

FIELD

5 The present invention relates to a method to mitigate false positives due to the collision of carrier frequency of radar-based sensors in a motion sensor system.

BACKGROUND

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In close proximity, high frequency sensors of the same carrier frequency have high probability of interfering with each other, resulting in false positives.

One known approach to address sensor interference uses sensors purposely tuned to different frequency channels. However, proper planning and deployment is required to ensure that sensors
15 tuned to the same frequency channel are not deployed adjacent or in close proximity with each other. In addition, ad-hoc introduction of new sensors can affect the existing plan. Sensor frequency also drifts over time eventually resulting in interference in a carefully planned system that was initially free of interference.

Another known approach uses a wireless or wired network system to connect all sensors and
20 pre-assigned time slot to each sensor such that neighbouring sensors operate at different time instances to avoid interference. For non-cooperative sensor systems, adding an extra network increases system cost. For cooperative networked sensor systems, high-accuracy time synchronization is necessary and significant effort is needed to allocate time slots either automatically or manually.

It is also known to pulse each sensor with randomised time intervals to reduce the probability
25 of continuous interference with neighbouring sensors.

An object of the present invention is thus to addresses the shortcomings of such existing systems.

SUMMARY OF THE INVENTION

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According to a first aspect of the present invention, there is provided a motion sensor system comprising: at least two sensors, wherein each of the two sensors comprises: a sensor controller configured to generate a transceiver control signal; a transceiver configured to be driven by the transceiver control signal to send a transmission signal and to receive a reflected signal; and a signal
35 processor configured to process information derived from the received signal, wherein in response to at least one of the signal processors detecting a reading in the processed information, at least one of the sensor controllers is configured to change an interval of its generated transceiver control signal so

as to increase an interval difference between the transceiver control signals generated by the two sensor controllers.

Each of the two sensors may further include a spike noise filter configured to remove the detected reading that remains after the interval difference is increased if it has a duration that is lower than a threshold. The sensor controller of each of the two sensors may be further configured to provide an indication of presence of a moving object if the detected reading that remains after the interval difference is increased has a duration that is greater than the threshold.

According to a second aspect of the present invention, there is provided a lighting system comprising a plurality of lights grouped into zones; a lighting controller configured to illuminate the plurality of lights; and the motion sensor system of the first aspect of the present invention, wherein the illumination of the lights in any one of the zones is in response to the lighting controller receiving the indication of the presence of a moving object from any of the two sensors of the motion sensor system.

According to a third aspect of the present invention, there is provided a motion sensing method comprising: generating a transceiver control signal in one of at least two sensors; utilising the transceiver control signal to drive one of the at least two sensors to send a transmission signal; receiving a reflected signal in one of the at least two sensors; and processing information derived from the received signal, wherein in response to one of the at least two sensors detecting a reading in the processed information, one of the at least two sensors is configured to change an interval of its generated transceiver control signal so as to increase an interval difference between the transceiver control signals generated in the two sensors.

BRIEF DESCRIPTION OF THE DRAWINGS

Representative embodiments of the present invention are herein described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 illustrates how pulse width overlap can occur between two adjacent sensors.

Figure 2A shows a block diagram of a sensor in accordance with one embodiment of the present invention.

Figure 2B shows a pulse signal used for a transceiver control signal to create an intermittent transmission signal for the sensor of Figure 2A.

Figures 2C and 2D show block diagrams of two possible configurations for a transceiver module of the sensor of Figure 2A.

Figure 3 shows a schematic of a motion sensor system having at least two of the sensors shown in Figure 2A.

Figure 4 shows a flowchart of the operation logic that the sensors shown in Figure 3 follows when seeking to determine whether a reflected signal contains interference attributable to presence of a moving object.

Figure 5 shows a signal for a reflected signal received by a sensor in a motion sensor system
5 having multiple sensors

Figure 6 shows a motion sensor system having an array of the sensors described in Figure 2A.

Figure 7 shows a table summarising the probability of collision between one sensor and any of its 8 neighbouring sensors in the array of Figure 6 against different pair collision probability rates.

10 DETAILED DESCRIPTION

In the following description, various embodiments are described with reference to the drawings, where like reference characters generally refer to the same parts throughout the different views.

15 The present application broadly relates to a motion sensor system that is able to detect the presence of moving objects in an area of interest. The system has a plurality of sensors each having a transceiver module that emits a high frequency wave (e.g. around 24 GHz) that propagates into the area of interest until it reaches and reflects off an object. Due to the Doppler effect, a moving object would modulate the original wave and reflect the wave back to the transceiver module, which
20 downconverts the received wave into an intermediate frequency (IF) signal. Detection of a Doppler frequency shifted reflected signal indicates that movement is detected. In a single sensor system, if all objects in an area of interest are stationary, the Doppler frequency is 0 Hz and the output signal of the sensor will be a constant signal (plus noise). However, if there is another sensor transmitting at the same time, so that there are two sensors A and B, each sensor will detect the transmission signal of the other, so that the IF signal output for each of the two sensors A and B will have a frequency
25 component $f_{TXA} - f_{TXB}$ (f_{TXA} being the frequency of the transmitted signal for sensor A, and f_{TXB} being the frequency of the transmitted signal for sensor B).

The system has a plurality of sensors because the area to be monitored is typically large, or spread over several zones, and beyond the coverage area of a single sensor. In several
30 implementations, the system has an array of sensors (such as a 3 X 3 matrix arrangement) in at least one of such zones, leading to adjacent sensors in close proximity. When sensors in close proximity operate at the same transmission frequency, interference occurs when control signals used to drive the transmission overlap. Such control signals are typically pulse signals when the sensors are in pulse mode. In this disclosure, use of the term "pulse width overlap" refers to such control signal overlap.
35 The sensors are typically programed to generate the same control signal. If so, the use of ideal sensors will result in constant pulse width overlap if they are powered up at the same time. Alternatively, pulse width overlap is entirely absent if such ideal sensors are powered up at different

times. However, each sensor is typically a non-ideal device with varying pulse intervals due to manufacturing tolerances and clock drifts. Regardless of power up time, pulse width overlap occurs periodically, which is described in greater detail below.

Figure 1 illustrates how pulse width overlap can occur between two adjacent sensors A and B.

Portion 150 of Figure 1 shows a signal 102 detected by sensor A, resulting from reflected waves occurring in an area being monitored for object movement. Portion 152 of Figure 1 shows a clock chart for each of sensor A and sensor B over several duty cycles that contribute to the signal 102 shown in portion 150. Dotted arrows 156 are used to illustrate how the clock charts in portion 152 for sensors A and B map onto the signal 102 of portion 150.

Each of the sensors A and B is driven by a pulse signal of pulse width T_{on} (i.e. the pulse width of the driving pulse signal). Sensor A has a pulse interval of T_A , while sensor B has a pulse interval of T_B . The pulse interval is the time taken for each of the sensors A and B to complete one duty cycle, i.e. an interval between the start of one pulse signal and the start of the next pulse signal. At time t_0 , interference is about to occur because the transmission signal of sensor A (resulting from its driving pulse signal of pulse interval T_A) and the transmission signal by sensor B (resulting from its driving pulse signal of pulse interval T_B) is about to overlap. Since the pulse interval T_B is slightly shorter than T_A , interference over duration d occurs over the next duty cycle $t_1 = t_0 + T_A$ of sensor A, which is proportional to the pulse interval difference between the pulse interval T_A and the pulse interval T_B , i.e. $(T_A - T_B) \Rightarrow d$. The pulse interval difference is thus the difference between the pulse intervals of the control signals used to drive transmission of the two interfering sensors.

In the following consecutive duty cycles $t_2 = t_0 + 2T_A$ and $t_3 = t_0 + 3T_A$, the sensor A would have detected a gradual increase of signal amplitude because of the interference spanning a duration of $2d$ and a duration of $3d$ respectively, since in these duty cycles, there is overlap between the pulse widths of the pulse signals transmitted by sensors A and B during the period where sensor A samples for reflected waves. This interference occurs until t_m where there is no longer any such pulse width overlap, with t_m being provided by the formula

$$t_m = t_0 + (2 \cdot T_{on}/d) \cdot T_A \quad (1)$$

However, interference occurs again at t_n , provided by the formula

$$t_n = t_0 + (T_A/d) \cdot T_A \quad (2)$$

whereby the duty cycles of t_0 and t_m , as explained above, then repeat.

From the perspective of the signal 102 detected by sensor A, the interference occurring between t_0 and t_m results in an interference duration 104 that is calculated by the formula

$$(2 \cdot T_{on}/d) \cdot T_A \quad (3)$$

The interference interval 106 which spans over t_0 and t_n is provided by the formula

$$(T_A/d) \cdot T_A \quad (4)$$

Sensors A and B seek to detect a signal due to moving objects. However a signal caused by moving object is indistinguishable from inter-sensor interference. Therefore a signal detected by either sensors A and B resulting solely from interference may produce false positives to the system and other affected electronic components that are in communication with the sensors and perform their intended function upon receipt, being unable to distinguish the false positives from a signal generated by detection of a moving object. The present invention seeks to eliminate such false positives by automatically increasing the interval difference between control signals generated in sensors used to drive transmission in a motion sensor system, which is described in greater detail below.

Figure 2A shows a block diagram of a sensor 202 in accordance with one embodiment of the present invention. The sensor 202 is based on the working principles described in Figure 1 above, so that the terminologies used in Figure 1 equally apply onto the sensor 202.

The sensor 202 has a sensor controller 210, a transceiver module 212 and a signal processor 204. The purpose of each of these components is described briefly below.

The sensor controller 210 is configured to generate a transceiver control signal 206 that is used to drive the transceiver module 212; and has a timer that is programmable to change the interval T_{202} of the transceiver control signal 206. The transceiver control signal 206 is a driver because it switches the transceiver module 212 between on and off states and causes the transceiver module 212 to send a transmission signal 214 upon being activated by the transceiver control signal 206. To minimize energy consumption and prolong sensor lifespan while maintaining detection performance, the sensor 202 is configured to work in pulse mode where its transmission signal 214 is sent intermittently rather than continuously.

Figure 2B shows a pulse signal of interval T_{202} used for the transceiver control signal 206 to create this intermittent transmission signal 214. Driven by such a periodic pulse signal, sensor 202 transmission is turned on and off rapidly, with T_{on} having a short duration to save energy.

Returning to Figure 2A, the transceiver module 212 generates and emits a transmission signal 214 of high frequency to an area of interest. The emission of the transmission signal 214 is determined by the transceiver control signal 206. The transceiver module 212 also receives and downconverts reflected signals from moving objects located in the area of interest into an intermediate frequency (IF) signal 208 that can be processed by the signal processor 204. Figures 2C and 2D show block diagrams of two possible configurations for the transceiver module 212. It will be appreciated that the present invention is not limited to these two implementations.

The transceiver module 212 of Figure 2C has two antennas, a transmitter antenna 222 and a receiver antenna 224. The transceiver control signal 206 is an input that switches the transceiver module 212 on or off, whereby the pulse signal causes the transceiver module 212 to have a duty cycle operation. When switched on (which occurs over the duration T_{on} of the transceiver control

signal 206, see Figure 2B), an oscillator 220 generates a 24 GHz signal that serves as the transmission signal 214 emitted through the transmitter antenna 222. When switched off (i.e. during the interval T_{202} outside of the T_{on} duration), the transceiver module 212 is turned off.

5 A reflected signal 216 is picked up by the receiver antenna 224. The received signal is downconverted by a mixer 228. The mixer 228 performs downconversion by using the oscillator 220 generated signal and the amplified received signal as inputs, and outputs a signal with frequency component $f_{TX} - f_{RX}$ (i.e. a subtraction operation is performed between the oscillator 220 generated signal and the received signal), typically in the kHz range (e.g. 0 ~ 2 kHz for detecting human motion or around 80 kHz to detect vehicular motion). The downconverted signal of frequency ($f_{TX} - f_{RX}$) is
10 the IF signal 208.

In comparison with the transceiver module 212 of Figure 2C, the transceiver module 212 of Figure 2D has one antenna, a TX/RX antenna 240. The same TX/RX antenna 240 serves to emit the transmission signal 214 and receive the reflected signal 216.

Similar to Figure 2C, the transceiver module 212 is activated by the transceiver control signal 206, which serves as an input to the transceiver module 212. When switched on (which occurs over
15 the duration T_{on} of the transceiver control signal 206, see Figure 2B), an oscillator 220 generates a 24 GHz signal that serves as the transmission signal 214. When switched off (i.e. during the interval T_{202} outside of the T_{on} duration), the transceiver module 212 is turned off. A reflected signal 216 is picked up by the TX/RX antenna 240.

20 A circulator 242 is used to direct signals to or from the TX/RX antenna 240 which is used for both transmission and reception. The generated 24 GHz signal is directed to the TX/RX antenna 240 by the circulator 242 for emission as the transmission signal 214. Upon receipt of the reflected signal 216, the circulator 242 directs the received signal to the mixer 228 for downconversion.

The mixer 228 performs downconversion by using the oscillator 220 generated signal and the
25 received signal as inputs, and outputs a signal with frequency component ($f_{TX} - f_{RX}$, i.e. a subtraction operation is performed between the oscillator 220 generated signal and the received signal), typically in the kHz range (e.g. 0 ~ 2 kHz for detecting human motion or around 80 kHz to detect vehicular motion). The downconverted signal is then output as the IF signal 208.

Returning to Figure 2A, the sensor 202 is configured to monitor any signal that is beyond
30 ambient noise levels, so that such signals may be due to a false reading attributed to pulse signals generated in an adjacent sensor, or a correct reading attributed to presence of a moving object. That is, while the sensor 202 seeks to capture a reflection of its own transmission signal 214 that is Doppler shifted due to object motion, it will be appreciated from the above description for Figure 1 that the reflected signal 216 can also contain interference resulting from transceiver control signal 206 overlap
35 with neighbouring sensors. The reflected signal 216 may thus contain components attributable to either Doppler shift due to object motion, interference resulting from transceiver control signal 206

overlap or both. After the reflected signal 216 is received by the transceiver module 212, these components are extracted from the received signal, so as to provide information that is derived from the received signal. For example, such extraction occurs during the above downconversion described in Figures 2C and 2D and the information that is derived from the received signal is the IF signal 208.

5 The signal processor 204 is configured to process the derived information for presence of a reading that is above ambient noise level. The detection of such a reading is passed on from the signal processor 204 to the sensor controller 210, for the sensor controller 210 to change the interval T_{202} of its generated transceiver control signal 206. As mentioned above, this reading results from one or more of object motion capture, inter-sensor interference or both, with the sensor 202 being unable
10 to distinguish between the two. Throughout this disclosure, use of the term "reading" when used in conjunction with the signal processor 204 refers to a signal which may be false due to inter-sensor interference or correct reading due to presence of a moving object, the signal being derived from the sampled reflected signal 216.

 From Figure 1, it can be seen that the interference resulting from two sensors operating in
15 proximity occurs during instances when their respectively generated transceiver control signals 206 overlap. To reduce the occurrence of such transceiver control signal 206 overlap and to reduce the interference duration 104, the sensor 202 is configured to change the interval T_{202} of its generated transceiver control signal 206, with the effect best appreciated when considering a plurality of the sensors 202 working in a motion sensor system.

20 Figure 3 shows a schematic of a motion sensor system having at least two of the sensors 202 shown in Figure 2A. A motion sensor system refers to one or more components that work together to achieve the objective of detecting motion capture of any object 320 (not necessarily limited to a vehicle) in a monitored area 250. Such components include the sensors 202 of Figure 2A, denoted as 202_A and 202_B and an optional central controller (not shown) that is in communication with the sensor
25 controller 210 of each of the sensors 202_A and 202_B to share data or to transmit, relay or receive commands that affect the operation of the sensors 202_A and 202_B. This central controller is absent in the implementation where the sensors 202_A and 202_B do not communicate with each other. The motion sensor system may contain more than two of such sensors 202_A and 202_B. However, for the sake of simplicity, the operation of only two of the sensors 202_A and 202_B are described.

30 Each of the sensors 202_A and 202_B is configured to operate at the same frequency, thereby simplifying installation and maintenance of the motion sensor system associated with motion sensor systems that use sensors operating at different frequencies requiring tedious planning and careful deployment. However, as the sensors 202_A and 202_B operate at the same frequency, each is subjected to interference resulting from pulse width interference as described in Figure 1.

35 In response to the signal processor 204 of any one of the sensors 202_A and 202_B detecting a reading from its IF signal 208 (which is derived from the sampled reflected signal 216), at least one of the sensor controllers 210 is configured to change the interval T_{202} of its generated transceiver control

signal 206. In a first implementation, if one of the signal processors 204 of the sensors 202_A and 202_B detects a reading in the IF signal, that signal processor can either have the sensor controller of its own sensor, the sensor controller of another sensor or both to change the interval T_{202} of its generated transceiver control signal 206. In a second implementation, both the signal processors 204 of the sensors 202_A and 202_B detect a reading in the IF signal. Each of the signal processors 204 can have the directly connected sensor controller 210 change the interval T_{202} of its generated transceiver control signal 206, so that the interval T_{202} of both the generated transceiver control signals 206 changes (one from the sensors 202_A and the other from the sensor 202_B). Alternatively, while both the signal processors 204 of the sensors 202_A and 202_B detect a reading in the IF signal, one or both the signal processors 204 sends a command to have only one of the sensor controllers 210 change the interval T_{202} of its generated transceiver control signal 206. As an example of the first implementation, if the signal processor 204 of the sensor 202_A (also referred to as signal processor 204_A) detects a reading, the signal processor 204_A can communicate to the sensor controller 210 of the sensor 202_A (also referred to as sensor controller 210_A) to change the interval T_{202} of its generated transceiver control signal 206. That is, the sensor controller 210 that changes the interval of its generated transceiver control signal 206 belongs to the sensor with the signal processor 204 that detects the reading in the IF signal 208. In another example of the first implementation, if the signal processor 204 of the sensor 202_A (also referred to as signal processor 204_A) detects interference, the signal processor 204_A can communicate, directly or through the above mentioned central controller, to the sensor controller 210 of the sensor 202_B (also referred to as sensor controller 210_B) to change the interval T_{202} of its generated transceiver control signal 206. The phrase "at least one" refers to one or both of the signal processors 204 or the sensor controllers 210, depending on the component with which this phrase is associated. In a motion sensor system having more than two such sensors 202, the phrase "at least one" then encompasses any one of to all of their signal processors 204 or their sensor controllers 210.

One possible scenario of the above implementations sees the monitored area 250 having multiple sensors 202_A and 202_B. The signal processor 204 of one of the sensors detects a reading suggestive of the presence of interference resulting from transceiver control signal 206 overlap. Any two interfering sensors 202_A and 202_B may be identified. The identified interfering sensors 202_A and 202_B may establish communication to compare the number of interfering neighbouring sensors each has. The sensor with less interfering neighbouring sensor will change the interval of its transceiver control signal 206, so that less sensors will be affected by the change.

Equation (3) above which provides the interference duration between the sensors 202_A and 202_B above can be re-written as

$$(2 \cdot T_{on} / (Pl - Ps)) \cdot Ps \quad (5)$$

while equation (4) above which provides the interference interval can be re-written as

$$(P_S/(Pl - P_S)) \cdot P_S \quad (6)$$

where Pl is the longer interval of the transceiver control signal 206 in the two interfering sensors 202_A and 202_B and P_S is the shorter interval of the transceiver control signal 206 in the two interfering sensors 202_A and 202_B.

5 From equation (5), an increase in the interval difference $Pl - P_S$ results in a decrease in the interference duration. Thus, when changing the interval T_{202} of a generated transceiver control signal 206, due to detection of a reading in a received signal, the change effected by the relevant sensor controller 210 should result in an increase in the interval difference between the transceiver control signals 206 generated by the sensors 202_A and 202_B. Similarly, from equation (6), the increase in the
10 interval difference $Pl - P_S$ results in a decrease in the interference interval.

A decrease in the interference duration assists to differentiate between motion and interference caused by transceiver control signal overlap as explained below.

Referring to the signal 102 of Figure 1, there are active periods such as over the interference duration 104 and inactive periods. An active period may be caused by three situations:

- 15
- first situation: object motion
 - second situation: interference (by neighbouring sensor)
 - third situation: object motion and interference happening around the same time.

After the interference duration is decreased through increasing the pulse interval difference:

- 20
- If active period is short, high probability second situation
 - If active period is long, could be the first situation or the third situation. While it is difficult to differentiate which of the first or third situations applies, such differentiation is unnecessary because either situation has object motion, so that the sensor 202 should provide an indication that motion is detected in both case.

Several worked examples are provided below to illustrate how increasing the interval
25 difference between the transceiver control signals 206 generated by the sensor controller 210 of the sensors 202_A and 202_B decreases the interference duration and the interference interval caused by transceiver control signal overlap.

In a first example, the pulse signal 206 has a repetition frequency of 2 kHz and a duty circle of 5%. This results in a pulse interval of 500 us and a pulse width of 25 us. Should there be a pulse
30 interval difference of 0.01 us between the sensors 202_A and 202_B, the parameters for equations (5) and (6) become

$$P_S = 500 \text{ us}, T_{on} = 25 \text{ us}, d = 0.01 \text{ us},$$

which results in

$$\text{interference duration} = (2 \cdot 25 / 0.01) \cdot 500 \text{ us} = 2.5 \text{ s}$$

and

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$$\text{interference interval} = (500 / 0.01) \cdot 500 \text{ us} = 25 \text{ s}$$

If, upon detection of this interference, the interval difference $Pl - Ps$ is deliberately increased to, for example, 1 us, then from equation (5)

$$\text{interference duration} = (2 \cdot 25/1) \cdot 500 \text{ us} = 25 \text{ ms}$$

and equation (6)

$$\text{interference interval} = (500/1) \cdot 500 \text{ us} = 250 \text{ ms}$$

The interference duty circle remains 10% for both cases, which is twice the duty cycle of the generated pulse signal 206, which is in line with the formula below for the interference duty cycle:

$$2 \cdot T_{on}/T_A \quad (7)$$

In a second example, the sensor 202_B has a longer pulse interval T_{202B} of 400.02 us and the sensor 202_A has a shorter pulse interval T_{202A} of 400 us. Equations (5) and (6) then become

$$\text{interference duration} = 2 \cdot 20 / (400.02 - 400) \cdot 400 \text{ us} = 0.8 \text{ s}$$

$$\text{interference interval} = 400 / (400.02 - 400) \cdot 400 \text{ us} = 8 \text{ s}$$

Should the pulse interval T_{202B} of the sensor 202_B be changed to 399 us, while the pulse interval T_{202A} remains at 400 us, so that the sensor 202_B now has the shorter pulse interval, equations (5) and (6) then become

$$\text{interference duration} = 2 \cdot 20 / (400 - 399) \cdot 399 \text{ us} = 15.96 \text{ ms}$$

$$\text{interference interval} = 400 / (400 - 399) \cdot 399 \text{ us} = 159.6 \text{ ms}$$

The interference duty circle also remains 10% for both cases of the second example.

The first and second examples evidence that an increase in the pulse interval difference can be achieved when the pulse interval T_{202} of one of the generated pulse signals 206 is increased, while maintaining the pulse interval T_{202} of the other generated pulse signal 206. This can be effected by the sensor controller 210 of one of the two sensors 202_A and 202_B increasing the pulse interval T_{202} of its generated pulse signal 206 while the pulse interval T_{202} of the other generated pulse signal 206 remains unchanged. Similarly, an increase in the pulse interval difference can be achieved by decreasing the pulse interval T_{202} of one of the generated pulse signals 206, while maintaining the pulse interval T_{202} of the other generated pulse signal 206. This can be effected by the sensor controller 210 of one of the two sensors 202_A and 202_B increasing the pulse interval T_{202} of its generated pulse signal 206 while the pulse interval T_{202} of the other generated pulse signal 206 remains unchanged. Similarly and although not shown, an increase in the pulse interval difference may be achieved by changing the pulse interval T_{202} of both the generated transceiver control signals.

Figure 4 shows a flowchart 400 of the operation logic that either of the sensors 202_A and 202_B follows when seeking to determine whether the reflected signal 208 contains a reading attributable to presence of a moving object.

From the description for Figure 2A, it was explained that the reflected signal 216 could contain a reading attributable to either Doppler shift due to object motion, interference resulting from transceiver control signal 206 overlap or both. Such information is present in the received signal that

the transceiver module 212 obtains when sampling the reflected signal 216, where this information is then extracted for processing.

At step 402, the signal processor 204 detects whether the information, derived from the received signal, contains any reading. Upon detection of a reading, the signal processor 204 determines at step 404 whether its duration is within a predefined range, which is a time window that depends on the type of motion that the sensors 202_A and 202_B are intended to detect. As such, the duration of the time window depends on application requirements. In one implementation, a lower limit of the predefined range is selected to be of a duration that does not overly delay triggering motion capture, such as 100ms, while an upper limit of the predefined range is selected to be a duration above which the detected reading is likely the result of motion capture. If the duration of the reading is less than this lower limit, the signal processor 204 categorises the detected reading as not being attributed to presence of a moving object and ignores it. If the duration of the reading is greater than the upper limit, the signal processor 204 will interpret the reading as being caused by motion capture, with no need to effect a change in the interval of the generated transceiver control signal. If the duration of the reading is within the lower limit and the upper limit, the signal processor 204 then sends a command, at step 406, to the sensor controller 210 to change the interval T_{202} of the transceiver control signal 206. As such, at step 406, the signal processor 204 is configured to determine whether the detected reading has a duration that is within the predefined range before changing the interval T_{202} of the generated transceiver control signal 206.

In one approach, the interval T_{202} at which the transceiver control signal 206 is generated is randomly selected from a list of candidate intervals, avoiding its current interval. The number of candidate intervals depends on the maximum number of sensors that are expected to interfere. The spacing between candidate intervals is calculated to ensure that the interference duration resulting from each of all the candidate intervals sums to be less than the first threshold by a safety margin.

The equation describing this relationship will be:

If N is odd:

$$2 \cdot \left(\sum_{i=1}^{\frac{N-1}{2}} 1/i \right) \cdot 2 \cdot T_{on}/d \cdot T_A = (1 - m) \cdot Th$$

If N is even:

$$\left(2 \cdot \left(\sum_{i=1}^{\frac{N}{2}-1} 1/i \right) + 2/N \right) \cdot 2 \cdot T_{on}/d \cdot T_A = (1 - m) \cdot Th$$

d is the spacing between candidate intervals

m is the safety margin

Th is the first threshold

N is the expected number of nodes that are expected to interfere

d can then be derived as follows:

5 If N is odd:

$$d = \frac{4 \cdot T_{on} \cdot T_A \cdot (\sum_{i=1}^{\frac{N-1}{2}} 1/i)}{(1 - m) \cdot Th}$$

If N is even:

$$d = \frac{2 \cdot T_{on} \cdot T_A \cdot (2 \cdot (\sum_{i=1}^{\frac{N}{2}-1} 1/i) + 2/N)}{(1 - m) \cdot Th}$$

The change in the interval T_{202} of the transceiver control signal 206 is thus selected from a list of intervals, where each depends on one or more of: the safety margin m , the duration of the first threshold Th and the number of sensors N in the motion sensor system that are expected to interfere.

10 For example,

T_A is 400 us, T_{on} is 20 us, N is 4, m is 20%, Th is 100 ms

$d = 2 \cdot 20 \text{ us} \cdot 400 \text{ us} \cdot (2 + 1/2) / (0.8 \cdot 100 \cdot 1000 \text{ us}) = 0.5 \text{ us}$.

Therefore, the 4 candidate intervals are:

- $P1 = T_A = 400 \text{ us}$
- 15 • $P2 = T_A + d = 400.5 \text{ us}$
- $P3 = T_A + 2d = 401 \text{ us}$
- $P4 = T_A + 3d = 401.5 \text{ us}$

The worst case scenario is if all 4 of the sensors ($S1$, $S2$, $S3$ and $S4$) interfere with each other and each sensor has its transceiver control signal at the different intervals of $P1$, $P2$, $P3$ and $P4$. For sensor $S3$, its interference duration with the other sensors $S1$, $S2$ and $S4$ are:

- $S3 \text{ \& } S1: 2 \cdot 20 \text{ us} / 1 \text{ us} \cdot 400 \text{ us} = 16 \text{ ms}$
- $S3 \text{ \& } S2: 2 \cdot 20 \text{ us} / 0.5 \text{ us} \cdot 400.5 \text{ us} = 32.04 \text{ ms}$
- $S3 \text{ \& } S4: 2 \cdot 20 \text{ us} / 0.5 \text{ us} \cdot 401 \text{ us} = 32.08 \text{ ms}$

25 The maximum continuous interference duration, being the sum of each individual interference duration, is 80.12 ms. This is less than the 100 ms threshold by about a 20% margin.

The change in the interval T_{202} leading to increase in the interval difference between the generated transceiver control signals 206 of the sensors 202_A and 202_B decreases the duration of interference due to transceiver control signal 206 overlap, as shown by the worked examples using equations (5) and (6). At step 408, a spike noise filter removes the detected reading that remains after the interval difference between the transceiver control signals 206 is increased, if the remaining

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detected reading has a duration that is lower than a threshold. This threshold may have the same duration as the lower limit of the predefined range established in the step 404.

At step 410, the sensor controller 210 provides an indication of presence of a moving object if the detected reading that remains after the interval difference between the transceiver control signals 206 is increased has a duration that is greater than the threshold of the step 408. That is, this remaining detected reading is processed at step 408 by the spike noise filter without being removed.

The flowchart 400 thus facilitates a motion sensing method where a transceiver control signal 206 is generated in one of at least two sensors 202_A and 202_B. The transceiver control signal 206 is used to drive one of the at least two sensors 202_A and 202_B to send a transmission signal. A reflected signal, for instance caused by reflection of the transmission signal, is received in one of the at least two sensors 202_A and 202_B. Information derived from the received signal is then processed, for example by the sensor 202_A or 202_B that receives the reflected signal. In response to one of the at least two sensors 202_A and 202_B detecting a reading in the processed information, one of the at least two sensors 202_A and 202_B is configured to change an interval of its generated transceiver control signal 206 so as to increase an interval difference between the transceiver control signals 206 generated in the two sensors 202_A and 202_B. In one implementation, the sensor 202_A or 202_B that changes the interval of its generated transceiver control signal belongs to the sensor 202_A or 202_B that detects the reading in the processed information.

In this motion sensing method, it may be determined that a duration of the detected reading is within a range before changing the interval of the generated transceiver control signal 206. The detected reading that remains may be removed after the interval difference is increased if this detected reading has a duration that is lower than a threshold (see the step 408). An indication of presence of a moving object is provided if the detected reading that remains after the interval difference is increased has a duration that is greater than the threshold.

Figure 5 shows a signal 508 for a reflected signal received by a sensor in a motion sensor system having multiple sensors, after performance of the step 406 of Figure 4.

The signal 508 has interference patterns 502, 504 and 506, each resulting from the transceiver control signal generated by the receiving sensor overlapping with the transceiver control signal generated by another adjacent sensor. That is, interference pattern 502 results from transceiver control signal overlap between the receiving sensor and a second sensor; interference pattern 504 results from transceiver control signal overlap between the receiving sensor and a third sensor; and interference pattern 506 results from transceiver control signal overlap between the receiving sensor and a fourth sensor.

A worst case spike width interval 510 occurs when the individual interference patterns 502, 504 and 506 group as shown in Figure 5. The spike noise filter of the step 410 of Figure 4 is designed to tolerate this worst case spike width, whereby its interval 510 is within the duration of the threshold of the step 408 of Figure 4. The number of sensors that a motion sensor system can handle depends

on the pulse duty cycle for each of the sensors. A smaller duty cycle results in the motion sensor system being able to accommodate more interfering sensors.

Figure 6 shows a motion sensor system having an array 600 of the sensors 202 described in Figure 2A.

5 A pair of sensors 202 working in such a high density scenario may not experience symmetrical inter-sensor interference. For instance, only one sensor 202 in this sensor pair may discover inter-sensor interference in its detected reading and change the interval of its transceiver control signal. Conversely, both sensors in the sensor pair may discover inter-sensor interference in each of its detected readings. Both sensors may then randomly select another interval to generate its
10 transceiver control signal from a candidate list (confer the candidate list described with respect to the step 406 of Figure 4). If both sensors select the same interval, inter-sensor interference still occurs. Each sensor will randomly select another interval from the candidate list until both operate transceiver control signals at different intervals, so that the interference duration is smaller than threshold.

 In the process of determining an operating interval from the candidate list, a ripple effect may
15 occur. A ripple happens where a sensor detects interference and randomly changes to another candidate pulse interval, where the new interval collides with another sensor (previously in a stable state) which in turn randomly changes its own pulse interval, which may collide with another sensor to cause a chain reaction.

 One implementation addresses this ripple phenomenon from one or more of the sensors 202
20 having its sensor controller 210 configured to reiterate the change in the interval T_{202} from the candidate list of intervals until its signal processor 205 finds that its detected reading has a stable state. A stable state is when the detected reading resulting from all inter-sensor interference is smaller than the first threshold (see the step 404 of Figure 4), so that the sensor 202 will not need to change the interval of its transceiver control signal.

25 Another implementation carefully chooses the new interval at which the transceiver control signal is generated instead of a randomly selecting one from a candidate list. One of the sensors calculates its neighbouring sensor pulse interval (in stable state) by observing interference duration and interference interval. When this sensor needs to change its pulse interval, it avoids the neighbouring sensor existing stable pulse interval to avoid causing a chain reaction. That is, one of the
30 sensors 202 determines, from the reading derived from sampling reflected signals, the interval used by the sensor controller of another sensor to generate its transceiver control signal and avoids the used interval when changing the interval of its generated transceiver control signal.

 The disclosed method of changing an interval at which a sensor transmits so as to reduce inter-sensor interference (also known as "collision") may also be combined with existing techniques
35 that use random sensor frequency to reduce the probability of inter-sensor interference in a motion sensor system with sensor high density, as described in greater detail below.

Figure 7 is a quantitative analysis of improvement after applying the technique of changing an interval of a transceiver control signal (as discussed with reference to Figures 2A to 2D, 3 to 5), on top of a known transmission frequency (f_{TX}) randomization technique, in a sensor array arrangement where each sensor has 8 neighbouring sensors (see Figure 6, which shows a portion of the array arrangement). The columns of table 700 in Figure 7 summarises the probability that each sensor in the array arrangement will collide with a number of its 8 neighbouring sensors in a motion sensor system against several pair collision probabilities: 1%, 3%, 5% and 10% (see the rows of table 700). A pair collision probability is the probability that two nodes have the same frequency after performing frequency randomisation.

At 1% pair collision rate, the probability that a sensor does not collide with any of its 8 neighbors is $(1 - 1\%)^8 = 92.27\%$. The complement $(1 - 92.27\%) = 7.73\%$ is the probability that there is at least one interfering node, which can be found in the "1.00%" row under the column "interfere > 0". That is, if the pair collision rate is 1%, there is a 7.73% probability that any node in the network will collide with at least one of its neighboring nodes.

At 3% pair collision rate, the probability that a sensor does not collide with any of its 8 neighbors is $(1 - 3\%)^8 = 78.37\%$. The complement $(1 - 78.37\%) = 21.63\%$ is the probability that there is at least one interfering node, which can be found in the "3.00%" row under the column "interfere > 0".

At 10% pair collision rate, the probability that a sensor does not collide with any of its 8 neighbors is $(1 - 10\%)^8 = 43.05\%$. The complement $(1 - 43.05\%) = 56.95\%$ is the probability that there is at least one interfering node, which can be found in the "10.00%" row under the column "interfere > 0".

From the table 700, it can be seen that using a randomisation sensor frequency technique that produces a 1% pair collision rate may result in a 7.73% probability of there being at least one interfering node, which may be acceptable for certain sensing applications. However, a less effective randomisation technique, such as one resulting in the 3% pair collision rate, where the probability of there being at least one interfering node increases to 21.63% may be unacceptable for the same sensing applications. The row for the 3% pair collision rate shows that there is a 0.14% probability of there being at least three interfering nodes (see the "interfere > 2" column, which is the sum of the probabilities of the columns 3, 4, 5, 6, 7 and 8). Implementations of changing an interval of a transceiver control signal (as discussed with reference to Figures 2A to 2D, 3 to 5) are able to tolerate a maximum of 3 interfering nodes (i.e. embodiments of the present invention still work for up to 3 interfering nodes) which results in a probability of 0.14% of nodes producing constant false positive results. This drop from a 21.63% of nodes producing constant false positive results to 0.14% brings about a 160 times improvement.

The combined method of a known transmission frequency randomization technique and the technique of an embodiment of the present invention (as discussed with reference to Figures 2A to 2D,

3 to 5) provides a solution to the problem of false positive occurrences in high density deployment, scenarios where neither method alone can solve the problem. One approach is such that after randomising the frequency, the interval of the transceiver control signal of the sensor is changed in response to receipt of a reading indicating that inter-sensor frequency collision may be present. The change may be selected from the candidate list described with respect to the step 406 of Figure 4. Letting the sensor frequency undergo randomisation first is also advantageous in the scenario where limitations are imposed on the maximum number of intervals in the candidate list, so that a combination of first randomising the frequency sensor, followed by changing the interval of the transceiver control signal of at least one of the sensors.

The motion sensor systems described above may be used in applications such as smart lighting, where only areas where movement activity is detected are kept brightly lit. Such a lighting system can have a plurality of lights grouped into zones and a lighting controller configured to illuminate the plurality of lights. The lighting system incorporates the above mentioned motion sensor systems, wherein the illumination of the lights in any one of the zones is in response to the lighting controller receiving the indication of the presence of a moving object from any of the sensors of the motion sensor system. Each sensor of the motion sensor system may belong to one or more sensor zones, where a trigger matrix describes which sensor zone triggers which lighting zone. In a lighting system containing many sensor zones and lighting zones, the lighting system may also obtain input from this trigger matrix when determining which lights are to illuminated.

In the application, unless specified otherwise, the terms "comprising", "comprise", and grammatical variants thereof, intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, non-explicitly recited elements.

While this invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes can be made and equivalents may be substituted for elements thereof, without departing from the spirit and scope of the invention. In addition, modification may be made to adapt the teachings of the invention to particular situations and materials, without departing from the essential scope of the invention. Thus, the invention is not limited to the particular examples that are disclosed in this specification, but encompasses all embodiments falling within the scope of the appended claims.

CLAIMS

1. A motion sensor system comprising:
 - at least two sensors, wherein each of the two sensors comprises:
 - 5 a sensor controller configured to generate a transceiver control signal;
 - a transceiver configured to be driven by the transceiver control signal to send a transmission signal and to receive a reflected signal; and
 - a signal processor configured to process information derived from the received signal,
 - 10 wherein in response to at least one of the signal processors detecting a reading in the processed information, at least one of the sensor controllers is configured to change an interval of its generated transceiver control signal so as to increase an interval difference between the transceiver control signals generated by the two sensor controllers.
- 15 2. The motion sensor system of claim 1, wherein the sensor controller that changes the interval of its generated transceiver control signal belongs to the sensor with the signal processor that detects the reading in the processed information.
3. The motion sensor system of claim 1 or 2, wherein the increase in the interval difference is
20 achieved by increasing the interval of one of the generated transceiver control signals, while maintaining the interval of the other.
4. The motion sensor system of claim 1 or 2, wherein the increase in the interval difference is
25 achieved by decreasing the interval of one of the generated transceiver control signals, while maintaining the interval of the other.
5. The motion sensor system of claim 1 or 2, wherein the increase in the interval difference is achieved by changing the interval of both the generated transceiver control signals.
- 30 6. The motion sensor system of any one of the preceding claims, wherein the signal processor is further configured to determine that a duration of the detected reading is within a range before changing the interval of its generated transceiver control signal.
7. The motion sensor system of any one of the preceding claims, wherein each of the two
35 sensors further comprises a spike noise filter configured to remove the detected reading that remains after the interval difference is increased if it has a duration that is lower than a threshold.

8. The motion sensor system of claim 7, wherein the sensor controller of each of the two sensors is further configured to provide an indication of presence of a moving object if the detected reading that remains after the interval difference is increased has a duration that is greater than the threshold.
9. The motion sensor system of any one of the preceding claims, wherein at least one of the sensors determines, from the detected reading in the processed information, the interval used by the sensor controller of the other sensor to generate its transceiver control signal and avoids the used interval when changing the interval of its generated transceiver control signal.
10. The motion sensor system of claims 6 to 9, wherein the change in the interval is selected from a list of intervals, where each depends on one or more of: a safety margin, a duration of a lower limit of the range and a number of sensors that are expected to interfere, the number of sensors belonging to the motion sensor system.
11. The motion sensor system of claim 10, wherein the number of intervals in the list depends on the number of the sensors that are expected to interfere.
12. The motion sensor system of claim 10 or 11, wherein at least one of the sensor controllers is further configured to reiterate the change in the interval of its generated transceiver control signal from the list of intervals until the detected reading is less than the first threshold.
13. The motion sensor system of any one of the preceding claims, wherein the two sensors are configured to operate at a same transmission frequency.
14. The motion sensor system of claim 13, wherein the transmission frequency is within a range of 3 to 100 GHz.
15. A lighting system comprising
a plurality of lights grouped into zones;
a lighting controller configured to illuminate the plurality of lights; and
the motion sensor system of claims 8 to 12, wherein the illumination of the lights in any one of the zones is in response to the lighting controller receiving the indication of the presence of a moving object from any of the two sensors of the motion sensor system.

16. A motion sensing method comprising:
generating a transceiver control signal in one of at least two sensors;
utilising the transceiver control signal to drive one of the at least two sensors to send
a transmission signal;
5 receiving a reflected signal in one of the at least two sensors; and
processing information derived from the received signal, wherein in response to one
of the at least two sensors detecting a reading in the processed information, one of the at least
two sensors is configured to change an interval of its generated transceiver control signal so
as to increase an interval difference between the transceiver control signals generated in the
10 two sensors.
17. The motion sensing method of claim 16, wherein the sensor that changes the interval of its
generated transceiver control signal belongs to the sensor that detects the reading in the
processed information.
15
18. The motion sensing method of claim 16 or 17, further comprising
determining that a duration of the detected reading is within a range before changing
the interval of the generated transceiver control signal.
- 20 19. The motion sensing method of any one of the claims 16 to 18, further comprising
removing the detected reading that remains after the interval difference is increased if
it has a duration that is lower than a threshold.
20. The motion sensing method of claim 19, further comprising
25 providing an indication of presence of a moving object if the detected reading that
remains after the interval difference is increased has a duration that is greater than the
threshold.