive to outliers. An array size between 300 and 500 e.g. 400 has turned out to be working well.

According to an embodiment of the invention, the received air born signal A is sampled with a frequency between 1MHz and 100GHz

According to an embodiment of the invention, the sampled received air born signal B is interpolated by a factor between 2 and 2000, preferably between 4 and 1000, most preferably between 6 and 100. This is advantageous in that in this way the resolution is increased and thereby a more accurate peak sample value is obtained. Using factor 9 has turned out to be a fine balance between the resolution and the amount of data to process.

According to an embodiment of the invention, the size of the at least one data processor at least 500Mips, preferably at least 600Mips, most preferably at least 700Mips. A data processor of such high capacity is advantages in that the speed of the processing of the received radio signal can be made at an acceptable level for the result of the data processing to be used in the control of the wind turbine. 800Mips has turned out to work well in an embodiment of the invention.

According to an embodiment of the invention, the distance X is at least partly used by a wind turbine controller as basis for determining a pitch reference of one of the blades of the wind turbine.

Moreover the invention relates to, an apparatus integrated in a wind turbine blade for establishing the distance X between a root antenna and a tip antenna, the apparatus comprising: a root antenna mounted at a root portion of the blade, a tip antenna mounted at the tip portion of the blade, a signal transmitter connected to one of the tip or root antennas, a signal receiver connected to the other of the tip or root antennas, and a data processing unit configured to control transmittal of a radio signal via the signal transmitter and processing of the radio signal received by the signal receiver, wherein the data processing unit, signal transmitter and signal receiver are located inside the wind turbine blade, wherein the processing of the radio signal results in determining a peak value of the received signal, and wherein the distance X is established based on the determined peak value.

According to an embodiment of the invention, the apparatus comprises at least two root antennas and at least two tip antennas and wherein the location of at least one of the tip antennas in the rotor plan can be determined based on distances established between the root antennas and the tip antennas. Based on distance information of preferably all four antenna sets deflection out of the idling rotor plane can be determined by the data processor e.g. by use of trigonometry or similar mathematic principle.

According to an embodiment of the invention, the distance X is established according to the method descried in any of the claims 1-16.

Moreover the invention relates to a wind turbine blade comprising at least one transceiver, at least one tip antenna, at least one root antenna and at least one data processor configured for determining the travel time of a radio signal traveling between a tip antenna and a root antenna.

Figures

A few exemplary embodiments of the invention will be described in more detail in the following with reference to the figures, of which

figure 1	illustrates part of a wind turbine,
figure 2	illustrates a blade of a wind turbine,
figure 3A-3D	illustrates part of a radio signal received and processing hereof, and
figure 4	illustrates blade position in time.

Detailed description of the invention

Figure 1 illustrates wind turbine blades 12 connected to a hub 13 which again is connected to the nacelle 14. The blades 12 and hub 13 are together referred to as the rotor which is rotating in a rotor plane.

According to an embodiment of the invention each blade 12 comprise antennas 1, 2 communicating with a transceiver 15. The antennas 1, 2 are preferably located so that at least during part of one revolution of a blade 12 in the rotor plan there is line of sight between the tip antennas 1 and root antennas 2. Figure 1 illustrates two tip antennas 1 and one root antenna 2 on one side of the blade and one tip and root antenna 1, 2 on the second side. This is to illustrated, that various ways numbers of antennas 1, 2 can be used, located differently at the blade 12. Further, the antennas 1, 2 can be integrated or located on the outside or inside of the blade 12.

It is preferred if the antennas 1, 2 are located so that there is always line of sight between pressure side root antenna and two pressure side tip antennas, suction side root antenna and two suction side tip antennas and pressure and suction sides root antennas and one of the tip antennas (suction or pressure side).

In general, the antenna configuration can wary a lot. It is preferred that to have line of sight between both root antennas and their respective two tip antennas at the same time in order to use triangulation method to calculate distance in rotor plane.

Figure 2 is an enlarged view of the blade 12 of figure 1. As illustrated the blade 12 bends with angle 10 due to load of wind acting upon it. If not already existing, the bend of the blade creates line of sight between the tip and root antennas 1, 2.

It is preferred, that the transceiver 15 is located inside the blade 12, however its location is not essential to the invention as it is not essential to the invention that the signal transmitter 3 and signal receiver 4 hereof are in the same enclosure. In fact, the transceiver 15 may be referred to as an electronic box including the necessary hardware (transmitter 3, receiver 4, data processor 5, data storage, etc.). A location at the root portion is however preferred. In this way one blade comprise all the needed hardware to determine the distance X between antennas 1, 2.

Figure 2 further illustrates the transceiver 15, which via communication channels 16 and a splitter 9 transmits an air born signal A, preferably a radio signal, to the tip antennas 1. The tip antennas 1 are then passing signal A on to the root antenna 2. Finally, when the root antenna 2 receives the signal A it is passed on to the transceiver 15 via communication channel 16.

The signal is preferably a radio signal, but could in principle be any kind of signal capable of propagating through cables and air. According to a preferred embodiment, of the invention the radio signal used is a so-called Ultra Wide Band (UWB) signal having a carrier frequency between 3,1 and 4,8GHz. However, the frequencies may vary depending on local restrictions.

The communication channels 16 are preferably cables. Accordingly, when using cables in a wind turbine these can conduct current from strokes of lightning, therefore suitable protection of the transceiver 15 and antennas 1, 2 are required for protection hereof.

According to an embodiment of the invention, it is the traveling time of the signal traveling between the tip and root antennas 1, 2 which is interesting. This is because the wired communication channels 16 are defined e.g. by means of cable length and hence the only variable path for the signal in the signal loop from transceiver 15 through tip antenna 1 and root antenna 2 and back to the transceiver is the air borne part between the tip and root antennas 1, 2. The length of the signal path between tip and root antennas 1, 2 is changing with the bending angle 10 of the blade 12.

The travel time may be found as the time of the peak 7D of figure 3D plus a calibration constant which according to an embodiment compensates for the different delays occurring in the system. An example of such delay could be delays in cables carrying the signal. From the travel time it is possible to determine a distance by dividing it with the speed of light which is c = 299792458 m/s.

As described above, one way of determine this traveling time and thereby the distance X is addressed in the prior art. However, the prior art method solves the problem of outliers in the measured traveling time by using a plurality of signal templates leading to a complex and slow measuring system which is only as robust as the difference between the templates.

To solve this problem, the present invention describes a robust measurement of travel time of a signal between the tip and root antennas 1, 2. This is done by processing the travel time data by a signal / data processor 5 preferably (but not restricted to be) part of the transceiver 15. No matter where the signal / data processor 5 is located, it comprises or communicates with a data storage (not illustrated) in which a reference signal C is stored. Further, the data storage may also comprise temporary storage of samples of the radio signal A, temporary storage values used in the calculation of the distance etc. as will be described below.

Reference to radio signal may refer to the air born signal and vice versa. Further, the direction of signal transmitted between tip and root antennas 1, 2 is not important to the invention.

Figure 3 illustrates the radio signal A (figure 3A), a sampled version B of the radio signal A (figure 3B), the reference signal C (figure 3C) and the result D of a correlation between the sampled version B and the reference signal C (figure 3D).

The reference signal C is by the processor 5 correlated with the sampled radio signal B. Result of the correlation is signal D having a peak value 7D selected as the part of the resulting curve D having the highest amplitude (an absolute value is preferred). One way of implementing the correlation is by shifting the reference signal C (indicated by the arrow) over the sampled radio signal B resulting in that all samples of signal B is multiplied by the reference signal C so to speak.

Ideally, the received radio signals A could be used with no further processing, however, in the real-world noise, disturbance, reflection, etc. makes further processing necessary. Therefore, it is not to know if signal A represents a reflection or the actual signal send between the antennas 1, 2. In the ideal scenario, the peak of signal A (or the peak 7B of the sampled version hereof signal B) can be used to determine what is referred to as a raw distance Xr. However, the raw distance Xr is preferably calculated to be sure that it is representing the distance and not confused by a disturbed signal. This is done as described below leading to a raw distance Xr found as the peak 7D of figure 3D. In most situations, the raw distance Xr is equal to the distance X, however to be sure the below analyses and calculations are made and if necessary correct the distance X accordingly.

The radio signal A is received as an analog signal by the signal receiver 4 e.g. every 10ms hence first point in time the signal is received could be referred to as T. The radio signal A received at time T is sampled with a GHz frequency resulting in a set of sample point 8 at a time T illustrated in figure 3B as signal B. According to an embodiment of the invention, a set of sample points may count up to around 100 individual sample points 8. A new set of data points is created after another 10ms i.e. at time T1 and so on. In this way, a set of sample points is obtained for each 10ms.

It should be mentioned that the number of sample points 8 of a set of sample points, sample frequency and the time between establishing a new set of data points may vary according to requirements to speed and precision of the result of the calculation of the distance X.

The 10ms is not essential and may e.g. follow the frequency by which the wind turbine controller is operated. The sample frequency determines the number of sample points 8 consisting the set of data points. Based on the sample points 8 of a set of sample points established e.g. at time T1 one distance X at time T1 is established preferably as the peak of this set of sample points.

Accordingly, a first set of sample points defined by the sample frequency is established as described above. Then at time T2, after e.g. 10ms (configurable) the received radio signal A is again sampled leading to a second set of sample points. The distance X at time T2 can then be determined based on the data points 8 of this second set of sample points, etc.

The sampled signal B is correlated with the reference signal C ideally resulting in a peak value 7D close to or at the center of the peak value 7B of the sampled signal B.

As mentioned, in the ideal scenario, this peak sample value 7B (or even the peak of signal A) can be used to determine the distance X. However due to possible disturbances of the radio signals A there is a risk that the correlation result (signal D) will have a peak value 7D based on a disturbed signal A instead of based on the correct signal – a peak derived from a set of sample points of such disturbed signal is referred to as an outlier.

Therefore, to be sure that the distance X determined at time T is the actual distance and not based on an outlier, the difference between this and the distance X determined at time T-1 is evaluated.

To filter out disturbed sets of sample data (i.e. outliers), a sample window 6 of e.g. 20 sample points 8 is introduces centered around the peak 7B from the sampled signal B. The number of samples points 8 covered by the sample window is preferably less than the number of sample points of the signal B and preferably less than 50 sample points 8. Experience has shown that 20 samples is an appropriate size of the sample window 6. To account for displacement of the blade 12 the sample window 6 is moved as will be described below.

It should be mentioned that to increase the resolution of the received sampled radio signal B an oversampling (or interpolation) hereof can be introduced. Hence between each of the samples points 8 of signal B 2 -2000 additional points may be introduced. The number is not essential but interpolation by factor 5 -15 e.g. factor 9 i.e. adding 8 points between two samples 8 has been found to be advantages.

As mentioned, due to the risk of outliers the raw distance Xr cannot always be blindly trusted when determine the distance X. To ensure this or correct if needed, the following steps are made.

First, a difference Δ between the raw distance Xr determined at time T and the distance X determined at time T-1 is found. The difference Δ is stored in a data storage. The distance X found at time T-1 is referred to as smoothed distance Xs.

What is referred to as the smoothed distance Xs is in this description preferably determined based on the peak 7D within the sample window 6 of the correlated signal D whereas the raw distance Xr is the peak of the entire signal D. Hence the peak of the signal D leading to the raw distance Xr may be higher (but outside the sample window 6) than the peak 7D leading to the smoothed distance Xs (always within the sample window 6). In the situation where the signal A is not disturbed in any way, the same peak may lead to the raw distance Xr and the smoothed distance Xs.

The data storage is preferably an array having a size of 300 and 500 values, the size is not essential but an array of 400 values has turned out to be appropriate. Other size array could be used but a trade-off between memory usage / speed to lock to the correct pulse peak and the ability to reject outliers should be considered when determining the size of the array. The array may be implemented as a ring buffer where the oldest values is discarded when a new value is stored in the array. An initial phase is taking place when the array is filled up with difference Δ values during which the resulting distances are being more and more reliable.

The nature of outliers is that they are unpredictable compared to a displacement of the blade 12. If the blade 12 is displaced, a sequence of peaks with small variety in size will follow each other whereas outliers typically will only be one or two peaks falling out of an otherwise continuously sequence of peaks. This is illustrated at figure 4 where distances X (one for each set of sample points i.e. one for each received signal A) are illustrated in time. At time T4-T7 and T15 outlier distances 11 pops out of the sequence of distances X. Outlier distances 11 are as indicated by the arrows corrected and “drawn back” in the sequence be the present invention as will now bed described.

As mentioned an array of e.g. 400 values representing differences Δ calculated at the last 400 received radio signals A is thereby established (at time T-1, T-2,..T-400). A median value of these 400 values is then established. If the difference Δ established at time T is large it may indicate that the raw distance Xr origins from an outlier. By storing the differences Δ in the array and afterwards calculate a new median value of the array, the impact of the outlier is significantly reduced. Hence the new median value will only be slightly different from the previously median value used to calculate the distance X at time T-1.

The median value and the difference Δ established at time T is then compared. If the absolute result of this comparison exceeds a difference threshold value, the median value established at time T is the residual at time T. If the difference Δ is equal to or less than the difference threshold value, the residual at time T will be the difference Δ established at time T.

Then the distance X can be established at time T. If the residual is lower than a residual threshold value a peak (7D at figure 3D) of the correlated signal of figure 3D will be detected within the sample window 6, where the sample window 6 is centred around the value of the previous smoothed distance Xs i.e. the value used to determine the distance X at time T-1. This peak 7D is then used to determine the distance X at time T.

At figure 3D the stipulated signal D1 illustrates the correlated signal at time T-1 with peak 7D1 used to determine the distance X at time T-1. It is seen that the peaks 7D, 7D1 of the signals D an D1 are close to each other, indicating that the blade 12 has not changed significantly from time T-1 to time T.

From figure 3D it is seen that the peak 7D of signal D is within the sample window 6 centered around the peak 7D1 of signal D1. Further a signal D2 is illustrated with a peak Xr, this is to illustrate an outlier 11.

If the residual is larger than the residual threshold value, the distance X will be found based on the previous established smoothed distance Xs plus the value of the residual.

The difference / residual threshold can be defined by different numbers and experience has shown that a threshold of 3 is appropriate. Preferably the difference threshold and the residual threshold is the same threshold or at least the same value.

Hence, preferably whenever a new radio signal A is received the following is established / done with a signal A received at time T:

- Sampling signal A resulting in signal B
- Correlating signal B with reference signal C resulting in signal D
- Establish a raw distance Xr based on the peak 7D of signal D
- Calculating the difference Δ between the raw distance Xr and the distance X / smoothed distance Xs established at time T-1
- Storing the distance Δ in an array (and removing the “oldest” distance Δ from the array)
- Calculating a median value of the distances of the array

- Establish a residual as the median value or the difference Δ depending on a comparison between the difference Δ and the median value established at time T, and
- Establish the distance X at time T based on
  - o the peak of signal D found within a sample window 6 centered around the peak of the smoothed distance Xs found at time T-1 or
  - o the smoothed distance Xs found at time T-1 plus the residual

  depending on a comparison between the residual and a residual threshold.

Figure 4 illustrates distances X determined at times T0 - T17 separated with e.g. 10ms. Applying the teaching describe in relation to figure 3, it is seen that at T5, T6, T7 and T15 outliers 11 has been replaced or ignored as described above. Further figure 4 illustrates that outliers at time T5 – T7 are ignored.

If the blade position changes significantly due to wind load acting upon it, the angle 19 and thereby the distance X are changing. The first signal A received after such deflection may fall outside the sample window 6 and as described above be considered an outlier 11 despite the fact that it new represents the new distance X. However, as outliers 11 continue to be detected the median value will change and thereby the residual. This will after a number of detected outliers 11 result in a residual having a value lower than the residual threshold and hereafter the distance X will again be determined as the peak 7D within the sample window 6 of the correlated signal D.

This adaption of the calculated distance X towards the actual distance X is illustrated as the changing of Dist. X at figure 4. It should be mentioned that figure 4 is a very simplified presentation hereof and only illustrates the principles of the invention. The first indication of a deflection of the blade 12 is illustrated as an outlier 11 at time T5 followed by outliers 11 illustrated at times T6, T7. The effect of the residual continues to be higher than the residual threshold is illustrated at times T8 - T10. At time T11 and the following times the residual is again below the residual threshold and the peak value 7D is again found within the sample window 6 of the correlated signal D.

A standalone outlier 11 is illustrated at time T15 which do not have any effect on the determined distance X due to the calculation and comparisons made above.

The established distance X can be used for further processing e.g. by one or more wind turbine controllers controlling the wind turbine. The travel time of the signal A and thereby the distance X established by the present invention can be converted to position of tip antennas 1 and thereby to position of the blade at the location of these antennas.

If more than one root antennas 2 and more than one tip antennas 1 are used (tip antennas 1 may be located between the blade tip and the blade root). A plurality of different distances here between can be established according to the method described above. By using mathematical relationships such as trigonometry between these distances the actual location in the rotor plan of the individual blades can be determined based on the position of the tip antennas 1. Alternatively, look-up tables made based on aeroelastic simulations made off-line could be used to determine the blade position. Hence, an actual distance can be calculated between the blade and tower and more a future distance between blade and tower can be estimated based on which pitch control of the individual blades can be made.

Therefore, the distance X can be used as basis for controlling pitch position and thereby power production, load, blade fatigue, odo meter input, individual pitch control, thrust force monitor/controller, tower clearance monitor/controller, wind shear monitor, wind gust controller etc. of the wind turbine.

Accordingly, the blade 12 including antennas 1, 2 and transceiver 15 is a sensor for measuring travel time of e.g. a radio signal from the transceiver 15 via the antennas 1, 2 and back to the transceiver 15. Since, only the airborne signal path between tip and root antennas 1, 2 changes in length the distance X can be determined from the measured travel time.

Hence from the above description it is now clear that the present invention relates to a method and apparatus mounted in / at a wind turbine blade either retrofitted or integrated in / at the blade from its manufacturing. By the present invention the distance between a root and a tip antenna can be determined based on processing the time a radio signal takes to travel between these antennas. A non-limiting example of the processing includes the following steps:

- Receive the radio signal
- Interpolate the 96 point received signal from radio with a factor 9
- Correlate the interpolated signal with a template pulse
- Calculate the difference between the interpolated signal and the smoothed signal which is put into an array with the last 400 differences
- Calculate the median of the array of the 400 differences
- If the absolute difference between the median and the current difference exceeds 3 the median will be used as residual else it will be the current difference
- If the residual is lower than 3 the peak of the interpolated signal will be detected in the range of +/- 10 points from the previous measurement. This gives the smoothed signal. If the residual is larger than 3 the signal will be found as the previous plus the residual

In addition, if the processing is made on signals from different sets of root and tip antennas, the distances obtained can be used to determine the location of the blade (based on the position of the tip antennas) in or out of the rotor plan also sometimes referred to as deflection of the blade.

In the above description, various embodiments of the invention have been described with reference to the drawings, but it is apparent for a person skilled within the art that the invention can be carried out in a number of ways not all of which are described above, using e.g. the examples and embodiments disclosed in the description in various combinations, and within a wide range of variations within the scope of the appended claims.

List of reference numbers

1. First / Tip antenna
2. Second / Root antenna
3. Signal transmitter
4. Signal receiver
5. Data processor
6. Sample window
7. Peak value
    - B. Peak of signal B
    - D. Peak of signal D
    - D1. Peak of signal D at time t-1
8. Sample point
9. Splitter
10. Bend angle
11. Outliers
12. Blades
13. Hub
14. Nacelle
15. Transceiver
16. Communication channel

A. Air born / received signal

B. Sampled air born signal

C. Reference signal

D. Correlated signal

D1. Correlated signal at time t-1

Xr. Raw distance

Xs Smoothed distance

X Distance

Claims

1. A method of determine the distance X between a first antenna (1) and a second antenna (2), the method comprising the steps of:

- by a signal transmitter (3), transmitting an air born signal A between a first antenna (1) to a second antenna (2),
- by a signal receiver (4), receiving the air born signal A from the first (1) or second antenna (2),
- by at least one data processor (5) at a time T,
  - sampling the received air born signal A thereby obtaining a sampled received air born signal B, and
  - correlating the sampled received air born signal B with a reference signal C, thereby obtaining a correlated signal D,
  - establish the distance X as the raw distance Xr at time T between the first antenna (1) and the second antenna (2) based on the peak value 7D of the correlated signal D.

2. A method according to claim 1, wherein the method further comprising the steps of:

- calculating a difference Δ between the raw distance Xr at time T and a smoothed distance $Xs_{(T-1)}$ wherein the smoothed distance $Xs_{(T-1)}$ is the distance X at time T – 1
- storing the difference Δ in a data storage together with a plurality of previously determined differences Δ,
- calculating a median value of the plurality of differences Δ of the data storage,
- establishing a residual as the median value if the absolute difference between the difference Δ and the median value exceeds a difference threshold, otherwise the residual is established as the difference Δ, and
- establishing the distance X at time T as the smoothed distance $Xs_{(T-1)}$ of the signal D at time T – 1 plus the residual if the residual exceeds a residual threshold, otherwise the distance X at time T is established based on the peak

value 7D found within the sample window 6 centered at the smoothed distance $Xs_{(T-1)}$ of the signal D at time T – 1.

3. A method according to any of claims 1 or 2, wherein the difference threshold is between 1 and 10, preferably between 1 and 6 most preferably between 1 and 5.

4. A method according to any of the preceding claims, wherein the residual threshold is between 1 and 10, preferably between 1 and 6 most preferably between 1 and 5.

5. A method according to any of the preceding claims, wherein the distance X is established periodically with a frequency between 1Hz and 500Hz, preferably between 25Hz and 250Hz and most preferably between 75Hz and 125Hz.

6 A method according to any of the preceding claims, wherein the location in or out of the rotor plane of the blade (12) is determined based on distances X from a plurality of sets of first antennas (1) and second antennas (2).

7. A method according to any of the preceding claims, wherein the first antenna is a tip antenna (1) and the second antenna is a root antenna (2).

8. A method according to any of the preceding claims, wherein the first and second antennas (1,2) are located at the blade (12).

9. A method according to any of the preceding claims, wherein the at least one antenna of the second antennas (2) is located at the root of the blade (12) and at least two antennas of the first antennas (1) are located at the outer half of the blade (12).

10. A method according to any of the preceding claims, wherein the center of the sample window 6 is varied from time T-1 to a subsequent time T.

11. A method according to any of the preceding claims, wherein the sample window 6 covers less sample points than the number of sample points of the sampled

received air born signal B, preferably less than 100 sample points, most preferably less than 50 sample points.

12. A method according to any of the preceding claims, wherein the data storage is an array facilitating storage of at least 200 difference Δ values.

13. A method according to any of the preceding claims, wherein the received air born signal A is sampled with a frequency between 1MHz and 100GHz.

14. A method according to any of the preceding claims, wherein the sampled received air born signal B is interpolated by a factor between 2 and 2000, preferably between 4 and 1000, most preferably between 6 and 100.

15. A method according to any of the preceding claims, wherein the size of the at least one data processor at least 500Mips, preferably at least 600Mips, most preferably at least 700Mips.

16. A method according to any of the preceding claims, wherein the distance X is at least partly used by a wind turbine controller as basis for determining a pitch reference of one of the blades of the wind turbine.

17. An apparatus integrated in a wind turbine blade for establishing the distance X between a root antenna (2) and a tip antenna (1), the apparatus comprising:

- a root antenna (2) located at a root portion of the blade (12),
- a tip antenna (1) located at the tip portion of the blade (12),
- a signal transmitter (3) connected to one of the tip or root antennas (1,2),
- a signal receiver (4) connected to the other of the tip or root antennas (1,2), and
- a data processing unit (5) configured to control transmittal of a radio signal A via the signal transmitter (3) and processing of the radio signal A received by the signal receiver (4),

wherein the data processing unit (5), signal transmitter (3) and signal receiver (4) are located inside the wind turbine blade (12),
wherein the processing of the radio signal A results in determining a peak value (7) of the received signal A, and
wherein the distance X is established based on the determined peak value (7).

18. An apparatus according to claim 17, wherein the apparatus comprises at least two root antennas (2) and at least two tip antennas (1) and wherein the location of at least one of the tip antennas (1) in the rotor plan can be determined based on distances X established between the root antennas (2) and the tip antennas (1).

19. An apparatus according to any of claims 17 to 18, wherein the distance X is established according to the method descried in any of the claims 1-16.

20. A wind turbine blade (12) comprising at least one transceiver (15), at least one tip antenna (1), at least one root antenna (2) and at least one data processor (5) configured for determining the travel time of a radio signal A traveling between a tip antenna (1) and a root antenna (2).

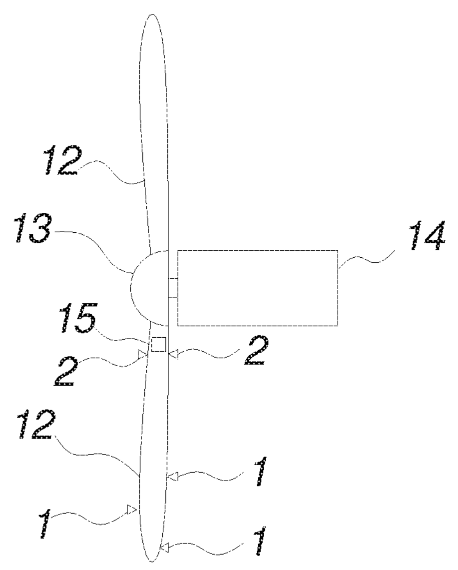

Fig. 1

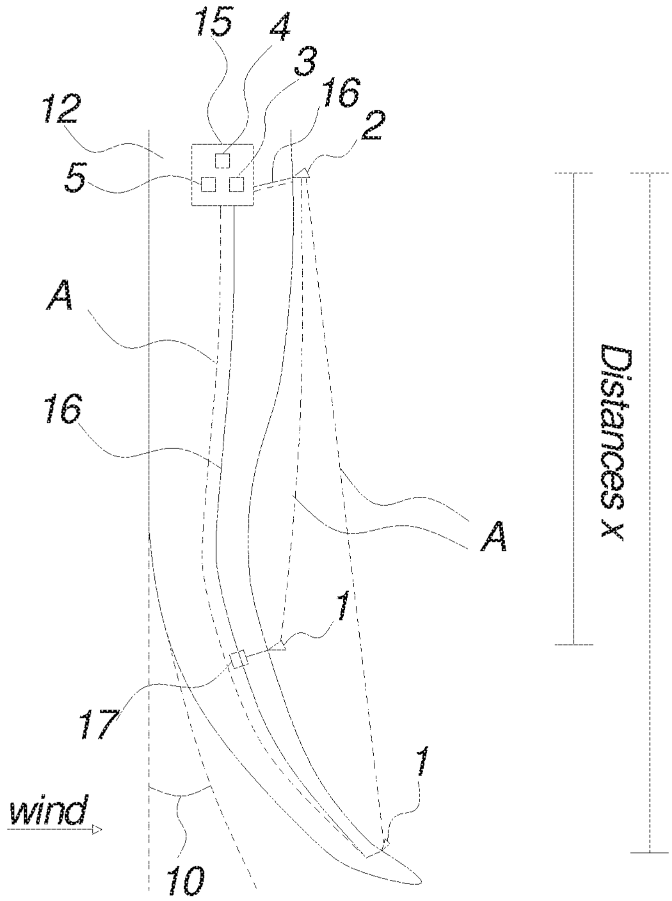

Fig. 2

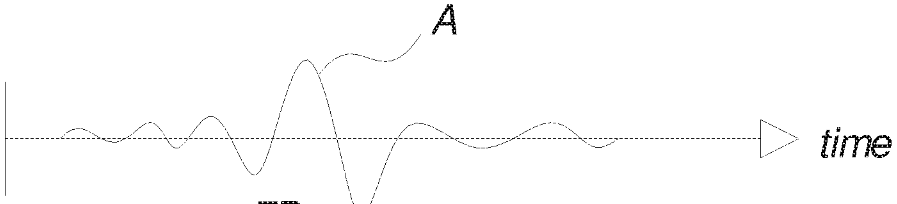

Fig. 3A

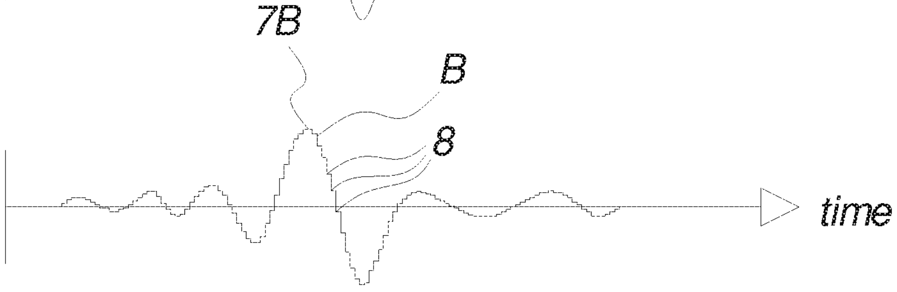

Fig. 3B

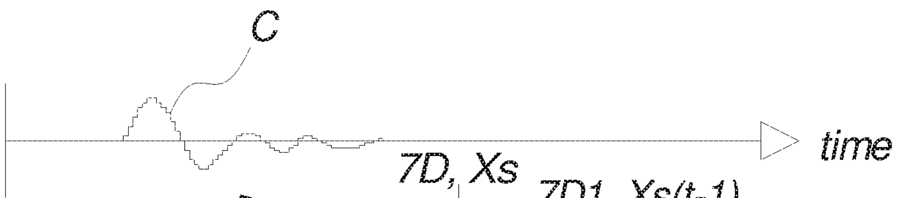

Fig. 3C

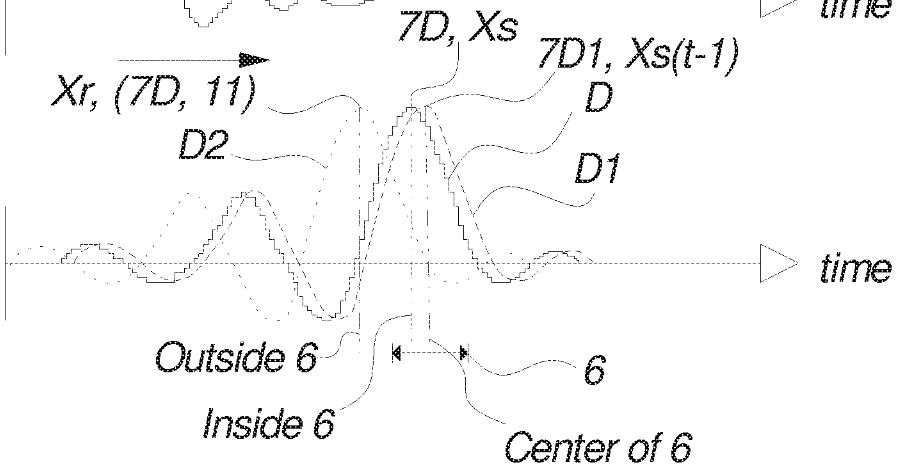

Fig. 3D

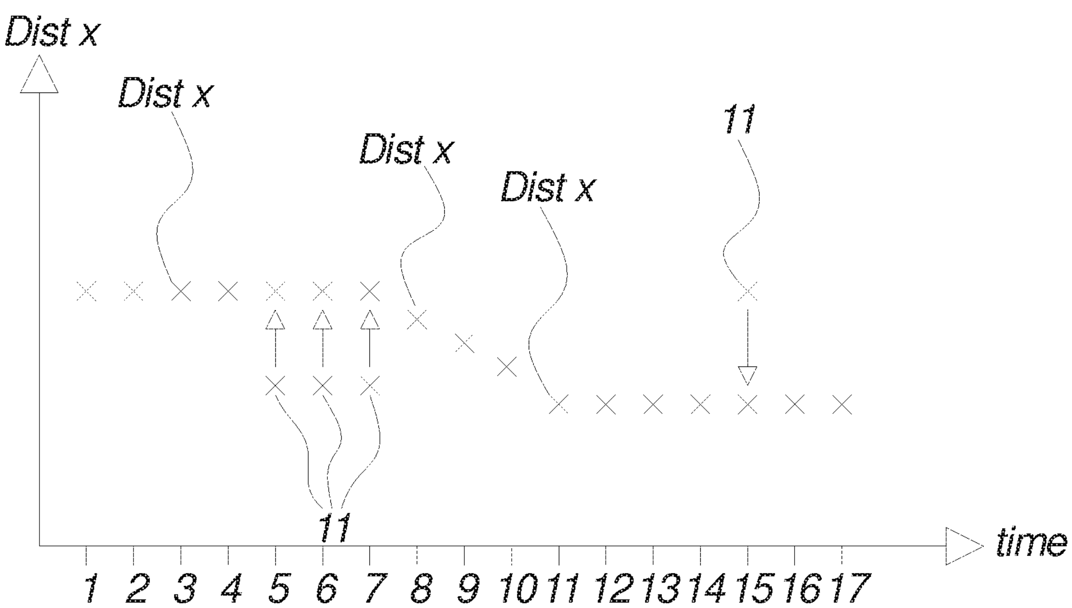

Fig. 4

DANISH PATENT AND TRADEMARK OFFICE

SEARCH REPORT - PATENT	Application No. PA 2017 70011

1. ☐ Certain claims were found unsearchable (See Box No. I).

2. ☐ Unity of invention is lacking prior to search (See Box No. II).

A. CLASSIFICATION OF SUBJECT MATTER

G 01 S 11/02 (2010.01); F 03 D 17/00 (2016.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

PCT-minimum documentation searched (classification system followed by classification symbols)

IPC&CPC: F03D, G01S, G01B

Documentation searched other than PCT-minimum documentation

DK, NO, SE, FI: IPC-classes as above.

Electronic database consulted during the search (name of database and, where practicable, search terms used)

EPODOC, WPI, FULL TEXT: ENGLISH

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.
X A	US 2015/0029053 A1 (DEWBERRY ET AL.), 2014.02.20, see especially fig. 5A, 5B, 6A; paragraphs [0008]-[0009], [0080]-[0084], [0094], [0175], [0192]; claims 16-17, 21-22	1, 4-5, 8-10 2-3, 6-7
A	US9140772 B1 (DEWBERRY ET AL.) 2015.09.22, see whole document	1-10
A	US6803851 B1 (KRAMER ET AL.) 2004.10.12, see whole document	1-10

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" Document defining the general state of the art which is not considered to be of particular relevance.

"D" Document cited in the application.

"E" Earlier application or patent but published on or after the filing date.

"L" Document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified).

"O" Document referring to an oral disclosure, use, exhibition or other means.

"P" Document published prior to the filing date but later than the priority date claimed.

"T" Document not in conflict with the application but cited to understand the principle or theory underlying the invention.

"X" Document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone.

"Y" Document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" Document member of the same patent family.

Danish Patent and Trademark Office
Helgeshøj Allé 81
DK-2630 Taastrup
Denmark

Telephone No. +45 4350 8000
Facsimile No. +45 4350 8001

Date of completion of the search report
31 May 2017

Authorized officer
Susanne Halkjær
Telephone No. +45 4350 8488

SEARCH REPORT - PATENT	Application No. PA 2017 70011

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.

SEARCH REPORT - PATENT	Application No. PA 2017 70011

Box No. I Observations where certain claims were found unsearchable

This search report has not been established in respect of certain claims for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched, namely:

2. ☐ Claims Nos.:
because they relate to parts of the patent application that do not comply with the prescribed requirements to such an extent that no meaningful search can be carried out, specifically:

3. ☐ Claims Nos.:
because of other matters.

Box No. II Observations where unity of invention is lacking prior to the search

The Danish Patent and Trademark Office found multiple inventions in this patent application, as follows:

SEARCH REPORT - PATENT	Application No. PA 2017 70011

SUPPLEMENTAL BOX

Continuation of Box [.]