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## **AUTO-FOCUSING METHOD AND SYSTEM**

### **Field of the Invention**

The present invention relates to methods and systems for measuring distance, particularly in the context of the auto-focusing of imaging systems.

### **Background of the Invention**

There are a number of types of auto-focusing methods currently available either on the market or described in literature. Three conventional types are described below.

#### **(1) Infrared-based auto-focusing methods**

In a conventional infrared-based auto-focusing method, pulses of infrared light are emitted in a beam towards the target on which focusing is desired. Light is reflected back from the target and detected by an infrared detecting device located at the optical device to be focused. By measuring the time delay between the transmitted and received signals or by comparing the powers of the transmitted and received signals, the distance from the target to the optical device to be focused may be calculated. The optical device may then be focused.

There are a number of problems associated with infrared-based auto-focusing methods, for example, such a method is sensitive to changes in temperature of both the target and the background, and the focused area tends to be large with just a single transmitter and receiver pair. Furthermore, the target itself may emit infrared light when its temperature becomes high enough and this may adversely affect the reflected infrared signal detected by the infrared detecting device.

(2) Ultrasound based auto-focusing methods

In principle, ultrasound based auto-focusing methods are similar to the infrared based methods described above, with the exception that the devices emit ultrasound instead of infrared radiation. Ultrasound based systems tend to consume more power than any other conventional auto-focusing methods and, as is the case in conventional infrared based methods, when a single receiving sensor is used, the target area is large.

(3) Contrast based auto-focusing methods

Contrast based auto-focusing methods do not require measurement of the distance to the target. In such methods, the optical device may be aimed at a target and the focusing of the lens may be adjusted to give maximum image contrast. The disadvantage of such methods is that strong reflecting light is required to obtain accurate focusing and the edge details on the target must be clear to obtain maximum contrast.

In view of the foregoing problems with conventional auto-focusing methods, a need exists for a method for auto-focusing that is unaffected by changes in temperature, enables highly accurate focusing onto a small target, and which maybe used in dark environments.

Summary of the Invention

According to a first aspect of the present invention there is provided a distance measurement apparatus comprising:

a transmitter for radiating pulses of radio waves;

a plurality of sensors aligned on a plane to receive said pulse signals emitted from the transmitter and reflected by an object in front of said plane;

an adder to combine the pulse signals received by said sensors;

a detector for detecting the combined pulse signal output from the adder;

a comparator for comparing the combined pulse signal with a reference pulse to identify desired pulses;

a delay determining device to determine the time between a transmitted pulse and a received pulse in respect of desired pulses identified by the comparator; and

a system to calculate the distance between the transmitter and the object from the determined delay time.

Preferably, the radio pulses emitted from the transmitter have an ultra-wide bandwidth.

In a preferred embodiment, the apparatus comprises three or more sensors to receive said pulse signals from said transmitter.

Preferably, said comparator comprises a shape matching apparatus.

In a preferred embodiment, the distance measurement apparatus further comprises an edge detector connectable to the output of the adder to determine the arrival of combined pulse signals having an amplitude greater than a predetermined value.

Preferably, the edge detector is arranged to trigger the comparator after the arrival of a combined pulse signal having an amplitude greater than a predetermined value to determine if the combined pulse signal is a desired pulse.

In a preferred embodiment, the distance measurement apparatus further comprises an average calculator connectable to the output of the delay determining device to calculate the mean of the determined time delays. This is particularly advantageous as it reduces the effect of spurious reflections in the correlation period.

In a preferred embodiment, the distance measurement apparatus further comprises a converter to convert the output from the average calculator to a signal corresponding to the distance to be measured.

Preferably, the system to calculate the distance  $d$  between the transmitter and the object is arranged to calculate said distance  $d$  from the determined delay time  $\tau$  according to the equation:

$$d = C \tau / 2$$

where  $C$  is the speed of light.

According to a second aspect of the present invention there is provided an auto-focusing device comprising the distance measurement apparatus defined above, and a lens focusing adjustment for focusing the lens dependent upon the distance measured using said distance measurement apparatus.

According to a third aspect of the present invention there is provided a method of measuring distance comprising the steps of:

transmitting pulses of radio waves;

receiving pulse signals using a plurality of sensors aligned on a plane, said pulse signals having been emitted from the transmitter and reflected by an object in front of said plane;

combining in an adder the pulse signals received by said sensors;

detecting the combined pulse signal output from the adder;

comparing in a comparator the combined pulse signal with a reference pulse to identify desired pulses;

determining the time between a transmitted pulse and a received pulse in respect of desired pulses identified by the comparator; and

calculating the distance between the transmitter and the object from the determined delay time.

According to a fourth aspect of the present invention there is provided a method of auto-focusing an imaging device comprising the method of measuring distance defined above, and further comprising the steps of focusing the imaging device dependent upon the distance measured.

Preferred embodiments of the present invention aim to enable highly accurate focusing onto a small target comparing signals from several sensors, such as UWB sensors. Such systems and methods are advantageous as they are suitable for use in dark environments and do not require additional light for focusing, whereas conventional auto-focusing methods commonly require high light intensity. Also, distance measurement is obtained easily and such systems and methods are robust against changes in temperature of a target object and background. Also, in a preferred embodiment, as the system is equipped with several UWB receiving sensors, it can form a narrow beam to focus on to a small target.

#### Brief Description of the Figures

Preferred features of the invention will now be described, for the sake of illustration only, with reference to the following Figures in which:

Figure 1a is a schematic diagram illustrating an embodiment of the present invention;

Figure 1b is a schematic block diagram of the signal processing according to an embodiment of the present invention;

Figure 2 is a graph showing the timings and shapes of transmitted and received signals according to an embodiment of the present invention; and

Figure 3 is a schematic diagram showing signal detection, shape matching and time delay calculation in an embodiment of the present invention.

#### Detailed Description of Preferred Embodiments

The principle embodying the invention is shown in Figures 1a and 1b. Figure 1a shows the distance measurement system of an auto-focusing device according to a preferred embodiment of the invention which includes a transmitter 2, which is preferably an ultra-wideband (UWB) transmitter, aimed at a target 4, the transmitter 2 being situated approximately in the centre of a planar array of receiving sensors (S1,S2,S3,S4), in this example, four ultra-wideband (UWB) receiving sensors. The array of receiving sensors (S1,S2,S3,S4) lies in a plane, hereinafter referred to as the UWB sensor plane, which is substantially orthogonal to the central axis (not shown) passing through the transmitter 2 towards the target 4.

As the receiving sensors S1,S2,S3,S4 are equidistant from the transmitter 2, signals reflected back from any point on the central axis should arrive simultaneously at all of the receiving sensors (S1,S2,S3,S4). Therefore, pulses transmitted from the transmitter 2 and reflected at a target point lying on the central axis, for example target point A, should all be received at the same time.

As shown in Figure 1b, the signals from all four sensors (S1,S2,S3,S4) are combined to produce a single output which is then processed to determine the appropriate reflection. Further processing occurs to determine the distance between the target 4 and the transmitter 2. This distance may then be used to focus the device.

The signals reflected from Point A and received by the four UWB sensors (S1,S2,S3,S4), when added, will give a strong pulse with a short rise time, as shown in Figure 2. By contrast, reflections from targets which do not lie along the central axis, for example, point B, do not arrive simultaneously at all four sensors (S1,S2,S3,S4) and therefore the combined output of the sensors in these circumstances will have a slower rise time and lower amplitude, and the resultant waveform will be wider than that of the signals received from targets which lie along the central axis, for example, point A, as shown in Figure 2. It is therefore possible to differentiate between reflections from targets lying along the central axis, for example at point A, and targets offset from the central axis, for example at point B.

A shape matching technique (matched filter) may be used to recognise and accept the pulse shape corresponding to the sharpest reflection from the target and ignore and reject any other signals.

In an ideal environment, that is one with infinite bandwidth, the shapes of the received pulses from the four sensors (S1,S2,S3,S4) would be the same as that of the transmitted pulse, although the amplitudes may differ.

If the transmitted signal be denoted by  $f(t)$ , then the combined output of the four sensors (S1,S2,S3,S4) from the target may be expressed as:

$$O(t) = af(t)+bf(t)+cf(t)+df(t) = (a+b+c+d) f(t) \quad (1)$$

where  $a$ ,  $b$ ,  $c$  and  $d$  represent attenuation factors for the four sensors (S1,S2,S3,S4).

$O(t)$  has the same shape as  $f(t)$ , which is known, a priori.

In practice, due to the finite bandwidths of the transmitter and receiver antennae, the received pulse shapes may differ from the transmitted pulse shapes. However, the received pulse shapes may be calculated from the properties of the transmitter and receiver antennae, and hence should also be considered as known, a priori.

For simplicity, ideal environments are assumed in the following description.

The shape matching pulse signal detection module according to an embodiment of the invention is shown in Figure 3 and comprises a pulse signal generator 6, and a signal assessor 8 for producing a trigger pulse to trigger the pulse generator 6 to produce a known waveform  $f(t)$ . The module also comprises a multiplier 10 arranged to multiply the output of the pulse generator 6 and the combined received signal  $O(t)$  from the signal assessor 8.

In the first branch of the shape matching pulse signal detection module shown in Figure 3, the combined output signal  $O(t)$  of the sensors (S1,S2,S3,S4) is assessed in the signal assessor 8. If the combined output  $O(t)$  is greater than a threshold value  $\eta$  determined by considering the SNR (signal-to-noise ratio) of the combined output signal  $O(t)$ , the local pulse generator 6 is triggered to produce a pulse  $f(t)$  matching the desired received pulses. The output  $f(t)$  of the local pulse generator 6 is correlated with the combined output signal  $O(t)$  of the sensors (S1,S2,S3,S4), in the multiplier 10 located in a second branch of the module.

The multiplier 10, which constitutes a comparator or 'correlator', is arranged to perform the correlation of the signals. If the correlation factor is high enough, that is, greater than a predetermined value  $\eta_1$ , then the received signal is deemed to match the desired signal reflected from the target 4 and the delay between the instant of transmission of a particular pulse and the edge

detection of the received pulse, as determined in the first branch, is measured by a time delay calculation system 12. The delay times obtained from time delay calculation system 12 for a sequence of pulses are averaged in an averaging system 14 to give an averaged delay time signal  $\tau$ .

There are at least two ways for the comparator implementation, one of which is cross correlation. Let the discrete time reference signal generated by the local pulse generator 6 be  $ref(i)$ , where  $i=1$  to  $L$ , and  $O(k)$  where  $(k-1, 2, \dots)$  is the discrete time combined signal received by the sensors (S1, S2, S3, S4). The cross correlation output may be denoted by:

$$O'(k) = \sum_{i=1}^L ref(i) \cdot O(k+i-1) \quad (2)$$

An alternative but more accurate expression for the cross correlation output is:

$$O'(t) = \frac{1}{L} \sqrt{\frac{1}{L} \sum_{i=1}^L \left( \frac{ref(i)O(k+i-1)}{|ref(i)|^2} - \frac{1}{L} \sum_{i=1}^L \frac{ref(i)O(k+i-1)}{|ref(i)|^2} \right)^2} \quad (3)$$

The shape matching instant  $m$  is the time at which the cross correlation output is a maximum  $O'(m)$ .  $L$  should be selected suitably so that  $\Delta t \cdot L$  is almost equal to the width of a pulse, where  $\Delta t$  is the discrete time between sampling pulses.  $Ref(i)$  may be set to be the same waveform as the transmitted signal  $f(i)$ .

If the amplitude of the combined output signal  $O(t)$  of the sensors (S1, S2, S3, S4) is less than  $\eta$  and/or the correlation factor is less than  $\eta_1$ , then

the shape of the received signal is deemed to be different from the desired pulse  $f(t)$  and the signal will be ignored.

It should be noted that if the target object 4 is very flat and orthogonal to the central axis, some reflections from symmetrical points around a small area of the central axis may also fall in the coherent time, as shown in Figure 2, which may cause a variation in the time delay measurements. For this reason, the time delay measurements  $\tau$  are averaged in the average module 14. This technique may increase the accuracy of the measurement of time delay  $\tau$  estimation. The reflections from random places may also fall in coherent time. However, the amplitudes of these reflections are typically small and have little correlation with the desired signal. Thus, they are considered to be noise.

Based on the time delay  $\tau$  from the instant of transmission of a particular pulse to the detection of the desired signal reflected from the target 4, the distance  $d$  from the transmitter 2 to the target 4 may be obtained by

$$d = C \tau / 2 \quad (2)$$

where  $C$  is the speed of light.

Thus, a signal proportional to the distance to be measured may be obtained from a signal corresponding to the measured time delay  $\tau$  and this signal may be used to drive the auto-focusing system of an imaging device so that the imaging device, for example a lens, may be focussed onto the target 4 as required.

The systems and methods described above as embodying the present invention may measure the distance between a target 4 and transmitter 2, and drive the auto-focus of an optical system to focus on a small area around a central axis. In practice, the size of the focused area depends on the duration

of the UWB pulse emitted from the transmitter 2, namely, the narrower the pulse, smaller the focused area.

The systems and methods described above are based on UWB devices, however, the transmitter 2 may be any transmitter radiating short pulses of radio waves, and the sensor(s) (S1-S4) may be any sensor that receives the corresponding short pulses.

In summary, systems and methods according to preferred embodiments of the present invention are particularly advantageous as:

- 1) Distance measurement and focusing are robust against changes in temperature of the target as well as the brightness of the environment.
- 2) More accurate focusing may be achieved than systems using infrared light.
- 3) There is no requirement for an imaging system for distance measurement.
- 4) The system and method embodying the invention is capable of highly accurate focusing onto a small area.
- 5) The system and method embodying the invention has low power consumption.
- 6) The system is not complex to implement.
- 7) The above-described systems may be incorporated, for example, into a camera, camcorder, projector, or other imaging system for the auto-focusing thereof.

- 8) The system and method embodying the invention is operable in dark environments, requiring no light for focusing, unlike conventional contrast methods.

Various modifications to the embodiments of the present invention described above may be made. For example, whilst the embodiments have been described in terms of there being four UWB sensors, any number of UWB receiving sensors may be adopted. In a preferred embodiment, there are preferably more than three sensors.

Furthermore, the transmitter 2 and/or the sensors (S1, S2, S3, S4) may be directional antennas, or may be omni-directional antennas. In the case that directional antennas are adopted, the distance measurement accuracy is increased. However, directional antennas are usually larger than omni-directional antennas. Thus, omni-directional or directional antennas can be selected according to the designer's priorities as between size and accuracy.

Furthermore, it will be apparent to those skilled in the art that modifications may be made to the embodiments chosen for illustration without departing from the spirit and scope of the invention.

**CLAIMS**

1. A distance measurement apparatus comprising:
  - a transmitter for radiating pulses of radio waves;
  - a plurality of sensors aligned on a plane to receive said pulse signals emitted from the transmitter and reflected by an object in front of said plane;
  - an adder to combine the pulse signals received by said sensors;
  - a detector for detecting the combined pulse signal output from the adder;
  - a comparator for comparing the combined pulse signal with a reference pulse to identify desired pulses;
  - a delay determining device to determine the time between a transmitted pulse and a received pulse in respect of desired pulses identified by the comparator; and
  - a system to calculate the distance between the transmitter and the object from the determined delay time.
2. The distance measurement apparatus according to claim 1, wherein the radio pulses emitted from the transmitter have an ultra-wide bandwidth.
3. The distance measurement apparatus according to claim 1, wherein the apparatus comprises three or more sensors to receive said pulse signals from said transmitter.

4. The distance measurement apparatus according to claim 1, wherein said comparator comprises a shape matching apparatus.
5. The distance measurement apparatus according to claim 1, further comprising an edge detector connectable to the output of the adder to determine the arrival of combined pulse signals having an amplitude greater than a predetermined value.
6. The distance measurement apparatus according to claim 5, wherein the edge detector is arranged to trigger the comparator after the arrival of a combined pulse signal having an amplitude greater than a predetermined value to determine if the combined pulse signal is a desired pulse.
7. The distance measurement apparatus according to claim 1, further comprising an average calculator connectable to the output of the delay determining device to calculate the mean of the determined time delays.
8. The distance measurement apparatus according to claim 7, further comprising a converter to convert the output from the average calculator to a signal corresponding to the distance to be measured.
9. The distance measurement apparatus according to claim 1, wherein the system to calculate the distance  $d$  between the transmitter and the object is arranged to calculate said distance  $d$  from the determined delay time  $\tau$  according to the equation:

$$d = C \tau / 2$$

where  $C$  is the speed of light.

10. The distance measurement apparatus of claim 1, wherein the comparator has an output signal  $O'(t)$ , wherein

$$O'(k) = \sum_{i=1}^L \text{ref}(i) \cdot O(k+i-1) \quad , \text{ or}$$

$$O'(t) =$$

$$\sqrt{\frac{1}{L} \sum_{i=1}^L \left( \frac{\text{ref}(i)O(k+i-1)}{|\text{ref}(i)|^2} - \frac{1}{L} \sum_{i=1}^L \frac{\text{ref}(i)O(k+i-1)}{|\text{ref}(i)|^2} \right)^2}$$

and  $\text{ref}(i)$  is said reference pulse where  $i=1$  to  $L$ ,  $O(k)$  where  $(k=1,2,\dots)$  is the discrete time combined signal received by said sensors, and  $L$  is selected so that  $\Delta t \cdot L$  is almost equal to the width of a pulse, where  $\Delta t$  is the discrete time between sampling pulses, and  $m$  is the shape matching instant at which  $O'(m)$  yields a maximum value.

11. An auto-focusing device comprising the distance measurement apparatus of claim 1, and a lens focusing adjustment for focusing the lens dependent upon the distance measured using said distance measurement apparatus.
12. A device according to any of claims 1 to 11 in which the transmitter is a directional antenna, and/or the sensors are directional antennas.
13. A device according to any of claims 1 to 11 in which the transmitter is an omni-directional antenna, and/or the sensors are omni-directional antennas.
14. A method of measuring distance comprising the steps of:

transmitting pulses of radio waves;

receiving pulse signals using a plurality of sensors aligned on a plane, said pulse signals having been emitted from the transmitter and reflected by an object in front of said plane;

combining in an adder the pulse signals received by said sensors;

detecting the combined pulse signal output from the adder;

comparing in a comparator the combined pulse signal with a reference pulse to identify desired pulses;

determining the time between a transmitted pulse and a received pulse in respect of desired pulses identified by the comparator; and

calculating the distance between the transmitter and the object from the determined delay time.

15. A method of auto-focusing an imaging device comprising the method of measuring distance according to claim 14 and further comprising the steps of focusing the imaging device dependent upon the distance measured.
16. A method according to claim 14 or claim 15 in which the transmitted pulses are directional, and/or the sensors are directional antennas
17. A method according to claim 14 or claim 15 in which the transmitted pulses are omni-directional, and/or the sensors are omni-directional antennas.