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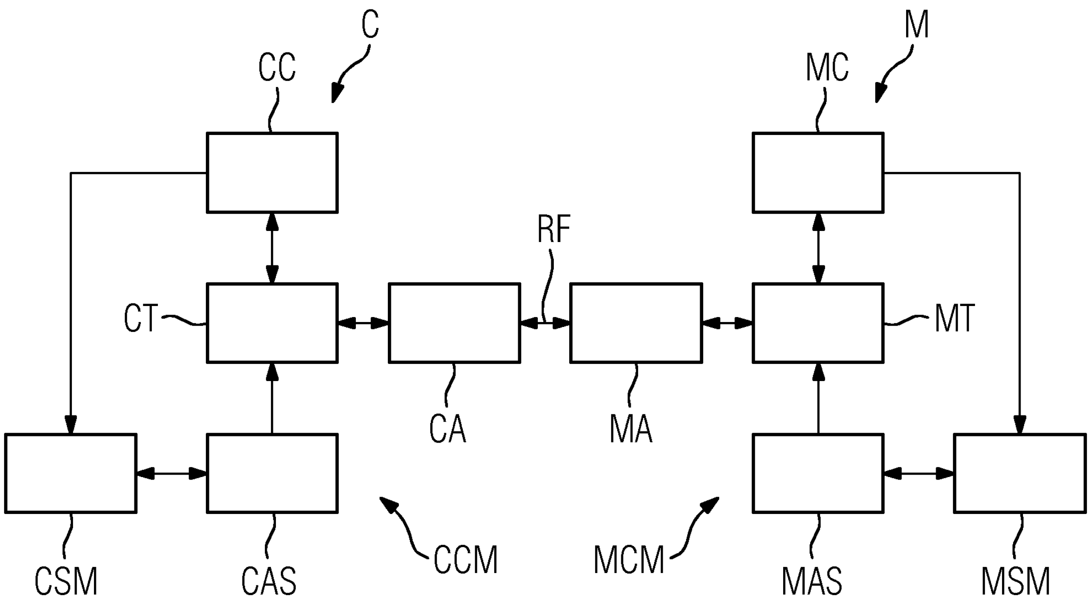
(54) Beam forming for industrial system

(57) Wireless communication in a dynamic industrial system shall be improved. Thus, there is provided a system for industrial application including a machine (M) capable of changing its position and having machine communication means (MCM) for wireless communication and a controller (C) designed for controlling the machine (M) and having controller communication means (CCM) for wireless communication with the machine communication means (MCM). The controller (C) is capable of aligning the machine communication means (MCM) and/or the controller communication means (CCM) to each other on the basis of an instruction from the controller (C) to the machine (M) to change its position.



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Description

[0001] The present invention relates to a system for industrial application including a machine capable of changing its position and having machine communication means for wireless communication, and a controller designed for controlling the machine and having controller communication means for wireless communication with the machine communication means. Furthermore, the present invention relates to a method of preparing a wireless communication in an industrial system between machine communication means of a machine capable of changing its position and controller communication means of a controller designed for controlling the machine.

[0002] The field of the invention concerns wireless industrial control. In this context, the normal wired connection between a machine and its controller implemented, for example, using Profinet is replaced by a bi-directional wireless connection. Such an approach has advantages in flexibility of operation and re-configuration.

[0003] The required bandwidth for wired industrial communications is increased all the time. Furthermore, in a wireless context, it may often be advantageous to implement a star/broadcast topology using TDMA where one controller controls several machines over a common air interface. Together these aspirations lead to increasing requirements for RF bandwidth. The bandwidth must be provided under the constraints of limited available spectrum and limited link budget to achieve the desired operating range.

[0004] An advantageous technology for providing additional bandwidth and range is beam forming. This is closely related to the choice of operating frequency. Considerably more spectrum is available at higher frequencies (e.g. 60 GHz). However, path loss between omnidirectional antennas is prohibitively high. Thus, beam forming is needed to achieve acceptable range performance. Fortunately, because antenna elements are small at high frequencies, the array of antenna elements required to achieve the necessary beam forming typically has practical size.

[0005] Ideally, a wireless communication link is provided by arranging for the antenna arrays at both ends of the link to point their beam in the direction of the other end of the link. However, if the link budget requires correct alignment of the antenna array beams to achieve communication, then it is not clear how to align the beams in the first place.

[0006] The conventional solution to this problem is initially to establish a communication channel between the end points of the link, whose bit rate is low enough to allow reliable communications with unaligned beams. A reduced bit rate link can be achieved in one of a number of ways:

- Reduce the occupied bandwidth of the transmitted signal - in this case the noise power will reduce in direct proportion to the occupied bandwidth.
- Reduce the modulation constellation size - for example, if the normal modulation was 64 QAM (constellation size = 64), this could be reduced to BPSK (constellation size = 2). The minimum acceptable signal to noise ratio for the smaller constellation size modulation would be lower than for the larger constellation size.
- Use spread spectrum - this provides a processing gain so that the minimum acceptable signal to noise ratio is further reduced, typically to values less than unity.

[0007] Once such a channel is available, adjustments can be made in the beam direction at either end of the link and the impact on the received signal level observed. For example, one approach could be to provide each link end with a table of antenna element weightings to provide a set of overlapped beams. Each entry in the table is tested in turn and the entry providing the highest signal level is selected. Once this process is completed, a further beam scan can be performed but with finer granularity of angle until the most favourable antenna pattern has been obtained.

[0008] This process can be performed at both ends of the link but in a coordinated fashion to avoid confusing signal level changes caused by antenna pattern changes at the opposite end of the link. For example, operation is effective if the transmitting end is able to establish an omni-directional pattern, perhaps using a single antenna element, while the receiving end is adjusting its beam.

[0009] In a wireless industrial control application, either or both of the ends of the link, typically the machine, can be mobile so it will be necessary to provide a capability to maintain alignment of the beams at both ends of the link as the machine moves. One approach to achieving this is to dither the pointing angle of the beam by a small amount to either side of its nominal pointing angle. When the dithering in a particular direction causes the received signal strength to exceed the level for the nominal direction, the nominal pointing angle is shifted to that direction. Again, coordination is required between the dithering at both ends of the link to avoid confusion of measurement. Dithering in one angular dimension is all that is required for a linear (one dimensional) array. If the array is two dimensional (azimuth and elevation), then dithering will be required in both of these dimensions.

[0010] The above approach is effective where the time required to align the ends of the links is acceptably small and where the rate of change of angle due to motion can be accommodated by the dither algorithm. While such algorithms are generally reliable, the level of reliability required for wireless industrial control is extremely demanding. Typically, the minimum acceptable mean time between corrupted messages is of the order of days or even months.

[0011] In view of that, it is the object of the present invention to provide a system for industrial application, where effective wireless communication is possible even if a machine changes its position dynamically. Furthermore, a corresponding method of preparing a wireless communication in such an industrial system shall be provided.

[0012] According to the present invention, this object is solved by a system for industrial application including a machine capable of changing its position and having machine communication means for wireless communication and a controller designed for controlling the machine and having controller communication means for wireless communication with the machine communication means, wherein the controller is capable of aligning the machine communication means and/or the controller communication means to each other on the basis of an instruction from the controller to the machine to change its position.

[0013] Since the controller gives instructions to the machine to change its position, the new position or movement is known or inherently contained in the instruction. Thus, the movement or new position of the machine can be predicted with the content of the instruction. Consequently, the communication means of the wireless communication can be aligned dynamically due to the available instructions of the controller.

[0014] Preferably, the machine communication means includes a machine antenna being designed for aligning to the controller communication means by control of the controller. Such antenna may be an antenna array, the beam of which can be formed electronically.

[0015] Similarly, the controller communication means may include a controller antenna being designed for aligning to the machine communications means by control of the controller. The controller antenna may also be designed as array antenna for electronic beam forming.

[0016] In one embodiment, each of the machine communication means and the controller communication means includes a transceiver for bidirectional communication. For such constellation, it is advantageous to align the beams in both communication directions.

[0017] The above object is also solved by a method of preparing a wireless communication in an industrial system between machine communication means of a machine capable of changing its position and controller communication means of a controller designed for controlling the machine, and aligning the machine communication means and/or the controller communication means to each other by the controller on the basis of an instruction from the controller to the machine to change its position.

[0018] This method has the same advantage as the above described system, specifically the alignment of the communication means can be anticipated by the instructions of the controller.

[0019] In a further development the controller may give several instructions to the machine, each to change its position, in a first calibration phase, one or both of the communication means are automatically aligned to one another at each position, and alignment values for each position are stored in a table. Thus, a first calibration can be performed over the range of movement of the machine.

[0020] The table may contain alignment values of the controller and may be stored in the controller. Thus, the alignment of the communication means can be performed with (nearly) no delay.

[0021] Furthermore, the table may contain alignment values of the machine and may be stored in the machine. Thus, the machine itself can evaluate alignment data from the instructions received from the controller. Thus, the wireless link is not stressed with the transmission of alignment data.

[0022] According to another preferred aspect, the controller gives several instructions to the machine, each to change its position, in a second calibration phase, one or both of the communication means are automatically aligned, where line of sight directions are excluded, and alignment values for each position are stored in an additional table. Such second calibration phase has the advantage that the wireless communication link is not limited to line of sight communication. Rather, additional communication paths can be used alternatively if the line of sight communication is not possible or disrupted.

[0023] During the first and/or second calibration phase, an omni-directional signal may be transmitted and the receiving one of the machine communication means or controller communication means may scan an angle region for a strongest signal. Thus, first and second calibration can be performed fully automatically.

[0024] The above features related to the method can also be used to further develop the inventive system and vice versa, where the respective functions are not limited to the means described.

[0025] The present invention will now be described in more detail in connection with FIG 1 showing a principal block diagram of an inventive industrial system. The claimed method can also be gathered from this figure.

[0026] The following described embodiments represent preferred examples of the present invention.

[0027] The proposed solution to the beam alignment problem is to make use of known position or known movements of the machines that carry antennas or antenna arrays (in the following for simplification only "antenna arrays"). The proposal is based on the assumption that means can be provided to locate the controller antenna array (part of controller communication means) and the machine antenna array (part of machine communication means) in two or three dimensions as required (the additional dimension in the case of three dimensions being height above the floor).

[0028] Since typically an antenna array that is connected to a controller will be fixed, it would be relatively straightforward to determine its position through surveying. For many machines whose position changes, each movement is a direct result of an instruction from the controller. Thus, the controller can anticipate the movement that the machine will make in response to its instruction and adjust the antenna beam direction accordingly.

[0029] Even without surveying, the movement-related beam pointing requirements can be determined through a calibration phase. The controller can instruct the machine to move over its available movement space in slow time. The beam can be aligned using an existing algorithm such as those described earlier. Next, the beam pointing information can be stored in two tables with entries corresponding to every position of the machine. In one embodiment, one table would reside in the wireless transceiver associated with the controller for the purposes of setting the controller beam angle(s) as a function of machine position and the other would reside in the wireless transceiver associated with the machine for the purposes of setting the machine beam angle(s) as a function of machine position.

[0030] The above approach will be most reliable where there is a line of sight path between the two ends of the link. Under some circumstances, another machine might occasionally move into position that causes it to block the line of sight path. In principle, it might then be possible to find an alternative path via a reflective surface. However, if a standard prior art solution were used, this path could take considerable time to find, which would probably be unacceptable for a high reliability, low latency industrial application. It would be highly advantageous if a good alternative path were already available.

[0031] A further aspect of this invention is for a second calibration phase to search for non line of sight paths. One proposed way of doing this would be, having found the direction of the line sight path at both ends of the link, to perform a calibration run that excludes the line of sight direction and angles around it. In this case, if the transmitting end establishes a single null in the main path direction, this will assist the receiving end in finding the direction of a reflected component by attenuating the line of sight path.

[0032] A concrete embodiment of the present invention is shown in the block diagram of FIG 1. It shows a system for realizing wireless industrial control. A controller C shall control machine M. The controller C includes a controller core CC, controller communication means CCM and controller storage means CSM. The controller communication means CCM comprises a controller transceiver CT, a controller antenna array CA and an angle scan controller CAS. The controller core CC is in bidirectional communication with the controller transceiver CT. The controller transceiver CT in turn has a bidirectional multichannel connection with the controller antenna array CA. The angle scan controller CAS of the controller C controls the character of the controller antenna or controller antenna array CA, respectively. For example, the angle scan controller CAS controls the controller antenna array CA such that the controller antenna array CA scans a pregiven angle region for finding the strongest signal during the first or second calibration phase. Additionally, the angle scan controller CAS may control the controller antenna array CA such that the reception or transmission beam is directed to a specific direction.

[0033] In the present example, a position look-up table is stored in the controller storage means CSM. Such table is established during a calibration phase by the angle scan controller CAS. An instruction for moving the machine M will also be passed to the position look-up table in order to obtain the actual angle for the controller antenna array CA, which is transmitted via the angle scan controller CAS and the controller transceiver CT.

[0034] In the present example, the wireless communication is performed in the RF region. However, other frequencies may be used.

[0035] The structure of the machine M is symmetrical to that of the controller C. This means that the machine M includes a machine core MC (i.e. the classical machine), machine communication means MCM and machine storage means MSM. The machine communication means MCM comprises a machine transceiver MT, a machine antenna array MA and an angle scan controller MAS. The functionality of the components of the machine M corresponds to the functionality of the components of the controller C. Thus, it is referred to the above description of the controller C.

[0036] During operation and calibration in one stage the controller C may act as transmitter and the machine M as receiver, whereas in another stage the machine may act as transmitter and the controller as receiver. Beam forming is accomplished if at least one of the antennas or antenna arrays CA and MA are directed to the other one. In such situation we simply say the one communications means is directed to the other communication means.

[0037] The functions involved in capturing the data for generating the table data are shown in FIG 1. The controller C enforces a range of movements onto the machine M over a low data rate channel to the machine M. For each position of the machine M the controller core CC first instructs the transceiver MT associated with the machine M to transmit using an omni-directional antenna, where the machine antenna array MA has an omni-directional characteristic. The controller core CC then instructs its transceiver CT to scan the angle of its antenna array CA and search for the angle that gives the strongest received signal. Once this is found, the controller C associates the angle with the position in its position look-up table in the controller storage means CSM and then instructs its transceiver CT to transmit using the best angle just found and uses the low data rate channel to instruct the transceiver MT associated with the machine M to scan the angle of its antenna array MA and search for the strongest signal. Once this is found, the machine M associates the angle with the position in its position look-up table in the machine storage means MSM. The controller C then repeats the process for the next position and so on.

[0038] The above process relies on the machine M always returning to the same position when instructed to do so. This may involve a measure of "dead reckoning". Where this is the case, there could be a build up of errors as the machine M moves many times over its available area/volume. In that event, the table would be updated for every re-visit to the same controller-specified position using the position obtained from a fine-tracking algorithm (using narrow angle dither).

[0039] The advantages of the present invention are as follows:

- More reliable wireless communications are guaranteed.
- Ability to use narrower beams is provided, allowing greater operation range/higher bandwidth.
- Potential for high bandwidth communications is provided even where line of sight may not always be available.

Claims

1. System for industrial application including

   - a machine (M) capable of changing its position and having machine communication means (MCM) for wireless communication and
   - a controller (C) designed for controlling the machine and having controller communication means (CCM) for wireless communication with the machine communication means (MCM), **characterized in that**
   - the controller (C) is capable of aligning the machine communication means (MCM) and/or the controller communication means (CCM) to each other on the basis of an instruction from the controller (C) to the machine (M) to change its position.

2. System according to claim 1, wherein the machine communication means (MCM) includes a machine antenna (MA) being designed for aligning to the controller communication means (CCM) by control of the controller (C).

3. System according to claim 1 or 2, wherein the controller communication means (CCM) includes a controller antenna (CA) being designed for aligning to the machine communication means (MCM) by control of the controller (C).

4. System according to one of the preceding claims, wherein each of the machine communication means (MCM) and the controller communication means (CCM) includes a transceiver (MT, CT) for bidirectional communication.

5. Method of

   - preparing a wireless communication in an industrial system between machine communication means (MCM) of a machine (M) capable of changing its position and controller communication means (CCM) of a controller (C) designed for controlling the machine (M),

   characterized by

   - aligning the machine communication means (MCM) and/or the controller communication means (CCM) to each other by the controller (C) on the basis of an instruction from the controller (C) to the machine (M) to change its position.

6. Method according to claim 5, wherein the controller (C) gives several instructions to the machine (M), each to change its position, in a first calibration phase, one or both of the communication means (CCM, MCM) are automatically aligned to one another at each position, and alignment values for each position are stored in a table.

7. Method according to claim 6, wherein the table contains alignment values of the controller (C) and is stored in the controller (C).

8. Method according to claim 6, wherein the table contains alignment values of the machine (M) and is stored in the machine (M).

9. Method according to one of the claims 5 to 8, wherein the controller (C) gives several instructions to the machine (M), each to change its position, in a second calibration phase, one or both of the communication means (CCM, MCM) are automatically aligned, where line of sight directions are excluded, and alignment values for each position are stored in an additional table.

10. Method according to one of the claims 5 to 9, wherein during the first and/or second calibration phase an omni-directional signal is transmitted and the receiving one of the machine communication means (MCM9 or controller communication means (CCM) scans an angle region for a strongest signal.

Amended claims in accordance with Rule 137(2) EPC.

1. System for industrial application including

   - a machine (M) capable of changing its position and having machine communication means (MCM) for wireless communication and
   - a controller (C) designed for controlling the machine and having controller communication

means (CCM) for wireless communication with the machine communication means (MCM),
characterized in that
- the controller (C) is capable of aligning the machine com-munication means (MCM) and/or the controller communication means (CCM) to each other on the basis of an instruction from the controller (C) to the machine (M) to change its position, wherein the aligning of the machine communication means (MCM) and/or of the controller communication means (CCM) is anticipated by the instruction from the controller (C).

2. System according to claim 1, wherein the machine communication means (MCM) includes a machine antenna (MA) being designed for aligning to the controller communication means (CCM) by control of the controller (C).

3. System according to claim 1 or 2, wherein the controller communication means (CCM) includes a controller antenna (CA) being designed for aligning to the machine communication means (MCM) by control of the controller (C).

4. System according to one of the preceding claims, wherein each of the machine communication means (MCM) and the controller communication means (CCM) includes a transceiver (MT, CT) for bidirectional communication.

5. Method of

- preparing a wireless communication in an industrial system between machine communication means (MCM) of a machine (M) capable of changing its position and controller communication means (CCM) of a controller (C) designed for controlling the machine (M),
characterized by
- aligning the machine communication means (MCM) and/or the controller communication means (CCM) to each other by the controller (C) on the basis of an instruction from the controller (C) to the machine (M) to change its position, wherein the aligning of the machine communication means (MCM) and/or of the controller communication means (CCM) is anticipated by the instruction from the controller (C).

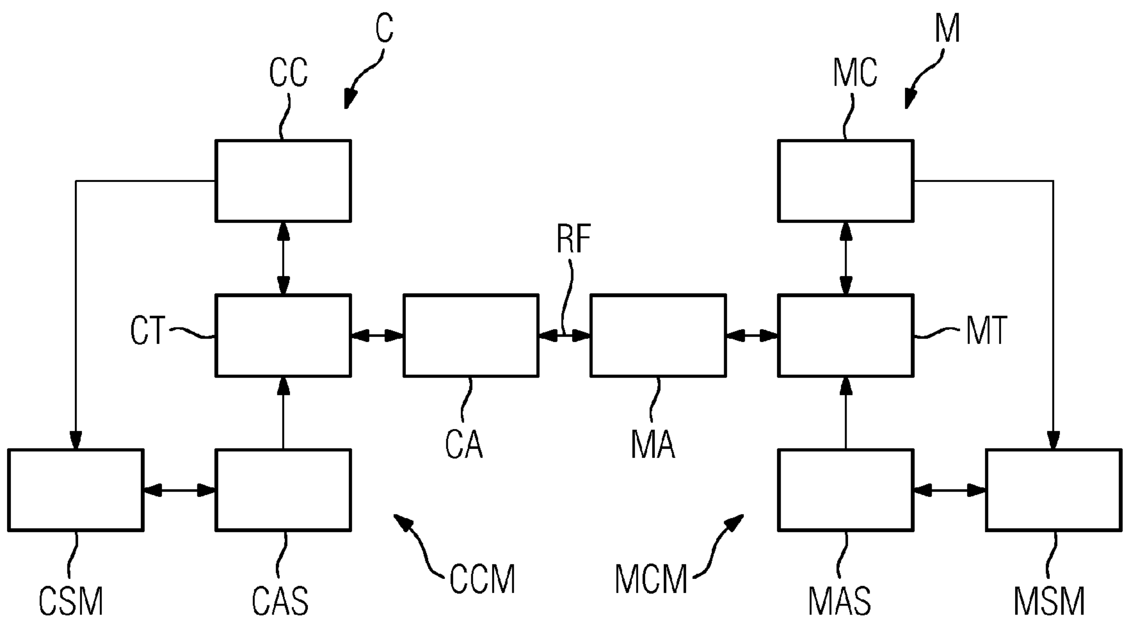
6. Method according to claim 5, wherein the controller (C) gives several instructions to the machine (M), each to change its position, in a first calibration phase, one or both of the communication means (CCM, MCM) are automatically aligned to one another at each position, and alignment values for each position are stored in a table.

7. Method according to claim 6, wherein the table contains alignment values of the controller (C) and is stored in the controller (C).

8. Method according to claim 6, wherein the table contains alignment values of the machine (M) and is stored in the machine (M).

9. Method according to one of the claims 5 to 8, wherein the controller (C) gives several instructions to the machine (M), each to change its position, in a second calibration phase, one or both of the communication means (CCM, MCM) are automatically aligned, where line of sight directions are excluded, and alignment values for each position are stored in an additional table.

10. Method according to one of the claims 5 to 9, wherein during the first and/or second calibration phase an omnidirectional signal is transmitted and the receiving one of the machine communication means (MCM9 or controller communication means (CCM) scans an angle region for a strongest signal.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EUROPEAN SEARCH REPORT

Application Number
EP 13 19 7225

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 2011/054690 A1 (GAL EHUD [IL]) 3 March 2011 (2011-03-03) * abstract; figures 3-5 * * paragraphs [0064], [0074] * * paragraphs [0099] - [0102] * -----	1-5 6-10	INV. H01Q3/00 H01Q3/26 H01Q1/27
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			TECHNICAL FIELDS SEARCHED (IPC)
			H01Q

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	8 May 2014	Unterberger, Michael

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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E : earlier patent document, but published on, or after the filing date
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 19 7225

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