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(71) Applicant (for all designated States except US): THE SECRETARY OF STATE FOR TRADE AND INDUSTRY IN HER BRITANNIC MAJESTY'S GOVERNMENT OF THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND [GB/GB]; 10/18 Victoria Street, London SW1H 0ET (GB).

(72) Inventors: and
(75) Inventors/Applicants (for US only): JACKSON, Douglas [GB/GB]; 46 Mount Cameron Drive, East Kilbride, Glasgow G74 2ES (GB). ROBERTSON, Andrew, Rae [GB/GB]; 7 Renock Court, Hamilton, Nr Glasgow (GB).

(74) Agent: BECKHAM, Robert, William; Ministry of Defence, Procurement Executive, Patent IA(4), Room 204, Empress State Building, Lillie Road, London SW6 1TR (GB).

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(54) Title: AUTOMATIC VEHICLE GUIDANCE SYSTEMS

(57) Abstract

A method of controlling one or more automatically controlled vehicles (10) using beacons (14, 24) and receivers (13, 23) (beacons being fixed and receivers on vehicles, or vice versa) uses a sequential switching system such that the effects of malfunctioning or masked beacons (14, 24) or receivers (13, 23) can be allowed for. The beacons sequentially emit signals, intervals between consecutive signals being equal until all beacons have been caused to signal, then after a first pause time of a first integer number of intervals the beacons emit signals in reverse order, and after all the beacons have been caused to signal, after a second pause time of a second integer number of intervals, the steps are repeated. The first and second integrals differ by an odd number. The invention also concerns apparatus for carrying out the method.
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AUTOMATIC VEHICLE GUIDANCE SYSTEMS

The present invention relates to automatic vehicle guidance systems.

There are many known examples of automatic vehicle guidance systems involving the repeated movement of one or more vehicles. A simple example is the system used for the transfer of coal waste to slag heaps. More complicated systems are used in the movement of materials within factories and warehouses. However, these systems usually rely on rails or on fixed paths defined by, for example, buried guide wires, and are governed by, inter alia, signals received from trip switches, photo-electric cells, or similar position sensors. The uses of such systems are therefore very inflexible, and the systems are suitable only for the most routine type of task.

There is a requirement for more flexible systems, and one such system is described in Patent GB 2129161B. This Patent describes a flexible system whereby vehicles travel freely under the control of signals generated by computers in response to the detection by one or more fixed cameras of vehicle position, the vehicles being equipped with devices, henceforth referred to as beacons, which transmit a frequency, such as an infra-red frequency, to which the camera or cameras respond. GB Patent 2129161B gives no description of the type of camera involved. A co-pending application in the name of the present Applicant describes a camera in the form of a bearing sensing device which provides a large field of view—almost 360° in azimuth and 70° or more laterally—which is particularly useful for this type of guidance system. The bearing sensing device focusses light from a beacon on to a substantially annular photo detector which has an electrode deposited at each end. The photo detector is made from a continuous P-N junction together with a highly uniform resistive sheet. When light falls on to the photo-detector current flows to each electrode and by comparing the contribution to these currents caused by the light focussed onto the photo detector from a beacon the point of contact of the beacon light can be calculated. This contribution must be separated from currents caused by ambient background radiation and by thermal effects.

A ratiometric converter by which the bearing of a beacon relative to an axis can be determined from the photo detector currents is the
subject of another co-pending Application in the name of the present Applicant. The ratiometric converter includes means for receiving signals from electrodes at extremities of the annular photo detector, means for processing the signals to separate therefrom components caused by a flash of light focussed on a position of the photo detector, means for distinguishing whether the sum of the components falls within a predetermined range, and, if the sum does fall within the predetermined range, means for processing the components in order to identify the position of the photo detector on which the flash of light is focussed.

In GB Patent 2129161B the control system requires a processing unit to signal a vehicle when it requires knowledge of the vehicle's position. In response to the signal a beacon on the vehicle is activated, the activation is detected by the processing unit, and the processing unit calculates the vehicle's position and (with reference to stored information) velocity and signals a vehicle control unit accordingly. This system requires very complex equipment if it is to control more than a very small number of vehicles, and is also limited to situations where beacons will always remain within camera view.

The present invention provides a method and apparatus for using a beacon array in a manner which simplifies control equipment and which allows for non-detection (through beacon failure or from masking of a beacon by, for example, interference between one vehicle and another) of an individual beacon.

According to the invention a method of controlling one or more automatically guided vehicles in which signals from beacons are intercepted by receivers remote from the beacons includes the steps of causing the beacons to sequentially emit signals, intervals between consecutive signals being equal until all beacons have been caused to signal, then after a first pause time of a first integral number of intervals causing the beacons to emit signals in reverse order, and after all the beacons have been caused to signal, after a second pause time of a second number of intervals, repeating the steps, the first and second integrals differing by an odd number.

The beacons preferably emit signals in the form of either visible or infrared light and the receivers are preferably cameras. The beacons may be at fixed positions with receivers mounted on vehicles,
or vice versa. When the beacons are mounted on the vehicles there are preferably 2 beacons on each vehicle. The difference between the first and second integrals is preferably one.

According to another aspect of the invention an automatic vehicle

guidance system includes a plurality of first devices in the form of signalling units and at least one second device in the form of a receiving unit, one device or devices being at fixed positions and the other device or devices being mounted on one or more vehicles, the system including means for causing the signal units to sequentially emit signals, intervals between consecutive signals being equal until all signal units have been caused to signal, then after a first pause time of a first integral number of intervals causing the signal units to emit signals in reverse order, and after all the signal units have been caused to signal, after a second pause time of a second number of intervals, repeating the steps, the first and second integrals differing by an odd number.

The first devices (beacons) preferably emit signals in the form of either visible or infrared light and the receivers are preferably cameras. The beacons may be at fixed positions with receivers mounted on vehicles, or vice versa. When the beacons are mounted on the vehicles there are preferably 2 beacons on each vehicle. The differences between the first and second integrals is preferably one.

One embodiment of the invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings, of which:

Figure 1 shows a vehicle of the type with which the method may be used;

Figure 2(a) and (b) show 2 environments in which the vehicle of Figure 1 can operate;

Figure 3 and Figure 4 are block diagrams of guidance systems for vehicles operating in the environments of Figure 2(a), Figure 2(b) respectively;

Figure 5(a) is detail of one type of a bearing sensing device;

Figure 5(b) is a section through a field of view of the device illustrated in Figure 5(a);

Figure 6(a) is a detail of a second type of bearing sensing device;
Figure 6(b) is a section through a field of view of the device of Figure 6(a);
Figure 7(a) is a plan view of a photo detector as used in the bearing sensing devices;
Figure 7(b) shows a potentiometric equivalent circuit for the photo detector of Figure 7(a);
Figure 8 shows a block diagram of a ratiometric converter for use with the photo detector of Figure 7(a);
Figure 9 shows an example of beacon timing according to the invention; and
Figures 10(a) to (d) shows examples of beacon timing which do not identify failed beacons.

A vehicle with which the invention can be used (Figure 1) has a body 10 mounted on wheels 11 driven and steered according to commands from a control box 12. The vehicle 10 can operate in an environment 2(a) in which a bearing sensing device 13, mounted on the vehicle receives signals from a plurality of fixed beacons 14; or in an environment (2(b)) in which beacons 24 (shown in dotted lines in Figure 1) mounted as far apart as possible on vehicle 10 send signals to fixed bearing sensing devices 23.

When operating in the environment illustrated in 2(a) the control unit 12 will typically contain (Figure 3) the bearing sensing device 13 which sends signals to transmitter 45 in a control unit 41 and which controls sequential flashing of beacons 24 and operation of a pilot unit 34. The ground control units contain a series of bearing sensing devices 23 each of which sends signals to an associated beacon check 30 and ratiometric converter 31. A signal from the beacon check 30 passes to a master timer 42 which sends signals to each ratiometric converter 31, to a master computer 43 and to a flash timer 44. The master computer 43 receives signals from each ratiometric converter 31 and sends command signals to a transmitter 45 which also receives signals from the flash timer 44, and which sends command signals to the receiver 40.

In one form of bearing sensing device 13, 23 (Figure 5(a)), an ultra-wide angle (fish eye) lens 50 directs a beam of light 51 from a beacon 14, 24 through a field stop 52 to a lens 53 which focusses the beam on to an annular photo detector 54. A bearing sensing device of
this type has a field view (Figure 5(b)) extending from horizontal to within about 20° of the vertical.

In a second form of bearing sensing device (Figure 6(a)) a beam of light 61 from a beacon 14, 24 passes through a cylindrical window 62 and is reflected by a spherical mirror 60 through a field stop 52 to be focussed by a lens 53 on to an annular photo detector 54. The cylindrical window 62 must be robust as well as of good optical quality and it must support the field stop 52, lens 53, and photo detector 54 and associated structure (not shown in this figure) which must be situated above the spherical mirror 60. The field of view of this type of bearing sensing device (Figure 6(b)) extends from slightly below the horizontal to slightly less than vertical.

The annular photo detector 54 (Figure 7(a)) is in the form of an annulus extending over almost 360° and is formed from a continuous P-N junction together with a highly uniform resistance sheet. Electrodes 70, 71 are deposited on the ends of the annulus. In use, when a beam of light falls on a point 72 of the annulus 54 current passes to both electrodes 70 and 71, and by comparing these currents, in a manner analogous to that illustrated in 7(b), the position 72 along the annulus can be identified as follows:

When the spot is close to 0° \( R_R \rightarrow 0 \) and the potentiometer constant \( K \rightarrow 1 \). When the spot is close to 360°, \( R_L \rightarrow 0 \) and the constant \( K \rightarrow 0 \). The potentiometer constant is then given by:

\[
K = (1 - \theta/360) 
\]

(i)

Great effort is made during manufacture of these devices to keep the resistivity of the sheet constant over the entire area of the device. It can be seen from Fig 7(b) that \( I_L = (1 - K) \) I and \( I_R = K \) I. To obtain an output which is related to \( \theta \) and which is independent of the incident light intensity, it is necessary to ratio the currents. This can be done in one of two ways to obtain an output which is linearly proportional to \( \theta \):

\[
\frac{I_L - I_R}{I_L + I_A} = (1 - 2K) = \frac{\theta - 1}{180} \quad \text{(ii)}
\]

\[
\frac{I_L}{I_L + I_R} = (1 - K) = \frac{\theta}{360} \quad \text{(iii)}
\]
In both cases the ratio is independent of I and therefore independent of the incident intensity. The ratios are also independent of the total sheet resistance \( R_L + R_R \); this is only true if the electrodes are loaded with zero impedance.

The ratiometric converter 31 (Figure 8) has a transconductance amplifier 80 with an input from electrode 70 of the photo detector 54 and an output to a differentiating amplifier 81 which has an output to a track and hold amplifier 82. Similarly an output from electrode 71 of photo detector 54 passes through a transducer amplifier 83 and a differentiating amplifier 84 to a track and hold amplifier 85.

The track and hold amplifiers 82, 85 receive inputs from the timer controller 32 or master timer 42 as well as from the differentiating amplifiers 81, 84, and have outputs to a subtractor 86 and an adder 87.

The adder has an output to an amplitude check 88 which has outputs to the timer controller 32 or master timer 42 and to a beacon check 30. The adder also has an output to a variable gain amplifier 89 through a first pole 90 of an analogue switch 92, a second pole 91 of which has an input from the subtractor 86. The variable gain amplifier 89 also receives a signal from a successive approximation register 93 which receives signals from the timer controller 32 or master controller 42 and from a digital comparator 94.

The variable gain amplifier 89 has an output to a 12-BIT fast analogue to digital computer (ADC) 95 which also receives inputs from the timer controller 32 or master controller 42 and from a feedback circuit containing a stable bias generator 96. The ADC 95 has outputs to a computer 33 or 43 (not shown) and 98 to the digital comparator 94 which also has a preset binary input 99.

In use, when vehicles 10 are operating in an environment such as that illustrated in Figure 2(a) the beacons 14 sequentially emit flashes of light under the control of the flash timer 15. Each flash has a duration of the order of 10 microseconds (μS).

The beacons (Figure 9 shows an example where there are 6 beacons) 14 flash with an identical interval \( t_1 \) between each pair of adjacent (in time) beacons. There is then an interval \( t_{DL} \) equal to an even or an odd (greater than 1) number of intervals \( t_1 \), then the beacons 14 sequentially emit flashes in reverse order. After a time
interval \( t_{D2} \) equal to an odd or an even number of time intervals the sequence is repeated. If \( t_{D1} \) is an even number of intervals \( t_1 \) then \( t_{D2} \) must be odd, and vice versa. This timing is shown in Fig 9 with a six beacon case and time intervals of \( t_{D1} = 4t_1 \), \( t_{D2} = 5t_1 \). If, for example, beacon 6 and one or more adjacent (in time) beacon or beacon fail the next beacon to flash is identified by measuring the time delay: \( T_{D1+p} \).

If \( p \) is even then next beacon is number \( [N - p/2] \)
If \( p \) is odd then next beacon is number \( [ \lceil p+1 \rceil ] \)

Note that the details are integer multiples of the delay time between individual flashes.

This method of timing allows synchronisation between the on-board timer and the land-based flash timer.

Figures 10(a) to 10(d) illustrates the inadequacies of other timing systems.

The on-board timer can keep track of the beacons by measuring the time at which a flash occurs, but it is essential that it is kept in synchronisation. A simple way of doing this is to accurately set and measure the time interval, \( T_D \), between successive firing cycles of the complete ring. This is shown for the case of six beacons in Fig 10a.

The delay is measured and if \( T_D = 4 \) units then the next flash is beacon 1. If beacon 1 has failed or is obscured, then \( T_D = 5 \) units indicating that the next flash is beacon 2. However if beacon 6 were to fail, the system would slip out of synchronisation as shown in Fig 10b. This cannot be prevented with the simple system.

This problem is overcome by alternately firing the ring of beacons in ascending then descending numerical order as shown in Fig 10c. The system can now distinguish whether beacon 1 or beacon 6 has failed. The situation for the failure of beacon 6 is shown in Fig 10d. If the firing is in ascending order and \( T_D = 6 \) then the next beacon to fire must be beacon 5 etc. It is still possible for the beacon check to get out of phase with the firing cycle by confusing the ascending and descending firing cycles.

Considering one vehicle 10 and one flash of light from a beacon 14, the bearing sensing device 13 on the vehicle 10 senses the flash which is focussed onto a point 72 on the annular photo detector 53. Electrical currents flowing between the point 72 and electrodes 70,
71, will now be a combination of photo-generated current due to the beacon light, photogenerated current due to background radiation, and thermally generated current. The currents due to the beacon light are separated and compared by the ratiometric converter 31, which also rejects light which is, by predetermined criteria, either too intense or too weak. The weak criterion may be based, for example, on the expected level of thermally generated current in the photo detector 53 as this is the factor which ultimately limits the minimum signal intensity for acceptable results. A typical range in terms of sighting distance is 20:1 corresponding to a range in incident intensity of 400:1 or 52 dB.

The current pulses from the electrodes 70, 71 are fed into the transductance amplifiers 82, 85 respectively. These amplifiers 82, 85 load the contact with a virtual short circuit to ground to provide maximum linearity of response, and also convert the current pulses into proportional voltage pulses. These pulses are fed to the differentiating amplifiers 81, 84 respectively. The differentiating amplifiers 81, 84 feed signals corresponding to rapidly varying voltage changes (from which current due to background radiation has been filtered) to the track and hold amplifiers 82, 85 respectively and the signals are held there in response to a signal from the timer controller 32, which has been forewarned by a signal from the bearing sensing device 13 via the beacon check 30, when the voltage pulses are in the peak regions.

It will be realised that the amplifiers 80, 83; 81, 84 and 82, 85 must be precisely matched in static and dynamic characteristics.

The stored voltages from the track and hold amplifiers 82, 85 are fed to the adder 87 and subtractor 86. The adder 87 provides a sum signal proportional to the total photoelectric current generated by the beacon 14 flash which is fed to the amplitude check 88. If the amplitude check 88 recognises that the signal from the adder 87 is outside the predetermined maximum and minimum limits it signals the timer controller 32 to discard the beacon 14 flash.

The sum signal from the adder 64 is also fed to the variable gain amplifier 89 through pole 90 of the analogue switch 92. A signal e₁
from the variable gain amplifier 89 is fed to the 12-BIT ADC 95
together with a stable bias signal $e_B$ generated by the stable bias
generator 96 in response to a signal $e_R$ from the ADC 95.

The number, $N_0$, which is the binary output 97 of the ADC 95 is:

$$N_0 = \frac{e_I + e_B}{e_R}$$ (iv)

To give an azimuth angle to an accuracy of 0.1° of a beacon 14
bearing to a fixed axis 16 of the vehicle 10 a scaling and current
Ratioing calculation is carried out as follows:

The gain $H$ of the variable gain amplifier 89 is automatically
adjusted until the output signal $e_I$ is at a value corresponding
to $N_0 = 3600$ from the ADC 95.

This gain adjustment is performed as a 16 step successive
approximation sequence under control of the timer/controller 32, the
successive approximation register 93 and the digital comparator 94.
The comparator 94 compares the output at the ADC with a preset word
equal to binary 3600 and provides a keep/reject signal to the success-
ive approximation register 93 indicating whether the ADC 95 output is
too high or too low. The total time required to adjust the gain is
approximately sixteen times the conversion time of the ADC.

Additional time is allowed for settling of the variable gain amplifier.

The bias voltage $e_B$ is precisely adjusted to give $e_B = \frac{225}{512} e_R$.

It is then easily seen for $N_0 = 3600$ that:

$$e_I = H e_B = \frac{225}{512} e_R$$ (v)

The gain of the variable gain amplifier 89 is thus held constant and
the analogue switch 92 is changed over so that the difference signal,
$e_D$, from the subtractor 86 is fed through pole 91 to the amplifier 89.
The amplifier signal $e_I$ is now given by: $e_I = H e_D$, and the binary
output number from the ADC 95 is given by:
\[ N = \frac{4096 (e_L + e_R)}{(e_R + e_R)} = 4096 (e_D) + 1800 \]
\[ = 1800 (e_D + 1) \quad \ldots \quad (vi) \]
\[ = e_S \quad \ldots \quad (vii) \]
\[ N = 1800 \frac{2I_L}{I_L + I_R} = 10 \theta \quad \text{(from iii)} \quad \ldots \quad (viii) \]

Since \( e_D = C (I_L - I_R) \) and \( e_S = C (I_L + I_R) \) \ldots \quad (vii)

The desired current ratio has been evaluated and correctly scaled.

The correct operation of the ratiometric converter 31 depends on the ability of the variable gain amplifier 89 to adjust its output signal \( e_I \) to within 0.028\% of \( e_B \) whilst accommodating the 52 dB dynamic range of the sum signal, \( e_S \), from the adder 87. A two-stage digitally programmable logarithmic amplifier arrangement is used to give the required gain characteristic.

When the total conversion is complete, the timer/controller 32 flags the computer 33 so that the azimuth angle may be stored. A beacon identification code is also provided from the beacon check 30 via the timer/controller 32. The beacon check 30 operates, for example, in response to a radio or other signal sent by each beacon 14 simultaneously with each flash of light, or, preferably, by the method described in our co-pending Application.

When 2, or more usually more than 2, beacon bearings are being stored by the computer it calculates the position of the vehicle 10 and signals the pilot unit 34 to make any necessary adjustments to the steering and speed of the vehicle 10. It will be realised that light must not be allowed to fall on the electrodes 70, 71 of the photo detector 53, hence there is a blind spot of, typically, 3° in the bearing sensing device 13 and hence there will usually need to be more than 2 beacons 14 taken into consideration when calculating the position of the vehicle 10.

When bearing sensing devices 13 are used in the environment of Figure 2(b), considering one vehicle 10 only, a signal from transmitter 15 is received by receiver 40 which relays the information of flash timer 44 to sequentially operate beacons 24. Signals from the beacons 24 are picked up by the array of bearing sensing devices 23, and
information from these is sent, by a manner similar to that described above with reference to the environment of Figure 2(a) to the computer 43 which works out the bearing of each beacon 24. The computer 43 selects the most suitable beacon bearings and thus computes the position and alignment (as the vehicle 10 has two beacons 24), of the vehicle 10 relative to a convenient set of co-ordinates.

It will be realised that operating in each of the environments 2(a)(b) will have its own advantages and disadvantages. For example in environment 2(a) the blind spot due to the electrodes 70, 71 on the photo detector 53 may be a disadvantage, but this environment does not require the use of a radio transmitter such as required in environment 2(b). As each vehicle 10 has its computer 33 this can be comparatively simple, compared with the computer 43 of environment 2(b). On the other hand the arrangement of environment 2(b) enables the computer 43 to store the positions and vector velocities of all vehicles 10 and arrange for collisions to be avoided.

Also each of the devices described above with reference to Figures 5, 6 has its own advantages. The lens 50 might be expected to be more accurate than the spherical lens 60, but does tend to be much more expensive.

It will be realised that whilst the bearing sensing devices have been described above as operating in 2 particular environments they may be equally valuable in other operating regimes.
What is claimed is:

1. A method of controlling one or more automatically guided vehicles (10) in which signals from beacons (14, 24) are intercepted by receivers (13, 23) remote from the beacons characterised in including the steps of causing the beacons (14, 24) to sequentially emit signals, intervals between consecutive signals being equal until all beacons (14, 24) have been caused to signal, then after a first pause time of a first integral number of intervals causing the beacons (14, 24) to emit signals in reverse order, and after all the beacons (14, 24) have been caused to signal, after a second pause time of a second integral number of intervals, repeating the steps, the first and second integrals differing by an odd number.

2. A method as claimed in Claim 1 characterised in that the signals are in the form of light.

3. A method as claimed in Claim 2 characterised in that the light is visible.

4. A method as claimed in Claim 2 characterised in that the light is infra red.

5. A method as claimed in any one of Claims 2 to 4 wherein the receivers (13, 23) are cameras.

6. A method as claimed in any one of Claims 1 to 5 characterised in that the beacons (14) are at fixed positions and the receivers (13) are mounted on vehicles (10).

7. A method as claimed in any one of Claims 1 to 5 characterised in that the receivers (23) are at fixed positions and the beacons (24) are mounted on vehicles (10).

8. A method as claimed in any one of Claims 1 to 7 characterised in that the difference between the first and second integrals is one.

9. An automatic vehicle guidance system including a plurality of first devices in the form of signal units (14, 24) and at least one second device in the form of a receiving unit (13, 23), one device or devices being at fixed positions and the other device or devices being mounted on one or more vehicles (10) characterised in that the system has means for causing the signal units (14, 24) to sequentially emit signals, intervals between consecutive signals being equal until all signal units (14, 24) have been caused to signal, then after a first pause time of a first integral number of intervals causing the signal
units (14, 24) to emit signals in reverse order, and after all the signal units (14, 24) have been caused to signal, after a second pause time of a second number of intervals, repeating the steps, the first and second integrals differing by an odd number.

10. An automatic vehicle guidance system as claimed in Claim 9 characterised in that the signal units are beacons (14,24) emitting visible light.

11. An automatic vehicle guidance system as claimed in Claim 9 characterised in that the signal units are beacons (14, 24) emitting infra red light.

12. An automatic vehicle guidance system as claimed in any one of Claims 9 to 11 characterised in that the signal units (14) are fixed and the receiving unit or units (13) is or are mounted on one or more vehicles (10).

13. An automatic vehicle guidance system as claimed in any one of Claims 9 to 11 characterised in that the or each receiving unit (23) is fixed and the signal units (24) are mounted in vehicles.

14. An automatic vehicle guidance system as claimed in Claim 13 characterised in that there are two signal units on each vehicle.
Fig. 4.
Fig. 5b.

EQUATORIAL PLANE

Fig. 6b.

EQUATORIAL PLANE

SUBSTITUTE SHEET
Fig. 8.
Fig. 9.

Fig. 10.

a

b

6 FAILS

6 FAILS

SUBSTITUTE SHEET
INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)  
According to International Patent Classification (IPC) or to both National Classification and IPC

IPC 4: G 05 D 1/02, G 01 S 1/70

II. FIELDS SEARCHED

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Documentation Search other than Minimum Documentation to the Extent that such Documents are Included in the Fields Search 6

III. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>EP, A3, 0007789 (IMPERIAL CHEMICAL INDUSTRIES LTD) 6 February 1980, whole document</td>
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* Special categories of cited documents: 16
“A” document defining the general state of the art which is not considered to be of particular relevance
“E” earlier document but published on or after the international filing date
“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
“O” document referring to an oral disclosure, use, exhibition or other means
“P” document published prior to the international filing date but later than the priority date claimed

IV. CERTIFICATION

Date of the Actual Completion of the International Search: 21st November 1988

Date of Mailing of this International Search Report: 28 DEC 1988

INTERNATIONAL SEARCHING Authority: EUROPEAN PATENT OFFICE

Signature of Authorized Officer: P.C.G. VAN DER PUTTEN
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ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.  PCT/GB 88/00769
SA 24344

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
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For more details about this annex: see Official Journal of the European Patent Office, No. 12/82