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(54) TEMPERATURE SELF-CORRECTION METHOD BY USING FITTING ATTENUATION DIFFERENCE IN DISTRIBUTED OPTICAL FIBER RAMAN TEMPERATURE MEASURING SYSTEM

(57) The invention relates to a temperature self-correction method by using a fitting attenuation difference in a distributed optical fiber Raman temperature measuring system. In the invention, a Stokes light and anti-Stokes light attenuation coefficient difference equation is obtained through a temperature demodulation principle; an attenuation coefficient difference-temperature fitting curve equation is obtained through a fitting curve; a temperature demodulation equation is obtained through the fitting curve equation and a ratio of light fluxes; after demodulation, primary correction of a temperature is realized; then, a Rayleigh noise is solved by combining with a relationship between Stokes light and anti-Stokes light signals and the Rayleigh noise; a corrected temperature demodulation formula is further obtained; re-correction is realized after demodulation; and a goal of temperature self-correction is achieved. Compared with a conventional method for eliminating the Rayleigh noise, the temperature self-correction method has the advantages that a temperature correction amount is improved; the precise measurement of the temperature is realized; an error problem caused by processing by regarding that Stokes light and anti-Stokes light attenuation coefficients are approximately equal is solved; and the requirement of precise detection of the temperature in a goaf and an adjacent old goaf of a coal mine is met.

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TEMPERATURE SELF-CORRECTION METHOD BY USING FITTING ATTENUATION DIFFERENCE IN DISTRIBUTED OPTICAL FIBER RAMAN TEMPERATURE MEASURING SYSTEM

BACKGROUND

Technical Field

The invention relates to the technical field of an optical fiber sensing instrument, in particular to a temperature self-correction method by using a fitting attenuation difference in a distributed optical fiber Raman temperature measuring system.

Related Art

With the sustained and rapid development of economy, demands of our country on energy sources are increasing. In order to ensure mining safety of a coal mine and to prevent spontaneous combustion, temperatures in a goaf and an adjacent old goaf of the coal mine must be detected. At present, a distributed optical fiber Raman temperature measuring system is used for coal mine spontaneous combustion temperature monitoring. Stokes light and anti-Stokes light in Raman scattering light have different sensitivity on the temperature, so that position and temperature information of each point on an optical fiber is accurately measured by combining a ratio demodulation method with an optical time domain reflection technology, and the detection on an optical fiber temperature field is realized.

Inherent loss may be generated by different wavelengths of Stokes Raman scattering light and anti-Stokes Raman scattering light in the optical fiber, and additional loss may be generated by optical fiber bending, stress and environment temperature change, so that the Stokes Raman scattering light and the anti-Stokes Raman scattering light have different attenuation. During temperature demodulation, the two are generally regarded as being approximately equal to be processed, or empirical values are directly used, so that a demodulation result generates a great error. Therefore, a novel method is needed for solving a temperature error problem caused by attenuation coefficients.

SUMMARY

The invention is directed to provide a temperature self-correction method by using a fitting attenuation difference in a distributed optical fiber Raman temperature measuring system, has the advantage of replacing inherent loss and additional loss by the fitting attenuation difference during temperature demodulation, and solves an error problem caused by processing by regarding that the two attenuation coefficients are approximately equal.

The temperature self-correction method by using the fitting attenuation difference in the distributed optical fiber Raman temperature measuring system is provided. The temperature correction method comprises the following steps that:

Step (1): a single-mode optical fiber with a total length being L is taken to be used as a sensing optical fiber 6; an optical fiber section I 8 and an optical fiber section II 9 with the same length on the sensing optical fiber 6 are put into a thermostat 7, a distance from a center point of the optical fiber section I 8 to a head end of the sensing optical fiber 6 is identical to a distance from a center point of the optical fiber section II 9 to a tail end of the sensing optical fiber 6, and other parts of the sensing optical fiber 6 are put in a room temperature environment; a temperature control range of the thermostat 7 is set; a temperature is sequentially increased from a minimum value of the temperature control range to a maximum value of the temperature control range according to the same temperature interval; and corresponding output signal values after each time of temperature change are measured by the distributed optical fiber Raman temperature measuring system;

Step (2): according to a ratio of a Stokes light flux to an anti-Stokes light flux in the optical fiber section I 8 and the optical fiber section II 9, a Stokes light and anti-Stokes light attenuation coefficient difference equation is obtained; according to the output signal values and the attenuation difference equation, a relationship diagram between an attenuation difference and a temperature is obtained; and after fitting, an attenuation difference-temperature fitting curve equation is obtained;

Step (3): according to the ratio of the Stokes light flux to the anti-Stokes light flux and the attenuation difference-temperature fitting curve equation, a temperature demodulation equation introducing a fitting attenuation difference can be obtained, and measured temperature values of the two optical fiber sections are obtained through the

equation;

Step (4): located environments of the optical fiber section I 8 and the optical fiber section II 9 are identical, so that Rayleigh noise attenuation coefficient change caused by environment change is avoided; after parameters of a pulse light source, a located environment of a detector and a type of the optical fiber are determined, Rayleigh noise in Stokes light and anti-Stokes light can be regarded as a constant value, so that a relationship equation between the Stokes light flux and the Rayleigh noise, and a relationship equation between the anti-Stokes light flux and the Rayleigh noise are obtained;

Step (5): according to positions of the optical fiber section I 8 and the optical fiber section II 9, three groups of data in the output signal values, and a demodulated temperature value, through the temperature demodulation equation introducing the fitting attenuation difference and the relationship equations between the light fluxes and the Rayleigh noise, a Rayleigh noise value is obtained; and

Step (6): according to the temperature demodulation equation introducing the fitting attenuation difference and the relationship equation between the light fluxes and the Rayleigh noise, by combining with the Rayleigh noise value, a final temperature demodulation equation introducing the fitting attenuation difference and further eliminating the Rayleigh noise is obtained.

Preferably, the ratio of the Stokes light flux to the anti-Stokes light flux in the optical fiber is:

$$I(T_l) = \frac{\phi_{st}(l)}{\phi_{as}(l)} = C \exp\left(\frac{h\Delta v}{k_B T_l}\right) \exp(\alpha_{st} - \alpha_{as})l$$;

in the Step (2), the Stokes light and anti-Stokes light attenuation coefficient difference equation is:

$$\alpha_{st} - \alpha_{as} = \frac{\ln(I(T_{L-l_0}))}{\ln(I(T_{l_0}))} \bigg/ (L - 2l_0)$$;

in the Step (2), the attenuation difference-temperature fitting curve equation is:

$$\Delta\alpha = kT + b$$; and

in the Step (3), the temperature demodulation equation introducing the fitting attenuation difference is:

$$T_l = \{\frac{k_B}{h\Delta v}[\ln\frac{I(T_l)}{I(T_{l0})} - l\Delta\alpha_l + l_0\Delta\alpha_{l0}] + \frac{1}{T_{l0}}\}^{-1},$$

wherein ϕ_{st} is a Stokes light flux; ϕ_{as} is an anti-Stokes light flux; l is a distance of a certain measuring point on the optical fiber; L is a total length of a temperature measuring optical fiber; C is a constant including a detection efficiency of the detector, a relative Raman gain and the like; K_B is a Boltzmann constant; h is a Planck constant; Δv is a Raman frequency shift; α_{st} is the Stokes light attenuation coefficient; α_{as} is the anti-Stokes light attenuation coefficient; T is the measured temperature value; and k and b are multinomial coefficients of the fitting curve.

Preferably, in the Step (4), the relationship equation between the Stokes light flux and the Rayleigh noise is:

$$\phi_{st}(l) = \phi_{tst}(l) + \phi_{rst},$$

and the relationship equation between the anti-Stokes light flux and the Rayleigh noise is:

$$\phi_{as}(l) = \phi_{tas}(l) + \phi_{ras}$$; and

in the Step (6), the final temperature demodulation equation introducing the fitting attenuation difference and further eliminating the Rayleigh noise is:

$$T_l = \{\frac{k_B}{h\Delta v}[\ln\left(\frac{\phi_{st}(l) - \phi_{rst}}{\phi_{as}(l) - \phi_{ras}} \Big/ \frac{\phi_{st}(l_0) - \phi_{rst}}{\phi_{as}(l_0) - \phi_{ras}}\right) - l\Delta\alpha_l + l_0\Delta\alpha_{l0}] + \frac{1}{T_{l0}}\}^{-1},$$

wherein ϕ_{rst} is the Rayleigh noise in the Stokes light, and ϕ_{ras} is the Rayleigh noise in the anti-Stokes light.

Compared with the prior art, the temperature self-correction method has the beneficial effects that:

in the invention, the Stokes light and anti-Stokes light attenuation coefficient difference equation is obtained through the temperature demodulation principle; the attenuation coefficient difference-temperature fitting curve equation is obtained through the fitting curve; the temperature demodulation equation is obtained through the fitting curve equation and the ratio of the light fluxes; after demodulation, primary correction of the temperature is realized; then, the Rayleigh noise is solved by combining with the relationship between the Stokes light and anti-Stokes light signals and the Rayleigh noise; a corrected temperature demodulation formula is further obtained; and re-correction is realized after demodulation. Compared with a conventional method for eliminating the Rayleigh noise, the temperature self-correction method has the advantages that a temperature correction amount is improved; the precise measurement of the temperature is realized; an error problem caused by processing by regarding that Stokes light and anti-Stokes light attenuation coefficients are approximately equal is solved; and the requirement of precise detection of the temperature in a goaf and an adjacent old goaf of a coal mine is met.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is flow diagram of a temperature self-correction method by using a fitting attenuation difference in a distributed optical fiber Raman temperature measuring system;

FIG. 2 is a device logical connection diagram of the temperature self-correction method by using the fitting attenuation difference in the distributed optical fiber Raman temperature measuring system;

FIG. 3 is an attenuation difference fitting curve diagram of the temperature self-correction method by using the fitting attenuation difference in the distributed optical fiber Raman temperature measuring system; and

FIG. 4 is a temperature correction diagram of the temperature self-correction method by using the fitting attenuation difference in the distributed optical fiber Raman temperature measuring system.

In the drawings, each reference number represents following parts:

1. industrial control computer, 2. high-speed pulse light source, 3. 1*3 Raman wavelength division multiplexer, 4. double-channel DTS special APD module, 5. high-speed data acquisition card, 6. sensing optical fiber, 7. constant-temperature water bath box, 8. optical fiber section I, and 9. optical fiber section II.

DETAILED DESCRIPTION

The following further explains and describes the invention through specific embodiments.

The invention provides a temperature self-correction method by using a fitting attenuation difference in a distributed optical fiber Raman temperature measuring system. As shown in FIG.1-FIG.4, the temperature self-correction method by using the fitting attenuation difference in the distributed optical fiber Raman temperature measuring system is provided. The temperature correction method comprises the following steps that:

Step (1): a single-mode optical fiber with a total length being L is taken to be used as a sensing optical fiber 6; an optical fiber section I 8 and an optical fiber section II 9 with the same length on the sensing optical fiber 6 are put into a thermostat 7, a distance from a center point of the optical fiber section I 8 to a head end of the sensing optical fiber 6 is identical to a distance from a center point of the optical fiber section II 9 to a tail end of the sensing optical fiber 6, and other parts of the sensing optical fiber 6 are put in a room temperature environment; a temperature control range of the thermostat 7 is set; a temperature is sequentially increased from a minimum value of the temperature control range to a maximum value of the temperature control range according to the same temperature interval; and corresponding output signal values after each time of temperature change are measured by the distributed optical fiber Raman temperature measuring system;

Step (2): according to a ratio of a Stokes light flux to an anti-Stokes light flux in the optical fiber section I 8 and the optical fiber section II 9, a Stokes light and anti-Stokes light attenuation coefficient difference equation is obtained; according to the output signal values and the attenuation difference equation, a relationship diagram between an attenuation difference and a temperature is obtained; and after fitting, an attenuation difference-temperature fitting curve equation is obtained;

Step (3): according to the ratio of the Stokes light flux to the anti-Stokes light flux and the attenuation difference-temperature fitting curve equation, a temperature demodulation equation introducing a fitting attenuation difference can be obtained, and measured temperature values of the two optical fiber sections are obtained through the equation;

Step (4): located environments of the optical fiber section I 8 and the optical fiber section II 9 are identical, so that Rayleigh noise attenuation coefficient change caused by environment change is avoided; after parameters of a pulse light source, a located environment of a detector and a type of the optical fiber are determined, Rayleigh noise in Stokes light and anti-Stokes light can be regarded as a constant value, so that a relationship equation between the Stokes light flux and the Rayleigh noise, and a relationship equation between the anti-Stokes light flux and the Rayleigh noise are obtained;

Step (5): according to positions of the optical fiber section I 8 and the optical fiber section II 9, three groups of data in the output signal values, and a demodulated temperature value, through the temperature demodulation equation introducing the fitting attenuation difference and the relationship equations between the light fluxes and the Rayleigh noise, a Rayleigh noise value is obtained; and

Step (6): according to the temperature demodulation equation introducing the fitting attenuation difference and the relationship equation between the light fluxes and the Rayleigh noise, by combining with the Rayleigh noise value, a final temperature demodulation equation introducing the fitting attenuation difference and further eliminating the Rayleigh noise is obtained. The Stokes light and anti-Stokes light attenuation coefficient difference equation is obtained through the temperature demodulation principle; the attenuation coefficient difference-temperature fitting curve equation is obtained through the fitting curve; the temperature demodulation equation is obtained through the fitting curve equation and the ratio of the light fluxes; after demodulation, primary correction of the temperature is realized; then, the Rayleigh noise is solved by combining with the relationship between the Stokes light and anti-Stokes light signals and the Rayleigh noise; a corrected temperature demodulation formula is further obtained; and re-correction is realized after demodulation, and the goal of temperature self-correction is achieved. Compared with a conventional method for eliminating the Rayleigh noise, the temperature self-correction method has the advantages that a temperature correction amount is improved; the precise measurement of the temperature is realized; an error problem caused by processing by regarding that Stokes light and anti-Stokes light attenuation coefficients are approximately equal is solved; and the requirement of precise detection of the temperature in a goaf and an adjacent old goaf of a coal mine is met.

The ratio of the Stokes light flux to the anti-Stokes light flux in the optical fiber is:

$$I(T_l) = \frac{\varphi_{st}(l)}{\varphi_{as}(l)} = C\exp\left(\frac{h\Delta v}{k_B T_l}\right)\exp(\alpha_{st}-\alpha_{as})l$$

;

in the Step (2), the Stokes light and anti-Stokes light attenuation coefficient difference equation is:

$$\alpha_{st} - \alpha_{as} = \frac{\ln(I(T_{L-l_0}))}{\ln(I(T_{l_0}))} \Big/ (L - 2l_0)$$;

in the Step (2), the attenuation difference-temperature fitting curve equation is:

$$\Delta\alpha = kT + b$$; and

in the Step (3), the temperature demodulation equation introducing the fitting attenuation difference is:

$$T_l = \{\frac{k_B}{h\Delta v}[\ln\frac{I(T_l)}{I(T_{l_0})} - l\Delta\alpha_l + l_0\Delta\alpha_{l_0}] + \frac{1}{T_{l_0}}\}^{-1}$$,

wherein ϕ_{st} is a Stokes light flux; ϕ_{as} is an anti-Stokes light flux; l is a distance of a certain measuring point on the optical fiber; L is a total length of a temperature measuring optical fiber; C is a constant including a detection efficiency of the detector, a relative Raman gain and the like; K_B is a Boltzmann constant; h is a Planck constant; Δv is a Raman frequency shift; α_{st} is the Stokes light attenuation coefficient; α_{as} is the anti-Stokes light attenuation coefficient; T is the measured temperature value; and k and b are multinomial coefficients of the fitting curve;

in the Step (4), the relationship equation between the Stokes light flux and the Rayleigh noise is:

$$\phi_{st}(l) = \phi_{tst}(l) + \phi_{rst}$$,

and the relationship equation between the anti-Stokes light flux and the Rayleigh noise is:

$$\phi_{as}(l) = \phi_{tas}(l) + \phi_{ras}$$; and

in the Step (6), the final temperature demodulation equation introducing the fitting attenuation difference and further eliminating the Rayleigh noise is:

$$T_l = \{\frac{k_B}{h\Delta v}[\ln\left(\frac{\phi_{st}(l) - \phi_{rst}}{\phi_{as}(l) - \phi_{ras}} \Big/ \frac{\phi_{st}(l_0) - \phi_{rst}}{\phi_{as}(l_0) - \phi_{ras}}\right) - l\Delta\alpha_l + l_0\Delta\alpha_{l_0}] + \frac{1}{T_{l_0}}\}^{-1}$$,

wherein ϕ_{rst} is the Rayleigh noise in the Stokes light, and ϕ_{ras} is the Rayleigh noise in the anti-Stokes light.

In a use process, an industrial control computer controls a high-speed pulse light source 2 through a serial port. Pulse light output by the high-speed pulse light source 2 is injected into the sensing optical fiber 6 through a wavelength division multiplexing coupling wave filtering module. Through the optical fiber section I and the optical fiber section II put into the thermostat 7, various weak backscattering light is generated in the sensing optical fiber 6. After the separation by the wavelength division multiplexing coupling wave filtering module of a 1×3 Raman wavelength division multiplexer 3, temperature-sensitive anti-Stokes Raman scattering light and temperature-insensitive Stokes Raman scattering light are obtained. A double-channel DTS special APD module 4 converts two kinds of received weak scattering light signals into electric signals and amplifies the electric signals. When sending out the pulse light, the high-speed pulse light source 2 triggers a high-speed data acquisition card 5. The high-speed data acquisition card 5 starts to collect signals output by the double-channel DTS special APD module 4, and then transmits the two paths of collected electric signals to the industrial control computer 1 for temperature demodulation operation.

Based on the above, according to the embodiment of the invention, the Stokes light and anti-Stokes light attenuation coefficient difference equation is obtained through the temperature demodulation principle; the attenuation coefficient difference-temperature fitting curve equation is obtained through the fitting curve; the temperature demodulation equation is obtained through the fitting curve equation and the ratio of the light fluxes; after demodulation, the primary correction of the temperature is realized; then, the Rayleigh noise is solved by combining with the relationship between the Stokes light and anti-Stokes light signals and the Rayleigh noise; the corrected temperature demodulation formula is further obtained; and re-correction is realized after demodulation. Compared with the conventional method for eliminating the Rayleigh noise, the temperature self-correction method has the advantages that the temperature correction amount is improved; the precise measurement of the temperature is realized; the error problem caused by processing by regarding that the Stokes light and anti-Stokes light attenuation coefficients are approximately equal is solved; the requirement of precise detection of the temperature in the goaf and the adjacent old goaf of the coal mine is met; and the error problem caused by processing by regarding that the two attenuation coefficients are approximately equal is solved.

The above scheme is subjected to feasibility verification by combining with concrete experiment data hereafter, and detail descriptions are shown as follows:

According to a verification experiment of the invention, the optical fiber section I and the optical fiber section II, respectively having distances being 25 m from the head end and the tail end, on the temperature measuring optical fiber 6 with the total length being 170 m are used and are put into the thermostat 7; the thermostat is used for controlling the temperature to be sequentially raised to obtain the output signal values; the attenuation coefficient difference is obtained through demodulation; and after fitting, the attenuation difference-temperature fitting curve equation is obtained:

$$\Delta\alpha(T)=7.8508\times10^{-7}T-1.3532\times10^{-5}.$$

The temperature obtained through demodulation by using the temperature demodulation formula introducing the fitting attenuation difference is shown as a curve b in FIG. 4. A curve a is a temperature curve obtained through demodulation by processing by regarding that the attenuation differences are approximately equal. The solved Rayleigh noise ϕ_{rst} is 62.5517, and the solved Rayleigh noise ϕ_{ras} is 28.7723. A final temperature curve obtained through demodulation after fitting attenuation difference introduction and further Rayleigh noise elimination is shown as a curve d in the FIG. 4. A curve c is a temperature curve obtained through demodulation after Rayleigh noise elimination and after the processing by regarding that the attenuation differences are approximately equal.

As shown in the FIG. 4, we can see that compared with a condition of not introducing the fitting attenuation difference, the condition of introducing the fitting attenuation difference realizes the obvious temperature rise; and compared with a condition of eliminating the Rayleigh noise without fitting attenuation difference introduction, the condition of eliminating Rayleigh noise after fitting attenuation difference introduction realizes the temperature more similar to a real value, and the measured temperature is corrected. The feasibility of the method is verified.

It is apparent to a person skilled in the art that the invention is not limited to details in the foregoing exemplary embodiments, and the invention can be implemented in another specific form without departing from the spirit or basic features of the invention. Therefore, the embodiments should be considered to be exemplary in all respects and not limitative. The scope of the invention is not defined by the foregoing description but by the appended claims. The invention is intended to include all the variations that are equivalent in significance and scope to the claims. No reference numerals in the claims should be considered as limitations to the related claims.

In addition, it should be understood that, although this specification is described according to each implementation, each implementation may not include only one independent technical solution. The description manner of this specification is merely for clarity. This specification should be considered as a whole by a person skilled in the art, and the technical solution in each embodiment may also be properly combined, to form other implementations that can be understood by the person skilled in the art.

CONCLUSIES

1. Een temperatuur-zelfcorrectiemethode voor het aanpassen van het dempingsverschil via een Raman-temperatuurmeetsysteem met gedistribueerde optische vezel, met als kenmerk dat de temperatuurcorrectiemethode de volgende stappen omvat:

Stap 1: Neem een single-mode vezel met een totale lengte van L als de waarnemende vezel. Plaats het vezelsegment I en het vezelsegment II, van dezelfde lengte, op de waarnemende vezel in een thermostaat, waarbij de afstand tussen het middelpunt van het vezelsegment I en het voorste uiteinde van de waarnemende vezel en de afstand tussen het middelpunt van het vezelsegment II en het uiteinde van de waarnemende vezel gelijk zijn en de andere delen van de waarnemende vezel worden op kamertemperatuur geplaatst. Stel vervolgens het temperatuurregelbereik van de thermostaat in en verhoog de minimumwaarde van het temperatuurregelbereik tot de maximale waarde bij hetzelfde temperatuurinterval en meet de overeenkomstige waarde van het uitgangssignaal na elke temperatuurverandering door het Raman-temperatuurmeetsysteem met gedistribueerde optische vezel;

Stap 2: Verkrijg de dempingcoëfficiëntverschilvergelijking van het Stokes-licht en het anti-Stokes-licht volgens de lichtstroomverhouding van het Stokes-licht en het anti-Stokes-licht in vezelsegment I en vezelsegment II en verkrijg de relatie tussen het dempingsverschil en de temperatuur volgens de waarde van het uitgangssignaal en de dempingsverschilvergelijking en verkrijg de gepaste curververgelijking van het dempingsverschil met betrekking tot de temperatuur na het aanpassen;

Stap 3: Volgens de gepaste curververgelijking van de lichtstroomverhouding van het Stokes-licht en het anti-Stokes-licht en het dempingsverschil, met betrekking tot temperatuur, kan een temperatuurdemodulatievergelijking worden verkregen door een passend dempingsverschil in te voeren en kan de temperatuurwaarde gemeten door twee vezelsegmenten worden verkregen door deze vergelijking;

Stap 4: Het vezelsegment I en het vezelsegment II bevinden zich in dezelfde omgeving, wat de verandering van de verzwakkingscoëfficiënt van Rayleigh-ruis veroorzaakt door veranderingen in de omgeving vermijdt en, nadat de parameters van de pulslichtbron, de omgeving waarin de detector zich bevindt en het type optische vezel zijn bepaald, kan de Rayleigh-ruis in het Stokes-licht en het anti-Stokes-licht worden beschouwd als een vaste waarde, zodat de relatievergelijking tussen de Stokes-lichtstroom en anti-Stokes-lichtstroom en Rayleigh-ruis wordt verkregen;

Stap 5: Volgens de posities van vezelsegment I en vezelsegment II, drie gegevensreeksen in de uitgangssignaalwaarde en de gedemoduleerde temperatuurwaarde, door een temperatuurdemodulatievergelijking te introduceren die past bij het dempingsverschil en de relationele vergelijking tussen de lichtstroom en de Rayleigh-ruis, kan de Rayleigh-ruiswaarde worden verkregen;

Stap 6: Volgens de temperatuurdemodulatievergelijking, die het gepaste dempingsverschil introduceert en de relationele vergelijking tussen de lichtstroom en de Rayleigh-ruis, gecombineerd met de Rayleigh-ruiswaarde, kan de uiteindelijke temperatuurdemodulatievergelijking die het gepaste dempingsverschil introduceert en verder Rayleigh-ruis elimineert worden verkregen en door deze demodulatievergelijking kan de temperatuur-zelfcorrectie worden voltooid.

2. Een temperatuur-zelfcorrectiemethode voor het aanpassen van het dempingsverschil via een Raman-temperatuurmeetsysteem met gedistribueerde optische vezel volgens conclusie 1, met als kenmerk dat de lichtstroomverhouding van het Stokes-licht en het anti-Stokes-licht in vezelsegment I en vezelsegment II de volgende is:

$$I(T_l)=\frac{\phi_{st}(l)}{\phi_{as}(l)}=C\exp\left(\frac{h\Delta v}{k_B T_l}\right)\exp(\alpha_{st}-\alpha_{as})l \quad ;$$

en de dempingcoëfficiëntverschilvergelijking van het Stokes-licht en het anti-Stokes-licht in stap 2 de volgende is:

$$\alpha_{st}-\alpha_{as}=\frac{\ln(I(T_{L-l_0}))}{\ln(I(T_{l_0}))}\bigg/(L-2l_0) \quad ;$$

en de gepaste curververgelijking van het dempingsverschil met betrekking tot de temperatuur in stap 2 de volgende is:

$$\Delta\alpha=kT+b \quad ;$$

en de temperatuurdemodulatievergelijking door een passend dempingsverschil in te voeren in stap 3 de volgende is:

$$T_l=\left\{\frac{k_B}{h\Delta v}\left[\ln\frac{I(T_l)}{I(T_{l_0})}-l\Delta\alpha_l+l_0\Delta\alpha_{l_0}\right]+\frac{1}{T_{l_0}}\right\}^{-1} \quad ;$$

waarbij ϕ_{st} de Stokes-lichtstroom is, ϕ_{as} de anti-Stokes-lichtstroom is, l 1 de afstand is van een meetpunt op de vezel, L de totale lengte van de temperatuurmeetvezel is en C een constante is, inclusief de detectie-efficiëntie en relatieve Raman-versterking van de detector, K_B de Boltzmann-constante is, h de Planck-constante is, Δv de Ramanfrequentieverschuiving is, α_{st} de verzwakkingscoëfficiënt van Stokes licht is, α_{as} de verzwakkingscoëfficiënt van anti-Stokes licht is, T de gemeten temperatuurwaarde is en k en b polynoomcoëfficiënten zijn van de gepaste curve.

3. Een temperatuur-zelfcorrectiemethode voor het aanpassen van het dempingsverschil via een Raman-temperatuurmeetsysteem met gedistribueerde optische vezel volgens conclusie 1, met als kenmerk dat de relatievergelijking tussen de Stokes-lichtstroom en de anti-Stokes-lichtstroom en Rayleigh-ruis in stap 4 de volgende is:

$$\phi_{st}(l) = \phi_{tst}(l) + \phi_{rst},$$

$$\phi_{as}(l) = \phi_{tas}(l) + \phi_{ras};$$

en de uiteindelijke temperatuurdemodulatievergelijking die het gepaste dempingsverschil introduceert en verder Rayleigh-ruis elimineert in stap 6 de volgende is:

$$T_l = \{\frac{k_B}{h\Delta v}[\ln\left(\frac{\phi_{st}(l)-\phi_{rst}}{\phi_{as}(l)-\phi_{ras}} \Big/ \frac{\phi_{st}(l_0)-\phi_{rst}}{\phi_{as}(l_0)-\phi_{ras}}\right) - l\Delta\alpha_l + l_0\Delta\alpha_{l_0}] + \frac{1}{T_{l_0}}\}^{-1};$$

waarbij ϕ_{rst} de Rayleigh-ruis in het Stokes-licht is en ϕ_{ras} de Rayleigh-ruis in het anti-Stokes-licht is.

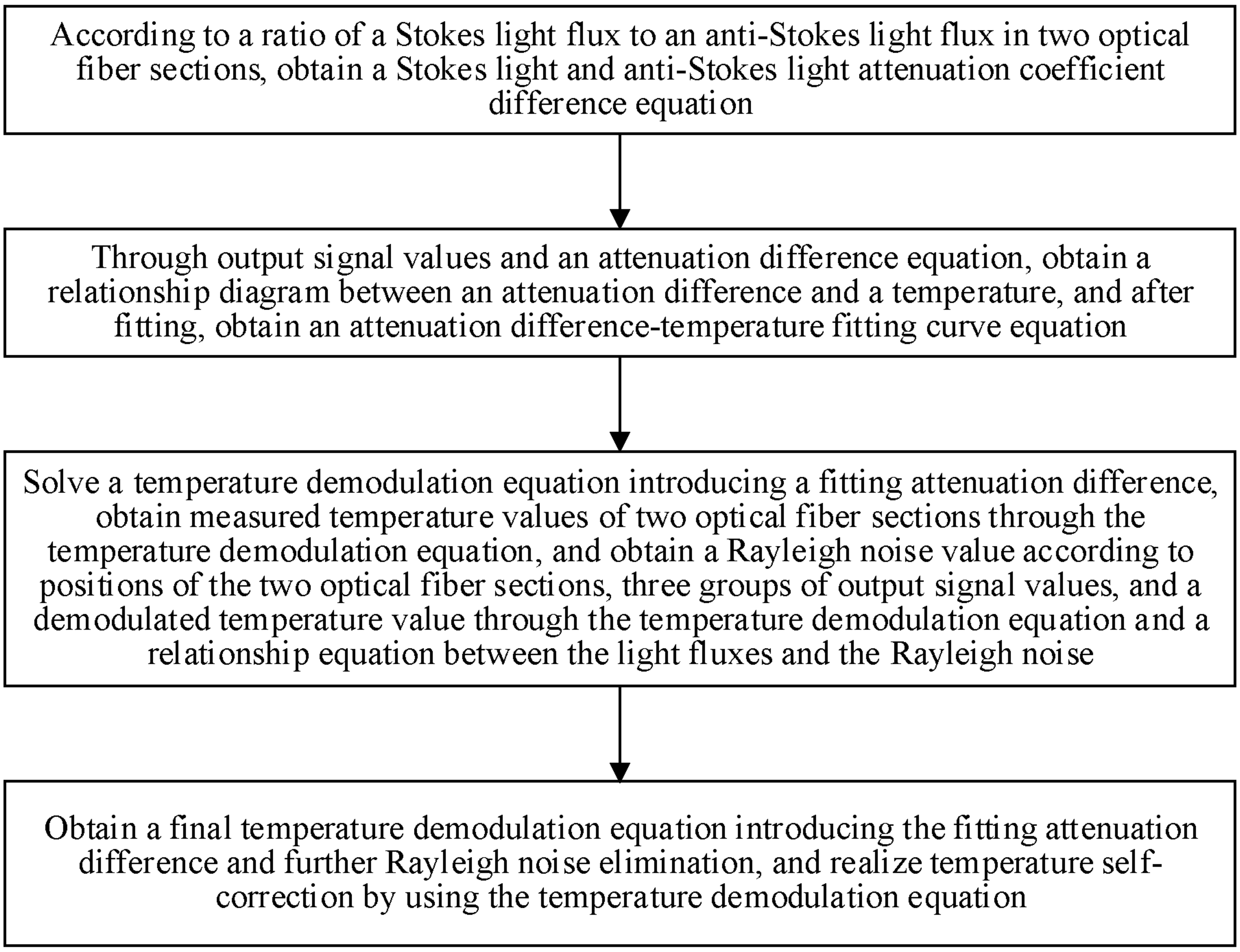

According to a ratio of a Stokes light flux to an anti-Stokes light flux in two optical fiber sections, obtain a Stokes light and anti-Stokes light attenuation coefficient difference equation
Through output signal values and an attenuation difference equation, obtain a relationship diagram between an attenuation difference and a temperature, and after fitting, obtain an attenuation difference-temperature fitting curve equation
Solve a temperature demodulation equation introducing a fitting attenuation difference, obtain measured temperature values of two optical fiber sections through the temperature demodulation equation, and obtain a Rayleigh noise value according to positions of the two optical fiber sections, three groups of output signal values, and a demodulated temperature value through the temperature demodulation equation and a relationship equation between the light fluxes and the Rayleigh noise
Obtain a final temperature demodulation equation introducing the fitting attenuation difference and further Rayleigh noise elimination, and realize temperature self-correction by using the temperature demodulation equation

FIG. 1

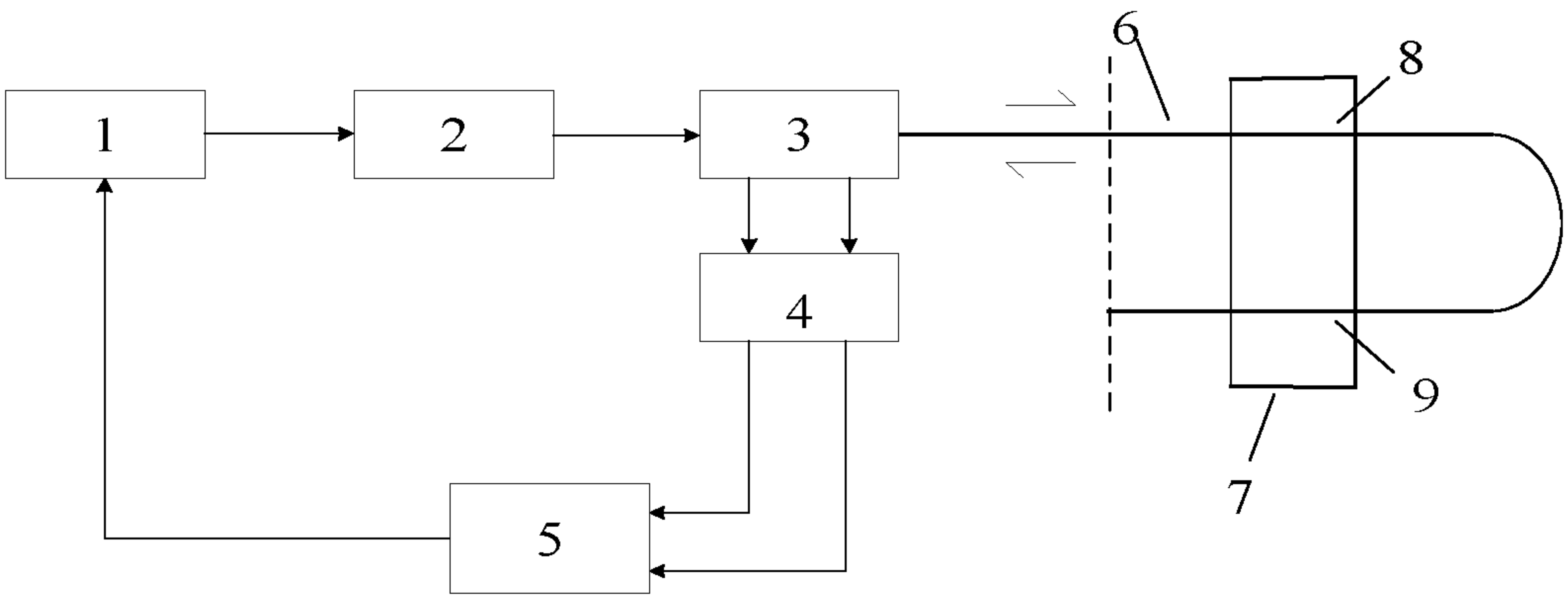
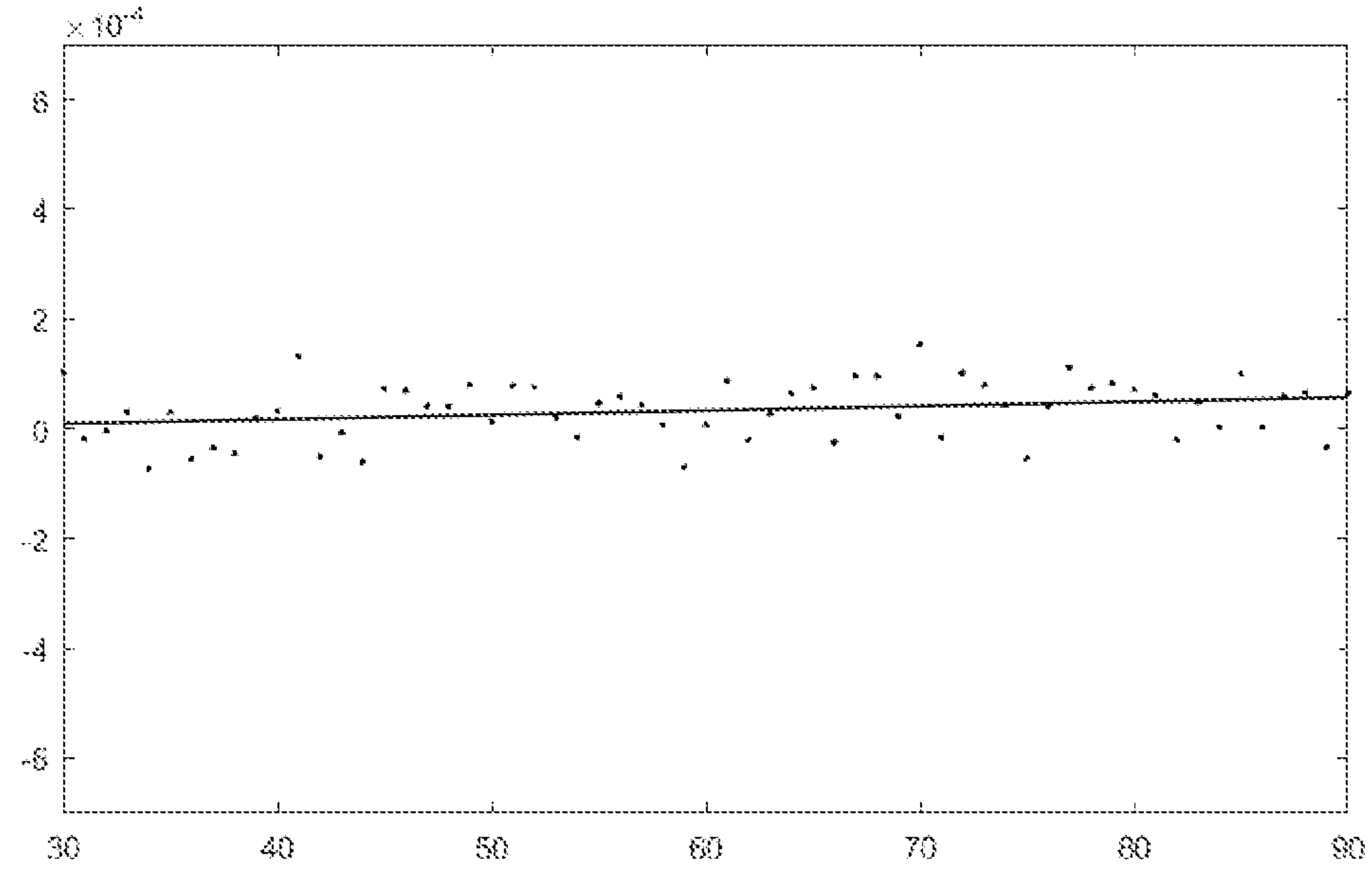
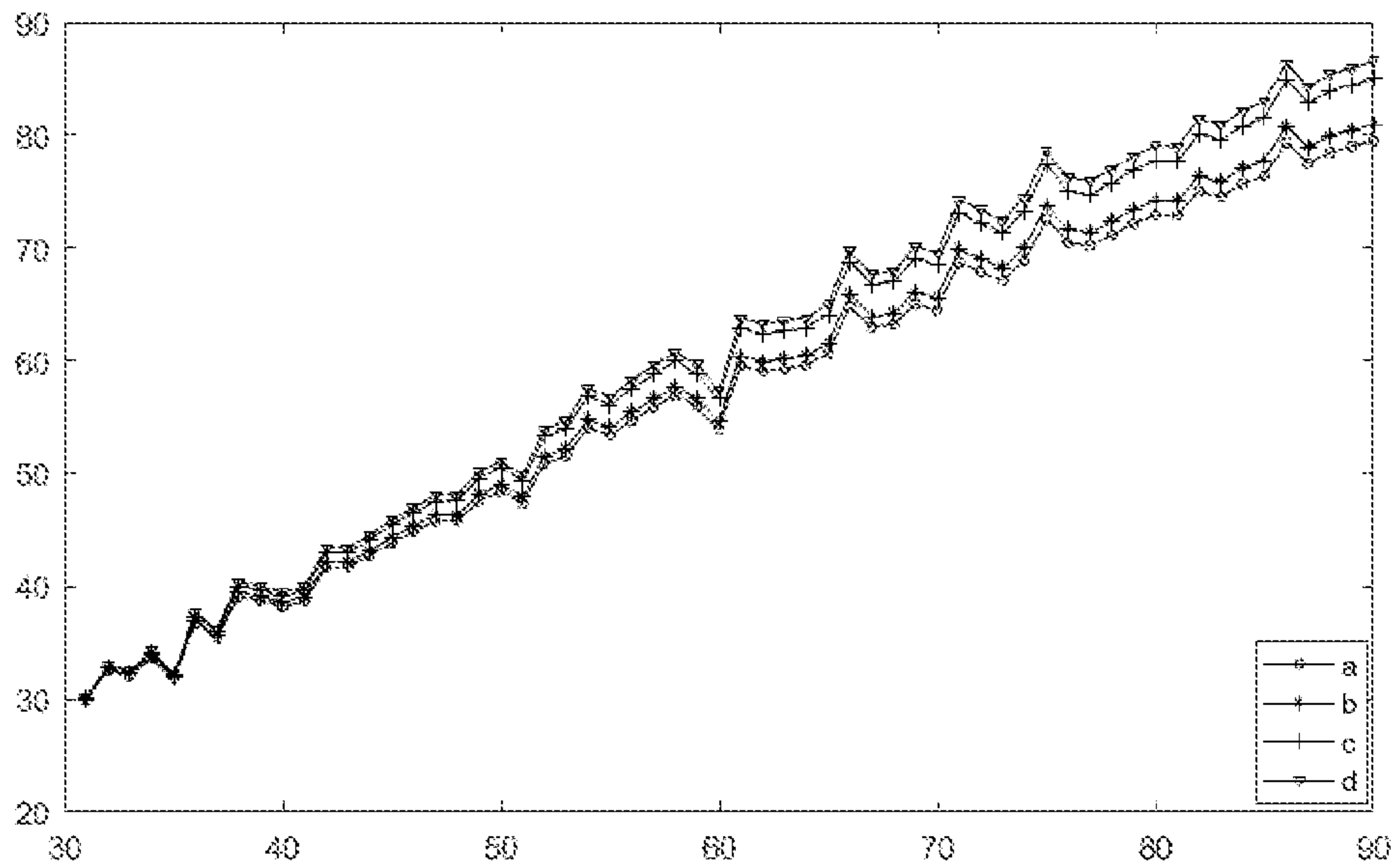

1
2
3
4
5
6
7
8
9

FIG. 2



× 10⁻⁴
6
4
2
0
-2
-4
-6
30
40
50
60
70
80
90

FIG. 3



90
80
70
60
50
40
30
20
30
40
50
60
70
80
90
a
b
c
d

FIG. 4

Rijksdienst voor Ondernemend Nederland

OCTROOIAANVRAAG NR.:
NO 140645
NL 2024922

ONDERZOEKSRAPPORT

BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK

RELEVANTE LITERATUUR

Categorie[1]	Literatuur met, voor zover nodig, aanduiding van speciaal van belang zijnde tekstgedeelten of figuren.	Van belang voor conclusie(s) nr:	Classificatie (IPC)
A	CN 109 580 033 A (UNIV CHINA THREE GORGES CTGU) 5 april 2019 (2019-04-05) * het gehele document * -----	1-3	INV. G01K11/32 G01K15/00
A	NICK VAN DE GIESEN ET AL: "Double-Ended Calibration of Fiber-Optic Raman Spectra Distributed Temperature Sensing Data", SENSORS, deel 12, nr. 12, 27 april 2012 (2012-04-27), bladzijden 5471-5485, XP055255217, DOI: 10.3390/s120505471 * alinea [0003]; figuur 1 * -----	1-3	
A	US 8 496 376 B2 (LEE CHUNG [US]; SUH KWANG [US]; SENSORTRAN INC [US]) 30 juli 2013 (2013-07-30) * samenvatting; figuren 2,3 * -----	1-3	
			Onderzochte gebieden van de techniek
			G01K

Indien gewijzigde conclusies zijn ingediend, heeft dit rapport betrekking op de conclusies ingediend op:

Plaats van onderzoek:	Datum waarop het onderzoek werd voltooid:	Bevoegd ambtenaar:
's-Gravenhage	22 juli 2020	de Bakker, Michiel

[1] CATEGORIE VAN DE VERMELDE LITERATUUR

X: de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur
Y: de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht
A: niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft
O: niet-schriftelijke stand van de techniek
P: tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur
T: na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvraage, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding
E: eerdere octrooi(aanvrage), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven
D: in de octrooiaanvraag vermeld
L: om andere redenen vermelde literatuur
&: lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

EOB FORM 02.83 (P0414B)

AANHANGSEL BEHORENDE BIJ HET RAPPORT BETREFFENDE HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK, UITGEVOERD IN DE OCTROOIAANVRAGE NR.

NO 140645
NL 2024922

Het aanhangsel bevat een opgave van elders gepubliceerde octrooiaanvragen of octrooien (zogenaamde leden van dezelfde octrooifamilie), die overeenkomen met octrooischriften genoemd in het rapport.
De opgave is samengesteld aan de hand van gegevens uit het computerbestand van het Europees Octrooibureau per
De juistheid en volledigheid van deze opgave wordt noch door het Europees Octrooibureau, noch door het Bureau voor de Industriële eigendom gegarandeerd; de gegevens worden verstrekt voor informatiedoeleinden.

22-07-2020

In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
CN 109580033 A	05-04-2019	GEEN	
US 8496376 B2	30-07-2013	CA 2692804 A1	22-01-2009
		CN 101743460 A	16-06-2010
		EP 2167928 A1	31-03-2010
		US 2010128756 A1	27-05-2010
		WO 2009011766 A1	22-01-2009

SCHRIFTELIJKE OPINIE

DOSSIER NUMMER	INDIENINGSDATUM	VOORRANGSDATUM	AANVRAAGNUMMER
NO140645	17.02.2020	08.07.2019	NL2024922

CLASSIFICATIE
INV. G01K11/32 G01K15/00

AANVRAGER
Anhui University of Science and Technology

Deze schriftelijke opinie bevat een toelichting op de volgende onderdelen:

- ☒ Onderdeel I Basis van de schriftelijke opinie
- ☐ Onderdeel II Voorrang
- ☐ Onderdeel III Vaststelling nieuwheid, inventiviteit en industriële toepasbaarheid niet mogelijk
- ☐ Onderdeel IV De aanvraag heeft betrekking op meer dan één uitvinding
- ☒ Onderdeel V Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid
- ☐ Onderdeel VI Andere geciteerde documenten
- ☐ Onderdeel VII Overige gebreken
- ☒ Onderdeel VIII Overige opmerkingen

DE BEVOEGDE AMBTENAAR

de Bakker, Michiel

Aanvraag nr.:

SCHRIFTELIJKE OPINIE

NL2024922

Onderdeel I Basis van de Schriftelijke Opinie

1. Deze schriftelijke opinie is opgesteld op basis van de meest recente conclusies ingediend voor aanvang van het onderzoek.

2. Met betrekking tot **nucleotide en/of aminozuur sequenties** die genoemd worden in de aanvraag en relevant zijn voor de uitvinding zoals beschreven in de conclusies, is dit onderzoek gedaan op basis van:

   a. type materiaal:

   ☐ sequentie opsomming

   ☐ tabel met betrekking tot de sequentie lijst

   b. vorm van het materiaal:

   ☐ op papier

   ☐ in elektronische vorm

   c. moment van indiening/aanlevering:

   ☐ opgenomen in de aanvraag zoals ingediend

   ☐ samen met de aanvraag elektronisch ingediend

   ☐ later aangeleverd voor het onderzoek

3. ☐ In geval er meer dan één versie of kopie van een sequentie opsomming of tabel met betrekking op een sequentie is ingediend of aangeleverd, zijn de benodigde verklaringen ingediend dat de informatie in de latere of additionele kopieën identiek is aan de aanvraag zoals ingediend of niet meer informatie bevatten dan de aanvraag zoals oorspronkelijk werd ingediend.

4. Overige opmerkingen:

Aanvraag nr.:

SCHRIFTELIJKE OPINIE

NL2024922

Onderdeel V Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid

1. Verklaring

Nieuwheid	Ja:	Conclusies 1-3
	Nee:	Conclusies
Inventiviteit	Ja:	Conclusies 1-3
	Nee:	Conclusies
Industriële toepasbaarheid	Ja:	Conclusies 1-3
	Nee:	Conclusies

2. Citaties en toelichting:

Zie aparte bladzijde

Onderdeel VIII Overige opmerkingen

De volgende opmerkingen met betrekking tot de duidelijkheid van de conclusies, beschrijving, en figuren, of met betrekking tot de vraag of de conclusies nawerkbaar zijn, worden gemaakt:

Zie aparte bladzijde

Re Item VIII

Certain observations on the application (Clarity)

1 Claim 1 is not clear.

1.1 Step 1 in the method of claim 1 refers to the output signal ("het uitgangssignaal"). This features lacks a proper antecedent; it is not clear what the output signal is and where and how it is measured.

1.2 The formulation in steps 3-6 is such that it is not clear wether the steps are actually performed. Step 3, e.g., reads: "Volgens de gepaste curvevergelijking [...] kan een temperatuurdemodulatievergelijking worden verkregen". In the inventive step analysis it is assumed that the intention of step 3 is such as to define that the temperature demodulation equation is (and not merely can be) obtained. The same applies to all definitions in steps 3-6.

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Documents

2 Reference is made to the following documents:

D1 CN 109 580 033 A (UNIV CHINA THREE GORGES) 5 april 2019

D2 NICK VAN DE GIESEN ET AL: "Double-Ended Calibration of Fiber-Optic Raman Spectra Distributed Temperature Sensing Data", SENSORS, deel 12, nr. 12, 27 april 2012, pp. 5471-5485

D3 US 8 496 376 B2 (SENSORTRAN INC) 30 juli 2013

Inventive Step

3 The present application meets the criteria of patentability, because the subject-matter of claims 1-3 involves an inventive step.

3.1 Document D1 is regarded as being the prior art closest to the subject-matter of claim 1, and discloses:

Een temperatuur-zelfcorrectiemethode voor het aanpassen van het dempingsverschil via een Raman-temperatuurmeetsysteem met gedistribueerde optische vezel, met als kenmerk dat de temperatuurcorrectiemethode de volgende stappen omvat:

Stap 1: Neem een single-mode vezel met een totale lengte van L als de waarnemende vezel (see fig.2). Plaats het vezelsegment I (point 1 in fig.2) en het vezelsegment II (point 2 in fig.2), van dezelfde lengte, op de waarnemende vezel in een thermostaat, waarbij de afstand tussen het middelpunt van het vezelsegment I en het voorste uiteinde van de waarnemende vezel en de afstand tussen het middelpunt van het vezelsegment II en het uiteinde van de waarnemende vezel gelijk zijn (this follows from the setup of fig.2) en de andere delen van de waarnemende vezel worden op kamertemperatuur geplaatst. Stel vervolgens het temperatuurregelbereik van de thermostaat in en verhoog de minimumwaarde van het temperatuurregelbereik tot de maximale waarde bij hetzelfde temperatuurinterval en meet de overeenkomstige waarde van het uitgangssignaal na elke temperatuurverandering door het Raman-temperatuurmeetsysteem met gedistribueerde optische vezel (par.[88]);

The subject-matter of claim 1 therefore differs from the method of D1 in that steps 2-6 are carried out and is therefore new.

3.2 As in the invention, document D1 is concerned with correcting fiber-optic Raman-based distributed temperature measurements for the difference in attenuation coefficient α between the Stokes (α_{st}) and the anti-Stokes (α_{as}) back-scattering signals. In D1, this correction is based on a reference position L_0 where a corresponding reference temperature T_0 is measured. Because of the back-folded constitution of the fiber it is possible to have two reference points at the same temperature. This way a value for Δα (= α_{st} - α_{as}) is obtained, where it is assumed that the two attenuation coefficients (and hence their difference Δα) is constant over the length of the fiber. The determined value for Δα is used in the temperature demodulation equation. The thermostat at different consecutive temperatures in D1 (par.[88]) is used for testing the accuracy/effectiveness of the correction; the actual correction is based on a single reference temperature value.

According to the invention, a function is estimated of Δα vs T and it is this function that is used for obtaining the temperature demodulation equation.

The problem solved can therefore be regarded as providing an alternative manner of correcting for the difference in attenuation coefficient between the Stokes light and the anti Stokes light (due to their difference in wavelengths).

3.3 The solution to this problem proposed in claim 1 of the present application is considered as involving an inventive step for the following reasons:

There is nothing in D1 that points the skilled person in the direction of obtaining a $\Delta\alpha$ vs T equation. The solution can further not be found in the further prior art documents D2 and D3, which both describe other solutions to deal with the problem of attenuation coefficient difference.

3.4 Claims 2 and 3 are dependent on claim 1 and as such also meet the requirements of novelty and inventive step.