1887 Michelson and Morley experiment: a new analysis with computer assistance

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The captioned experiment was long in argument for interpreting its small measurement compared to the expected result. To investigate those comparing numbers, this paper reports a method of simulating the experiment, in which all the trial steps can be performed on a computer, except for the visually inspected fringes replaced by the fringe positioning calculations, which show that: 1) the derived light path difference never exists in the actual mirror adjustments; 2) rotating the apparatus not only changes the path difference between the two arms but also splits the two coincident light beams; 3) adjustments performed with the instrument differently oriented yield fringes in different variation curves; and 4) alternatively used light sources occasionally deform the fringes. The combination of the last three causes: a) original observations shrunk in their average treatment; and b) irregular or turbid fringe pattern when rotating the instrument. Although the first consequence implies a positive rectification to the current experimental interpretation, to prevent the second mentioned deficiency, the experiment chose not to observe the fringes on the screen directly, but to measure the distance in which the movable mirror was manually adjusted to restore fringe consistency. Such repeated operational disturbances to the working apparatus resulted in uncertainty and inaccuracy of the original measurements. Therefore, this paper suggests that the Michelson-Morley experiment should be concluded as delivering no result instead of reporting a null result.

Michelson-Morley experiment | detection of ether | simulation of experiment

The 1887 Michelson-Morley (M-M) experiment was long in dispute for interpreting its small measurement as a "null result." The Pro's opinions agreed with this by reasoning that the fringes measured were too small compared to the expected, while some of the Con's views dissented it by emphasizing the ether's periodical effect being already revealed from the averaged fringes despite their smallness[1]. Though the two opinions went opposite as "small means null" and "small but periodical, " they shared the same ground for the departure — "the effect of ether is detected always small, " which was not just initially quoted from the captioned experiment, but was repeatedly confirmed by other similar detections followed [2] [3].

However, it is logically possible for the fringe variation to be so small that it can be easily favored as null? If it is, the "null result" implies denying the Earth's motion around the sun at a known speed of 30 km/s (average) that is merely to the solar system alone, unless the luminiferous ether behaves in a dynamic manner that it can be dragged by moving objects. Now suppose it could, the small fringe measurement would be well explained, but the confused relations between the ether, space and objects have since been created: First, to what extent is the luminiferous ether entirely dragged by a moving object? And second, in what range is the luminiferous ether dragged as the cuts of pieces by different members of a celestial group, such as the sun, planets and planetary satellites travelling together in their miscellaneous orbital mixtures?

In view that the M-M experiment holds tremendous significance for fundamental physics, it is necessary to explore new approaches to investigate the origin of those comparison numbers. This work attempts to simulate the experiment on a computer, as all the trial steps can be performed with the software Auto CAD (Autodesk Computer-Aided Design) and MS Excel (Microsoft Excel) according to the optical geometrical conditions set by the experiment, such as aligning, adjusting, and rotating the instrument; defining the light paths along two arms, measuring total light path length along each arm of the apparatus, and calculating the path-length difference between the two arms and its changes after rotating the apparatus, upon which a changed fringe position in response to the instrumental rotation can be calculated.

Auto CAD has been widely used for graphic design in various industries since the late 1980s. The highest accuracies of CAD for drawing, moving and turning an object in linear and angular dimensions are 10^{-11} meters and 10^{-8} degrees respectively. Also, with CAD assistance, the light beam thickness can be narrowed to zero so that each light path between two mirrors or inside a glass panel can be properly defined according to the law of reflection or refraction of light.

Although the fringe simulation can be conducted at the highest precision of CAD, the simulation work itself is unable to help verify the experimental model of the triadic relations between the ether, light, and space. Therefore, a vague conception of those relations would confuse the understanding of the said model's principle and the assumed conditions, from which the expected fringes are obtained for comparison with the actual detections. Therefore, it is necessary to open the old topic about ether, space, and light for a brief discussion first; following which the process and results of the simulation works will be presented in detail, which are mainly the compilation of tables, illustrations, and descriptions.

Significance

If it is the ether carrying the waves of light propagating in absolute space, can it be detected on earth by using an appropriate instrument? The M-M experimental theory illustrated "yes, " but its actual detections delivered the "surprise, " This paper investigates the mystery by simulating the experiment on a computer, from which the path difference between the two arms and the splits between two coinciding beams were obtained for calculating the average fringes. The zeroed simulation results and their root reason analysis have revealed the necessity to call for re-evaluating the M-M experiment, so that the Newton's conception of absolute space can be more tested and fairly judged for the advancement of physical science.

Reserved for Publication Footnotes

Discussion

The luminiferous ether "functions" as no different from empty space. The early conception of "aether" (now "ether") could date back thousands of years ago, in which its properties were differently defined in different eras. Ancient Greek mythology assumed the aether as pure air for the breath of the gods, and medieval science presumed the ether as the fifth element of the substance (after the earth, air, water and fire) which fills the full region beyond the terrestrial sphere.

In the scientific revolution era between the 16^{th} and 17^{th} centuries, the wave theory of light and the mechanical theory of gravity assumed ether as their own media to support light propagation and gravitational transmission. They both agreed on the ether's permeation in full space but demanded the ether's properties in conflict. Thriving until the late 19^{th} century, the latter dropped out of mainstream physics, while the former, giving the medium of light a new name, "the luminiferous ether," began to prevail.

Although the conceptual definition of "ether" changed with time, one thing behind it did not change: the continuous attempt to materialize space through an analog of the fulfillment of celestial effects[1] with the transference of kinetic energy that dominates most of the dynamical exchanges on earth. Transferring kinetic energy from one body to another requires direct contact or indirect contact (via a vibrating medium). Because wave theory considers light propagating in waves, it satisfies the analogical imagination that light needs something in space to transmit its waves, like sounds travelling by air or ripples spreading in water.

However, does such analogical "likeness" really mean that the transmission of light should be identical to the wave propagation in mass, considering that the former travels in empty space while the latter relies on a medium of materials in which tangible molecules cannot be absent? Further, does the ether possess any sort of mass that, to the best of our knowledge, only pertains to physical substances?

If it does, then, regardless of how small the density of the ether's mass is, its permeation in full of the universe would gradually slow the motion of all celestial objects, leading their orbital radiuses to be smaller and smaller, thus rushing towards the dominant center of the celestial structure, meaning that all the celestial groups in the universe are in their obvious process toward their ultimate collapse. Apparently, this is not reality (the planetary speeds in our solar system do not seem slower so far) or the foreseeable future of the universe.

To mitigate this logic difficulty, there was another version of the explanation that the luminiferous ether is a special kind of material — a pure "light-bearing" substance possessing no mass at all. However, even with such an assumed property for the luminiferous ether, a simple question immediately casts doubt on why the higher skies we see at night do not look as bright as day since the sun is still shining in all those regions beyond the shadow of the earth, and the luminiferous ether is yet permeating the same from time to time. This logic flaw reflects the improbability to convince that the luminiferous ether exists as a real substance with no mass.

Nonetheless, one still argues that the luminiferous ether may exist in immaterial form. It sounds that the aforementioned logic problem has been solved, but it implies the denial of the ether's fluidity since the luminiferous ether existing in the form of nihility has no ability to mobilize in space. In other words, the luminiferous ether cannot peel off from each part of space. Because such assumed luminiferous ether has no effect on any events of mechanics, frankly, it is just a different name for space, or a redundant concept for physics, which "functions" as no different from empty space.

The absolute and relational concepts of space. There are three basic units of kilograms, seconds, and meters for measuring the three primary dimensions of mechanics — mass, time (duration), and length, which individually correspond to matter, time (passage), and space, the three fundamental elements of the universe. According to Newton's concept of absolute space and time, these three fundamental elements are independent of one another. Hence, Newton's mechanics believe that in any physical event of mechanics, the aforementioned three elements separately contribute to the mechanical result of a physical event. That is: space provides the boundless arena for objects moving in any possible direction as determined by their superposed momenta; time allows each physical event to experience its duration from inception to completion; and matter is the only performer to conduct the physical "drama" with time and space functioning as curtain (s) and stage (s).

Thus, in Newton's mechanics, it is the length, the quantitative measurement of distance, correlating with the properties of space, meaning that in any physical circumstances, it is the properties of space, not that of the luminiferous ether, jointly contributing to the consequences of a mechanical event with mass and time. Because, it is space accommodating spatial points arrayed continuously in every azimuth, which allows physical objects to stay or move in freedom, it is obvious that space is seamless, homogenous, and boundless in all directions. These are the apparent properties of space that can be easily imagined and understood. Nevertheless, however, there is an abstract domain of properties of space, which is essential to physics but difficult to recognize. That is, whether space exists as characterized by Newton's absolute concept or as advocated by Leibniz's relativistic concept. The two concepts of space were debated the longest in the history of physics to emphasize their own focus on the arguing thesis, in which the former claimed that the real nature of space is regardless of anything external other than space itself, and the latter highlighted that the practical scheme to describe any object's motion is inseparable from choosing other objects as the start of positioning points or the orienting of base lines.

It is needless to say that an established reference frame requires visible. Therefore, each working reference frame must be fixed to or oriented toward a set of objects. Since there is no physical substance truly at rest, meaning there is no frame of reference to be genuinely static, it is natural for humans to believe that the relational concept of objects in motion is universally applicable to all phenomena of motion, because humans observe any object in motion relying on the comparison between the object's motion and the reference body he has chosen.

Here, without prejudice to any point of view on the difference, we may prepare to be challenged by the following questions that someone might ask: First, can the non-direct use of space as a human's tool of reference validate the claim of the non-existence of absolute space if that is because mankind lacks the ability to perceive it? Second, should the relational concepts of motion by objects be directly extended to the transmission of various fields (thermal, gravitational and electromagnetic), because the latter is of wave-type propagation and thus should behave differently from the former due to source motion independence?

To answer these questions, especially the second one, it is necessary to widen the subject from the motion of objects to another branch of physics, where the field's transmission in space is given the main research endeavors.

[1] The effects of heat and attraction brought by thermal radiation and gravitational transmission to and from all particles of mass segregated by space.

Isotropy of true space and symmetric field's expansion in it. The most ordinary part of our daily life is seeing the motion status of an object being changed by another through physical contact. For instance, a golf ball starts to fly on a golf court because it obtains kinetic energy from a golf club strike (direct contact). The generator turbines of a hydroelectric power reservoir begin to revolve because they receive kinetic energy from the falling water running down the reservoir, which pushes the turbine blades to rotate (direct contact).

These two real-life scenarios tell us that, on a relatively microscopic scale like our terrestrials, direct contact between two objects, or indirect contact between them through a vibrating medium (an earthquake underneath the ocean could damage those far coastal buildings via the tsunami caused by it) dominates the pattern of objects' motion in change. Therefore, physical contact, either direct or indirect, is the only way for kinetic energy to be transferred from one object to another.

However, at the macroscopic level of a vast cosmic structure, celestial objects influencing each other need no direct or indirect contact. In the entire universe, there are countless celestial objects segregated by space, which does not isolate them from communication. They constantly "talk" to each other in two versions of a language — thermal radiation and gravitational transmission in order to send and take signals to and from each other for them to interact. The speed of thermal radiation is already known as finite, which is the speed of light, but the speed of gravity is yet to be identified. If it is also finite, or even the same as that of light, the force of gravity may need to consider the effects of "time delay" and "true gravitational route."

Celestial objects fulfill celestial effects by seamlessly transmitting their thermal and gravitational fields. Thermal radiation allows each particle of mass to release its domestic heat energy to prevent massive objects from self-explosion owing to their continuous heat accumulation. At the same time, internal gravity inside massive objects provides a pulling force for the body to remain at a certain volume. Therefore, domestic heat expansion and inner gravitational attraction fight themselves for the "push and pull" balance to maintain the stability of these massive objects.

To a usual celestial group, such as a star-planet-satellite system which is quite like a family with the three-generation of the parent-child-grandchild, it is imaginable that thermal radiation allows the family members to share their heat with each other, and gravitational attraction unites the whole family together, which accepts the dominant member as the group center while other sub-group members orbit their own "parent" in due branch of the family tree. This is why a celestial unit, like our solar system, can sustain a long period of peaceful life, if there is no sudden enormous impact from outside interference.

Here, light is not suggested as a separate type of celestial effect, because it is not a different phenomenon from thermal radiation. Likewise, electromagnetism is also not recommended either because it cannot always be present with its material source, although electromagnetism sometimes occurs under certain conditions. Even so, the behavior of their field propagation is still qualified to represent the features of all transmitting fields through the empty space.

From a mechanic perspective, each particle of mass is a unique carrier of its own kinetic energy. Therefore, transferring kinetic energy from one body to another requires direct or indirect contact. However, from a field point of view, each particle of mass is a source of celestial effects that are influential in the non-contact model, meaning that the fulfillment of celestial effects is different from the transference of kinetic energy. Considering that celestial effects influence celestial objects without requiring the source and targets to have direct or indirect contact, and that each particle of mass is a constant source of thermal and gravitational fields together, it is obvious that every particle of mass has a dual role in influencing other particles, regardless of where it remains and what environment it takes.

It is the carrier of its own kinetic energy, which can be transferred from one body to another by direct or indirect contact. It is also a producer of thermal and gravitational fields together, evoking celestial effects on other particles of mass. Being influential to other particles by crossing distances in the void, celestial effects begin to work only when their fields reach their target. Further, the fulfillment of celestial effects even disregards whether the source body exists or not once the thermal and gravitational fields are sent outwards.

Thus, there are two types of motion in the universe: the movement of tangible particles and radial extension of various fields (thermal, gravitational and electromagnetic). For the type of latter, it is already known that the expansion of thermal or electromagnetic fields is characterized by wave-type propagation; thus, it features source motion independence. Therefore, the transmission of various fields should behave differently from the motion of objects.

The featured thermal and gravitational transmission, which was widely conceived to be similar to electromagnetic propagation, has long been a hot topic in physics in the second half of the 19^{th} century after Maxwell published his group equations of electromagnetism. These group equations implicitly revealed the need for a unique reference frame, to which, the speed of electromagnetic wave is meant according to Maxwell's equations, though the subject was named as seeking evidence for proving the existence of "the luminiferous ether."

Here, there are two questions regarding the nature of space associated with thermal and gravitational transmission which must be asked and answered. First, relative to what frame of reference, is the transmission speed of a thermal or gravitational field definite and consistent with all the radial directions from their shared starting point?

In other words, relative to what reference system is an instantaneous output of thermal or gravitational field expanding as the perfect spherically symmetric? Is that absolute space? Second, what are the transmission speeds of celestial effects, or specifically, what is the speed of gravity? Is that the same as heat or light?

So far, there has been no direct observational or experimental evidence confirming "yes" or "no" for the second question above. Although gravitational fields exist everywhere, direct detection of their speed is extremely difficult, because it requires a single source to provide rhythmic changes in gravitational field strength, which should be measurable for detecting instruments on the earth.

Regarding the first question above, there have been almost half a century's efforts to detect the luminiferous ether by using a Michelson-type interferometer. This long-period ether detection work spanned from the early 1880s to the end of 1920s, in which the 1887 M-M experiment was the earliest and most famous, and Dayton Miller's ether-drift measurement was the longest and hardest of those endeavors.

From what was expected, observed, and compared, it is clear that the actual purpose of the 1887 M-M experiment was not to discover any physical properties of the luminiferous ether but to detect the relative motion between the luminiferous ether and the earth, which would have immediately proven the existence of absolute space if the experiment could deliver the expected result.

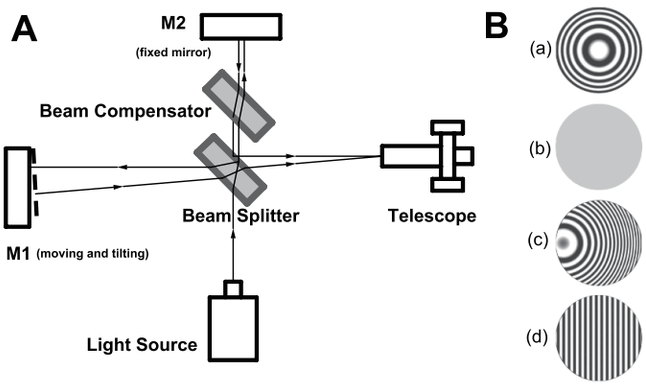

Fig. 1. Diagram of the instrument and the fringes by the adjustments

Pre-description

Distinctive fringes achieved by mirror adjustments. According to the theoretical model employed by the M-M experiment, the speed of light c and the speed of instrument v are both relative to the luminiferous ether (the absolute space). Based on this assumed condition, together with the instrument aligned to have its two arms at equal length, light beams passing by different instrumental arms will consume a different amount of time, because the mirrors at different instrumental arms move at different component velocities to the absolute space, which yields different extra light paths for different light beams to pass (Fig. 1A).

This time-consumption difference produces a light path difference between the two arms, with which an initial circular interference fringes can be altered by the mirror adjustments. These adjustments must be continuously performed until the required fringe pattern is obtained on the screen. When rotating the apparatus through a certain change in its azimuth, the light path difference originally achieved by the adjustments also changes. Thus, in response to the changed light path difference, the interference fringes will re-allocate to their new positions on the screen, so the displaced fringes can be measured from the field of view through the telescope. This is the basic schematic concept conceived for designing the 1887 M-M experiment.

However, only making two instrumental arms at an equal length cannot get the instrument ready to work, since the fringe pattern the instrument works with is quite distinctive — that is, a small group of vertical stripes appearing in alternate bright and dark lines. Such a fringe pattern can be obtained from a series of mirror adjustments, in which the movable and tilting mirrors should be cooperatively adjusted to make the paths traveled by the two light beams meet the three optical geometrical conditions, with which the required fringe pattern can be formed for the observations.

Adjusting a Michelson-type interferometer is primarily a four-step mirror-moving-tilting process (SI 2.1), by which the required fringe pattern evolves in sequence from (a) to (d) through (b) and (c) (Fig. 1B). Pattern (a), the equal inclination fringes, is obtained by adjusting M1 and M2 for them to be strictly perpendicular to each other while keeping the path difference as it is. Pattern (b), the full darkness of the fringes evolved from (a) by spreading out the central dark-dot through moving M1 to a specific position, with which the path difference is reduced to exactly zero. Pattern (c), the fringes obtained from a slight retreat of (b) toward (a) but with a lower number of rings than the latter, to be further adjusted by a tiny tilt to M1 to drive the central dark-dot aside. Based on pattern (c), the required fringe pattern (d) in a small group of vertical stripes (ideally $6-10$ bright or dark lines) can be obtained from the final adjustment to M1.

With the known conditions for the two beams producing the required fringes and the practical experience to achieve those conditions through the adjustments, the correlation between the evolved fringes, the quantity of the path difference, and the status of the mirror adjustments, can be summarized together to recognize their connections (Table 1).

We now summarize the three optical geometrical conditions, in which the two light beams travel along their due paths to finally form the required fringes, as they are going to be used in the simulation trials, 1) light paths along the output arm of the apparatus are not strictly parallel but are slightly slant toward the vertex of a small wedge, the critical condition to form the localized interference, 2) light beams coincide with each other at the vertex of that wedge, where, 3) the path difference traveled by the two light beams is extremely close to zero.

The expected fringes on the derived path differences. In order to obtain the expected fringes to be measured in the experiment, the experimental theory derived the path difference before rotating the apparatus under the following assumed conditions: 1) light beam outward from its source traveling in the same direction as the instrument in absolute space; 2) mirrors on the two orthogonal arms being set perfectly perpendicular to each other as there is no tilting adjustment to the tilting mirror; and 3) counting the aberration of light in defining the light path along the traverse arm of the apparatus.

The same theory then ascertained that the light path difference after rotating the apparatus should be the same as that prior to the rotation but at a negative value, because rotating the apparatus at 90° means an orientation exchange between the two arms, which would reverse the longer-shorter status of the two light paths. Therefore, the change in the light path difference after rotating the apparatus is twice the path difference before the rotation, upon which the fringe variation of 0.4 was expected to be measured [4].

However, as discussed earlier, tilting the mirror is an essential step in bringing the two beams into localized coincidence,

Table 1. Fringes evolving in mirror adjustments

Fringes pattern	(a)	(b)	(c)	(d)
Mirror orienting	M1⊥M2	M1⊥M2	M1 tilt*	M1 tilt†
Mirror adjusting	—	M1	M1	M1
Paths' difference (D)	D≠ 0	D=0	D≈0‡	D→0§

*Slightly retreat from (b) back toward (a) to bring the central dark dot aside by tilting M1. †Further tilting and moving M1 to make the stripes straighter and the bright (or dark) lines' number be appropriate (6-10 ideally). ‡Close to zero. §Extremely close to zero.

Table 2. Path difference in rotating the apparatus

	Before rotation	After rotation	Total change
Theoretical	$\frac{v^2}{c^2}l$*	$-\frac{v^2}{c^2}l$	$2\frac{v^2}{c^2}l$
Practical	0†	unknown	to be verified‡
Simulating	0†	known§	see Table 3

*Half arm length, which is indicated as D in the M-M's paper for deriving the path difference before rotating the apparatus. †Extremely close to zero. ‡Verification through actual tests. §See the first and second subsections under "Simulation" Section.

which is a critical condition for forming the required fringe pattern to suit the smooth observation, because tilting the mirror means changing the reflection of the beam from the tilting mirror. Therefore, the true light path segments after the tilting mirror are no longer the same as those determined by the experimental theory for predicting the path difference before rotating the apparatus.

Table 2 presents the comparative path difference gathered from the different modes and phases of their trial practice, as shown in the marked lane "theoretical, practical and simulating" respectively. This comparison bill tells us that the theoretically derived path difference never exists in the actual mirror adjustments. So the predicted fringes, though being correct in order of magnitude, are unclear of the instrumental azimuth with which the fringe variation is expected to be produced and measured.

Method to simulate the mirror-adjustment. Compared to the original interferometer invented by Albert Michelson for his first ether detection in 1881, the instrument used in the 1887 M-M experiment was improved with more mirrors to increase the light path distance along the two armsfor amplifying the light path difference and magnifying the varied fringes (Fig. 2). To suit the said improvement of the instrument, some additional changes were made by the experiment, such as setting the moving and tilting mirrors separate instead of previously combined, arranging the incident angle of the light beam at the splitter, compensator and each mirror no longer as regular as before (45° or 90°).

Despite such changes to the apparatus, the three optical geometrical conditions for two light beams forming the featured fringes remain non-change. Thus, the two tasks for simulating the preliminary adjustments are: 1) drawing an instrumental layout according to its actual dimensions as given in the M-M's paper on their experiment, supplementing them with certain proper dimensional estimation for those units that were not detailed in their positions, and 2) tentatively positioning and orienting the two adjusting mirrors so that the two light beams are roughly coincident with each other on the screen of the telescope where the light path difference between the two arms is about zeroed (SI 1.1).

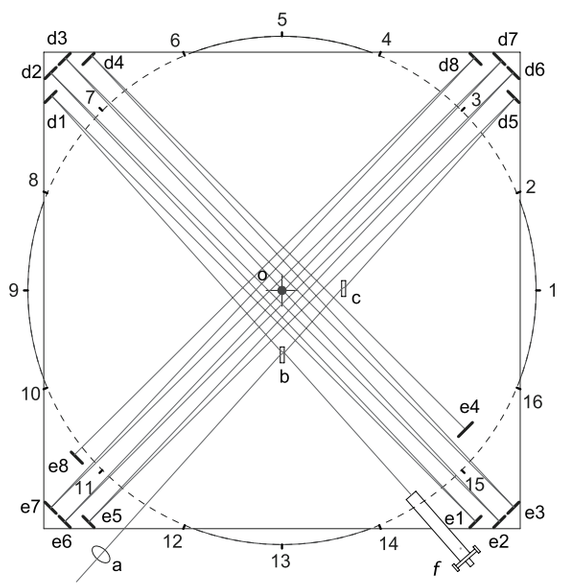

Fig. 2. Michelson interferometer in full-turn observation

To finish the second task aforementioned, define each light path segment according to the law of reflection or refraction of light by assuming the instrument is at the absolute rest. After all the light path directing components are properly aligned and oriented, and the adjusting mirrors are cooperatively moved and tilted, it is easy to make the two light beams meet the three optical geometrical conditions when considering the instrument at rest.

The subsequent work to improve the adjustment is to modify all the light path segments by counting on the absolute motion of the instrument, so that the finally recombined light beams still satisfy the three optical geometrical conditions. This is not a technically difficult task, but a time-consuming job. The first light path segment to be modified is ab (from the light source to the beam splitter), for which, the apparatus is to be moved along a chosen azimuth to pass a specific distance. For example, taking the azimuth $O1$ (O is the central pinning point of the instrument) as the chosen azimuth, whose azimuthal angle is assumed to be 0° (Fig. 2), along which the apparatus and light beam ab spend the same time to finish their own journey in the same or different directions. To determine the specific distance for the apparatus to pass, the mirror-adjusting simulation requires the assistance of CAD and Excel, with which the said distance can be worked out from their cooperative use.

All the light path segments can be modified by the following steps (taking ab as an example here) : 1) measure the length of ab_1 (adding a numeral subscript under b is to differentiate the different length measurement from the different refinement of the segment) defined by assuming that the instrument is at the absolute rest; 2) calculate the time to be spent for the light beam to travel in it; 3) use the calculated time to multiply the instrumental speed v to obtain the first distance for the instrument to pass; 4) copy the entire instrument with the ab_1 then paste them into a void space of the CAD; 5) after freezing ab_1, move the instrument through the first given distance along the chosen azimuth; 6) unfreeze ab_1 in the paste and extend b_1 to its new position of b_2, where the light beam falls on the displaced beam splitter; 7) measure the current length of ab_2 then re-calculate the time to be spent for the light beam to travel in it, with which the second quantity of distance for the instrument to pass is obtained; 8) repeat the process from steps 4 to 7 to reduce the time difference consumed by the instrument and light beam until it comes down to zero — the modified path length of ab_i is obtained (usually $i = 3$ is sufficient when the speed of the instrument is not greater than 30 km/s) ; and 9) modify the subsequent path segments one by one so that all the path segments could have their correct starting and ending points at each of the light-path-directing components.

Now, add up the entire modified path segment lengths along each arm of the apparatus and compare the two totals— usually, the previously zeroed light path difference now becomes non-zero. Commonly, both the ending points of the two light paths emerge away from their previously coincident point, that is, the originally combined light beams are split apart. Now, it is time to tentatively adjust the tilting and movable mirror by following the aforementioned procedure until the expected conditions from the mirror adjustments re-occurs (two light beams locally coincide with their path difference being zeroed). For detailed steps to simulate the mirror adjustments, see the relevant files in the Supplementary Information (SI 3.1).

Here, it is necessary to mention whether the aberration of light should be introduced to the light path definition along

a particular arm of the instrument. In this simulation trial, all the light path segments were defined according to the law of reflection or refraction of light. Why was the effect of the aberration of light not applied to the light path definition along the traverse arm of the apparatus as demonstrated in the M-M's paper on their experiment?

Because, the interferometer used in the 1887 M-M experiment made the light beam travel toward the mirror at various angles other than 45° or 90°, thus there was no so called "the traverse arm" to be recognized for applying the aberration of light to the light beam along it, thus the simulation work considered that if the aberration of light is appropriate to be applied, let it be applied to all of those light path segments instead of that just along a particular arm of the instrument.

However, if doing so for all light path segments, including those inside the splitter and compensator, to be defined and modified more accurately, the fringe simulation would be more complicated than just following the law of reflection and refraction of light. Therefore, to ensure that each light path segment is correctly defined and modified with the precision level of the final results accepted, the effect of the aberration of light was not applied to the fringe simulation work.

Furthermore, it is quite doubtful whether the aberration of light should be applied to the light path definition in the M-M experiment. The discovery of the aberration of light relied on the use of the telescope, which manifests two essential conditions for finding that effect. One is the motion of the telescope together with the earth, and the other is the featured structure of the telescope.

As all kinds of optical telescopes need to be equipped with eyepieces and the objective lenses at the separation of a distance, the light collected by the telescope is not a single ray of light but a bunch of light rays running parallel from the remote source of light, which fall down to the different depths of the telescope. Therefore, although all the mirrors of the interferometer used in the M-M experiment did move with the earth, none of them received the light like that done by the described telescope, with which the aberration of light could be admitted to the real effect.

Simulation

Method to simulate the instrument to rotate. In the actual 1887 M-M experiment, the interferometer was rotated not at a single angle of 90° but at a full turn of 360° to measure the fringes at each of the 16 equidistant points, aiming to reflect the "ether wind" blowing the instrumental arms in the 16 different directions. In addition, to suit the needs for applying the average treatment to the data aggregate, the experiment chose to take six consecutive turns of the observations as the complete conduction of an individual arranged detection.

By following the same idea, the simulation trial was arranged to move the instrument along each of the 16 equiangular azimuths marked from $O1$ to $O16$ (Fig. 2), to obtain the full-range fringe variation from the full-turn observation, which is equivalent to the actual detection in which the "ether wind" kept changing its blowing direction towards the instrumental arms while rotating the apparatus.

Now, we simulate the observation with the instrument in motion toward azimuth $O2$ (that is equivalent to the "ether wind" toward the instrument at 22.5°) by taking the adjustment done with the instrument in motion along azimuth $O1$ as an example. The initial steps to simulate the observation at azimuth $O2$ are the same as steps 1 to 9 for the mirror adjustments, but change the instrumental motion toward azimuth $O1$ to $O2$. The subsequent tasks to follow step 9 are: a) adding up all the path segment lengths along each arm of the apparatus to obtain the light path difference between the two arms, b) measuring the splits of the two beams away from their previously coincident point, and c) measuring the angles between the light paths along the output arm and the longitudinal axis of the telescope, and then recording them in the Excel form. Using this method of moving the instrument along each of the rest azimuths one by one, a full-turn rotation of the fringe simulation can be fully finished for its data average treatment. For the detailed procedures of the full-turn simulation, see the relevant Excel forms and CAD drawings in the Supplementary Information (SI 3.2).

Path difference in changes and lateral shifts of beams. To determine whether the changed path difference is irrelevant to the choice of the instrumental azimuth with which the mirror adjustments are being separately made, the simulation work selected the four different instrumental azimuths of $O1$, $O3$, $O5$, and $O7$ to conduct the mirror adjustments, from which the four sets of the changed path difference are available to verify the said question. These four sets of changed path differences indicate that when the mirror adjustments are done with the instrument differently oriented, the changed path differences over the full-turn observations appear in different curving shapes (Table 3, or SI 1.2 with more digits).

In addition, it was also found that rotating the apparatus not only changed the light path difference between the two arms but also split the coincidence between the two light beams (Table 4, or SI 1.2 with more digits). Before knowing this phenomenon found in the fringe simulation, it seemed natural that the fringe variation was purely generated from the changed path difference because of rotation of the apparatus. Now, we know that there is an additional effect from that rotation: the splits of two light beams from their original coincident point.

There is one point that needs to be clarified here. When it is said that rotating the apparatus is to split the two coincident light beams, it is only true in the simulation work, in which all the light beams were narrowed to a zeroed width so that the zero-thickness light beams could travel along their own central optical axis, allowing all the light path segments to be properly defined according to the law of reflection or refraction of light. In the actual experiment, however, rotating the apparatus does not mean a complete separation between the two light beams but the lateral shifts by two light beams starting from their original coincident point, because in any practical tests using a Michelson-type interferometer, the light beam emitted from its source has an initial thickness.

Usually, the two split light beams have the same thickness as the initial one, thus maintaining almost no change throughout the full length of the light paths subject to one condition: they come from the same light source with the collimated light-ray emissions. Hence, theoretically, each of such arranged light beams can be considered as containing a bunch of light rays traveling parallel with their own optical axis.

With such an understanding of the light beams used in their practical conditions, the split of two coincident beams actually means their lateral shifts that constitute a new superposition of light waves, in which each pair of the interfering rays previously achieved by the mirror adjustments will meet their new mates with their encountered phase differences. The phase differences in periodical change along the zone overlapped by the two beams will refresh the fringe position on the screen. Such a refreshed fringe position on screen is the fringe variation to be measured experimentally.

In the real practices of mirror adjustments, the brightest white stripe always occupies the central in the field of view

Table 3. Path difference (δ)* measured from apparatus moving toward different azimuths (10^{-4} mm)

	Marked sixteen equiangular azimuths†															
	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16
O1‡	0.00	-1.96	-2.96	-3.14	-3.14	-3.63	-4.63	-5.84	-6.34	-5.45	-3.06	-0.51	3.06	4.58	4.24	2.40
O3‡	2.04	0.50	0.00	0.32	0.75	0.59	-0.36	-1.65	-2.44	-1.97	-0.08	2.65	5.13	6.35	5.91	4.16
O5‡	-3.15	-3.68	-2.98	-1.46	0.00	0.53	-0.16	-1.68	-3.14	-3.68	-2.98	-1.46	-0.01	0.52	-0.17	-1.70
O7‡	-8.36	-7.88	-5.99	-3.26	-0.78	0.44	0.00	-1.75	-3.87	-5.41	-5.91	-5.60	-5.17	-5.33	-6.28	-7.57

*For convenient comparison with the result expected to be measured by the M-M experiment, all the path differences δ were simulated with the instrumental speed v assumed as 30km/s. †See Fig. 2. ‡Marked azimuth along which the instrument was in motion when the adjustment was being conducted.

Table 4. Beam lateral shifts (d1/d2)* measured from apparatus moving in different directions (mm)

	Marked sixteen equiangular azimuths†															
	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16
d1/O1‡	0.00	-0.66	-0.90	-0.69	-0.05	0.91	2.05	3.20	4.18	4.84	5.08	4.87	4.23	3.27	2.13	0.98
d2/O1	0.00	-0.98	-2.14	-3.29	-4.27	-4.91	-5.14	-4.90	-4.23	-3.25	-2.10	-0.94	0.03	0.68	0.90	0.66
d1/O3‡	0.90	0.24	0.00	0.21	0.85	1.81	2.96	4.11	5.09	5.75	5.99	5.77	5.14	4.17	3.03	1.88
d2/O3	2.14	1.16	0.00	-1.15	-2.13	-2.77	-3.00	-2.76	-2.10	-1.11	0.04	1.20	2.17	2.82	3.04	2.80
d1/O5‡	0.05	-0.61	-0.85	-0.64	0.00	0.96	2.11	3.25	4.23	4.89	5.14	4.92	4.29	3.32	2.18	1.03
d2/O5	4.27	3.28	2.13	0.97	0.00	-0.65	-0.87	-0.63	0.03	1.01	2.17	3.32	4.30	4.94	5.16	4.93
d1/O7‡	-2.05	-2.72	-2.96	-2.74	-2.11	-1.14	0.00	1.15	2.13	2.79	3.03	2.82	2.18	1.22	0.07	-1.08
d2/O7	5.13	4.15	3.00	1.84	0.87	0.22	0.00	0.24	0.90	1.88	3.04	4.19	5.17	5.81	6.03	5.79

*For convenient comparison with the result expected to be measured by the experiment, all the beam lateral shifts d1/d2 were simulated with the instrumental speed v assumed as 30km/s. †See Fig. 2. ‡Marked azimuth along which the instrument was in motion when the adjustment was being made.

(SI 2.2), because the two interfering rays falling down here come along the two optical axes by traveling the same light path length. Therefore, the total light path length traveled by the two central light rays is the shortest value of those traveled by other pairs of interfering rays. This means that the central interfering rays superpose their waves just in phase. This is the case prior to the rotation of the apparatus.

Now, we consider the circumstances after rotating the apparatus. As previously described, rotating the apparatus is to split the two coincident light beams (with zero width) in the simulation works. However, in the actual test, rotating the apparatus means a split of each pair of interfering rays contained in the light beams. Therefore, practically, when every previously paired interfering ray splits apart from their original coincident point, there would be other neighboring light rays stepping-in to form the new interference along the superposition zone overlapped by the two beams.

It is obvious that the newly paired interfering rays no longer superpose each other with their initial phase differences unless those differences are at integer times the original phase difference. For instance, after rotating the apparatus, the originally adjusted interfering rays at the center of the fringes will be replaced by the newly paired interfering rays that still superpose each other but are not in phase again, unless the mentioned circumstance occurs. Similar, to those originally interfering rays aside from the central bright fringe, rotating the apparatus makes them superpose with their newly encountered phase differences.

According to the knowledge of light interference, such re-superposed light waves between the newly paired interfering rays represent a re-set of their phase superposition, meaning that a fringe variation will appear on screen being ready for observation. Therefore, determining the displacement of a particular fringe after rotating the apparatus is a feasible method for calculating a fringe variation on the screen.

Dual effects co-determine the varied fringes. The aim of this section is to determine how the dual effects of path differences in changes and lateral shifts by beams, co-shape the varied fringes. According to the knowledge of light interference, the distinctive fringes used in the 1887 M-M experiment were generated from the periodic changes in phase differences between the two superposed light beams.

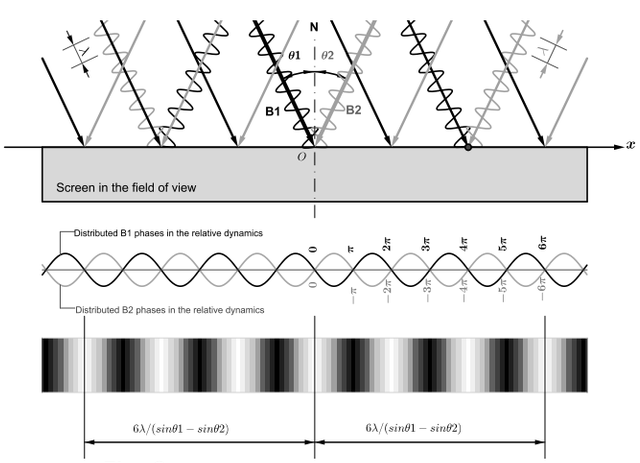

Fig. 3. Fringes adjusted before rotating the apparatus

The two light beams superimpose with their light waves in phase and out of phase, creating constructive and destructive interference of light. When rotating the adjusted apparatus, the changed light path differences between two arms and the lateral shifts of two light beams contribute together to the phase superposition between each pair of interfering rays. Thus, the dual effects co-influence the periodic distribution of the phase differences.

Thus, it is the dual effects and not the changed path difference alone, determining the fringe position on the screen. Therefore, if we know the original position of the adjusted fringes and their new position after rotating the apparatus, the difference between the new and old seats of the fringes will be the fringe shift to be measured by the experiment.

Now, consider the fringes obtained from the mirror adjustments (Fig. 3). Let S_b be the one-dimensional position for a chosen bright fringe n_b (an integer number that takes the central bright fringe at O, the origin of the uniaxial coordinates Ox, as the starting number of 0), and S_d be the same for a selected dark fringe n_d (also an integer number that takes the dark fringe neighboring to the origin O as the beginning number of 1), S_b and S_d can be expressed in the following equations when giving a specific number to the integer n_b or n_d,

$$S_b = \frac{2n_b\lambda}{\sin\theta_1 - \sin\theta_2}, (n_b = 0, \pm1, \pm2, \pm3, ...), \qquad [1]$$

or

$$S_d = \frac{(2n_d \mp 1)\lambda}{\sin\theta_1 - \sin\theta_2}, (n_d = \pm1, \pm2, \pm3, ...), \qquad [2]$$

where, λ is the wavelength of the used light, and θ_1 and θ_2 are the incident angles of light beams B_1 and B_2 falling on the plane of the screen respectively (Note: alternate use of Eq. 2 correlates with the choice of n_d as positive or negative).

For the central white stripe to be sharply contrasted to those aside, it is ideal to make the incident angles of B_1 and B_2 equal, that is, set $\theta_1 = -\theta_2 = \theta$, then the above two equations become

$$S_b = \frac{n_b\lambda}{\sin\theta}, (n_b = 0, \pm1, \pm2, \pm3, ...), \qquad [3]$$

or

$$S_d = \frac{(2n_d \mp 1)\lambda}{2\sin\theta}, (n_d = \pm1, \pm2, \pm3, ...). \qquad [4]$$

Now, we consider the fringes reformed by rotating the apparatus (Fig. 4). As any appearing light fringes are generated from the constructive and destructive interference of light distributed on a plane or a curved surface, the fringe position freshened by the instrumental rotation, should come from the periodic changes of the phase differences superimposed by the two light beams.

If two light beams come from the same light source, all the light rays in them have the same phase status at the points where they pass the same path length. When using sodium light to obtain equal inclination fringes, the difference in the phase status for any paired interfering rays is solely determined by the length difference of the paths traveled by the two interfering rays, meaning that the freshened fringe position on the screen ultimately depends on the newly distributed light path differences caused by rotating the apparatus.

With this understanding of the interference used in the M-M experiment, we know that the impact of the dual effects on the varied fringes is virtually the impact on the paired interfering rays, where the encountered phase difference is decided by the discrepant path distance traveled by the two interfering rays. We also know a triadic relationship between the length

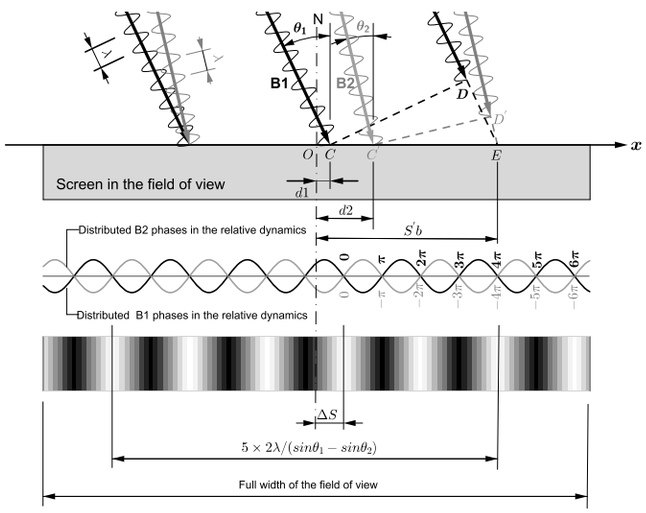

Fig. 4. Fringes shifted after rotating the apparatus

of a light path, the number of waves contained in it, and the wavelength of the light, with which the phase difference of any newly paired interfering rays, can be calculated.

Now, assume that the light beams B1 and B2 laterally shift from their originally coincident point of O. In other words, they fall on the screen at their new positions of C and C'. These positions can also be expressed as d_1 and d_2 (Table 4) on the uniaxial coordinate Ox with point O as its origin respectively. In addition, suppose that at point E, there are two paired interfering rays (from the different arms of the apparatus) superposing each other in phase to produce a bright stripe on the varied fringes.

In the right triangles $\triangle CDE$ and $\triangle C'D'E$, DE and $D'E$, which are proportional to the length of CE and $C'E$ respectively, can be seen as the path addition to the path distance traveled by the central light rays B_1 and B_2 separately, because in the simulation trials, the zeroed-thicknesses B_1 and B_2 represent the two central light rays running along the two optical axes by the two arms.

Let θ_1 and θ_2 be the incident angles of $B1$ and $B2$ to the plane of the screen (taking the anti-clockwise direction as the positive), δ indicates the length difference between two light paths traveled by $B1$ and $B2$ (Table 3), λ represents the wavelength of the used light, S'_b is the new position of the chosen bright stripe n_b on the uniaxial coordinate Ox, which satisfies the following condition:

$$(S'_b - d_1)sin\theta_1 - (S'_b - d_2)sin\theta_2 + \delta = 2n_b\lambda,$$

from which, the S'_b comes as

$$S'_b = \frac{2n_b\lambda + d_1\sin\theta_1 - d_2\sin\theta_2 - \delta}{\sin\theta_1 - \sin\theta_2}. \qquad [5]$$

To obtain the fringe shift after rotating the instrument, it is practicable to choose any particular fringe as its variation indicator, because the featured interference is approximately equal-spacing fringes, considering that the final alternative use of white light comes from the extended light source.

For simplicity, select the central bright fringe as the fringe displacing indicator to calculate the fringe shift, that is, let $n_b = 0$, namely $S_b = 0$. Then, the equation below reflects the displacement of the indicator on the uniaxial coordinate Ox

Table 5. The means and final means of the simulation fringes ($\triangle f$)

	Marked sixteen equiangular azimuths*															
	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16
$O1^{\dagger}$	0.00	-0.03	-0.11	-0.21	-0.26	-0.17	0.04	0.32	0.57	0.69	0.65	0.54	0.26	0.08	-0.01	-0.01
$O3^{\dagger}$	0.08	0.08	0.00	-0.11	-0.18	-0.14	0.03	0.27	0.49	0.59	0.54	0.38	0.18	0.04	0.00	0.04
$O5^{\dagger}$	-0.29	-0.33	-0.27	-0.13	0.00	0.05	-0.01	-0.15	-0.28	-0.33	-0.27	-0.13	0.00	0.05	-0.01	-0.15
$O7^{\dagger}$	-0.49	-0.59	-0.54	-0.38	-0.18	-0.04	0.00	-0.04	-0.08	-0.08	0.00	0.11	0.18	0.14	-0.03	-0.27
Means‡	-0.17	-0.22	-0.23	-0.21	-0.15	-0.08	0.01	0.10	0.17	0.22	0.23	0.22	0.15	0.08	-0.01	-0.10
	0.17	0.22	0.23	0.22	0.15	0.08	-0.01	-0.10	-0.17							
Final Means	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00							

*See Fig. 2. †Marked azimuth along which the instrument was in motion when the adjustment was being made to obtain the required fringes. ‡The lower row of the means averaged at azimuths O9 through O16 to O1 is superposed with the upper row of the means averaged at azimuths O1 to O9, which is equivalent to the average treatment method as presented in tables of the M-M's paper of their experiment.

(Ox is equivalent to the horizontal line on the cross-wire of the telescope) after rotating the instrument.

$$S'_b - S_b = \frac{d_1 \sin\theta_1 - d_2 \sin\theta_2 - \delta}{\sin\theta_1 - \sin\theta_2}. \qquad [6]$$

For the central bright stripe to stand out the sharpest, the incident angles of $B1$ and $B2$ need to be set as $\theta_1 = -\theta_2$. Now, let ΔS be the displacement of the fringe variation indicator, then Eq. 6 can be simplified as

$$\Delta S = \frac{1}{2}(d_1 + d_2 - \frac{\delta}{sin\theta_1}). \qquad [7]$$

Let λ be the wavelength of $B1$ and $B2$, the fringe-spacing is the absolute value of $\frac{\lambda}{\sin\theta_1}$ (θ_1 can be positive or negative), then, the fringe shift (Δf) after rotating the instrument is the ratio of ΔS to the fringe-spacing,

$$\Delta f = \frac{|\sin\theta_1|}{2\lambda}(d_1 + d_2 - \frac{\delta}{\sin\theta_1}), \qquad [8]$$

Here, λ was input as 5.5×10^{-7} m, the same value as adopted by the M-M's paper in calculating their experimental result.

According to Eq. 8, the four sets of the simulation fringes were summarized into one form for their average treatment (Table 5 or SI 1.3 with more digits).

Original findings shrink in their average treatment. We can see from the M-M's paper on their experiment that the four-day measurements (July 8, 9, and 11 at noon and 8, 9, and 12 in the evening) were gathered into two groups for the noon and evening observations, and all the findings in each group were averaged to obtain the "means" and the "final means" of the measurements. Additionally, all the table listings are not the original measurements of the fringes but those of the screw head readings averaged from the six consecutive turns of the observations. They indicate the distance the movable mirror was manually moved to restore the fringe consistency at each of the 16 equidistant points.

In fact, such a changed method of fringe measurement was not the initial thought of the experiment. The original design of the experiment was to measure the fringe variation by visually inspecting them on screen, so that there would be no operational disturbances to any part of the apparatus during its rotations. We now have two questions regarding this changed method of fringe measurement. First, why was the originally designed fringe-observing method changed by the experiment? Second, the changed method is equivalent to the original thought to conduct the experiment? Frankly, we see no explanations from the M-M's paper of their experiment.

Furthermore, there is another issue concerning the data average treatment to be discussed. As presented in the tables of the M-M's paper, the only algorithm made for the original observations was the three-round average treatment: 1) averaging the screw-head readings gathered from the six consecutive turns of the observations, 2) computing the means of the screw-head numbers individually collected from their three days' measurements, and 3) calculating the final means of the screw-head numbers by cutting the full-turn observations into two half-turns of the observations (from the equidistant point 16 through 1 to 8 and from point 8 to 16, respectively), then overlaying them for their final average treatment.

According to the M-M's paper of their experiment, measuring a fringe variation at the equidistant point 16 was done twice within six minutes. Theoretically, measuring a fringe at the same equidistant point twice should obtain the same result if there are no environmental disturbances affecting the working apparatus. Even so, practically, the blowing direction of the "ether wind" could still be affected due to the continuous instrumental revolution together with the underneath ground around the earth's self-rotation axis.

Now, consider the possible extreme case of the earth's absolute motion being parallel to the light paths' plane of the instrument. Since it is known that the M-M experiment was conducted at Cleveland, U.S., where the Northern Latitude is 41.5°, we can roughly calculate the maximum direction change of the "ether wind" to be not greater than 1.5° (that is much smaller than the equiangular angle of 22.5° as indicated in Fig. 2) meaning that the impact on the discrepancy between two different measurements at point 16 caused by the earth's self-rotation can be ignored. Therefore, the two measurements done there should be approximately the same or at least the difference should be within a reasonable error range.

However, as we can see from the tables in the M-M's paper, there is always a relatively large disparity between the initial and final measurements of the screw-head numbers at the equidistant point 16, and the only thing done to them was bringing them into the three rounds of average treatments, through which the "final means" of the measurements were obtained. When the final means of the screw-head numbers were changed to the final means of the fringes according to the ratio of a single turn of the screw head to the fringe position being altered by that turn, the final means of the screw-head numbers turned out as that of the fringe observations. There-

fore, it is the final means of the fringes providing the "evidence" for the 1887 Michelson-Morley experiment concluding that its ether-detection result is too small to verify the relative motion of the ether and the earth.

To determine what the "final means" implies to the raw findings collected from the multiple arranged measurements, the same method of data average treatment was applied to the four sets of the simulation fringes, which were obtained from the mirror adjustments performed with the instrument in motion toward the four different directions $O1$, $O3$, $O5$, and $O7$ at their absolute azimuthal angles of 0°, 45°, 90°, and 135°, respectively.

Of course, applying the same average treatment method to the simulation fringes features its own character that the first round of the treatment can be exempted, as there are no disparities in measuring the light path distances and calculating the fringe variation once the mathematical model of the trial has been set for the computer to work on.

Therefore, the calculation work to obtain the final means of the simulation fringes only needs to go through the second and third rounds of the average treatments. From doing so, it was found that the final means of the simulation fringes were all shrunk down to zero, except for the one at the equiangular azimuth $O4$ but that is also very small.

The means and the final means of the simulation fringes indicate that, when the conventional average treatment is applied, the amplitude of raw fringe measurements over the full-turn observations could shrink to a wide range, depending on the combination status of the chosen instrumental azimuths, in which the mirror adjustments are individually conducted for the multiple arranged detections. In other words, seeking the final means of raw fringe measurements is to ease the variation curving of the raw fringe observations.

Now, a concern about the detailed operation method of the M-M experiment arises: what factors were considered in the experiment to set an instrumental azimuth with which the mirror adjustments were individually started to prepare the instrument for work? We see no descriptions or explanations in the M-M's paper of their experiment.

Analysis

What caused the small result of the M-M experiment. It is needless to say that preparing a Michelson-type interferometer for work by its mirror-adjustment can only be done when it is at rest on the ground. Hence, whether noticed or not, conducting mirror-adjustment to the said interferometer is actually to choose a specific azimuthal angle between the absolute motion of the instrument and the beginning emission of the used light.

Besides, the simulation results show that the interference fringes gathered from the full-turn observations appear in the different variation curves, if the mirror adjustments are separately made with the instrument in motion toward the different azimuths. Therefore, it would be helpful if we knew the azimuths, along which the instrument was in motion while the adjustment was being underway for each of the individual arranged detections at noon or in the evening of their respective three days.

Unfortunately, however, no such information can be found in the M-M's paper of their experiment. Therefore, we have to consider all possible choices of the instrumental azimuth the M-M experiment may have considered to take, to analyze their influences on the observational results. One of which, we believe, could have been adopted by the experiment.

Principally, there were a total of three different options to set the telescope-arm in a specific azimuth, with which the mirror adjustments were conducted: 1) choosing one by one from the three equiangular-apart azimuths of the apparatus to conduct the adjustments for noon and evening observations in their respective three days; 2) selecting one from the 16 equidistant points as the fixed mark, by which the telescope-arm was at rest to start the adjustments; and 3) randomly choosing an equidistant point by which the telescope-arm was set static to commence the adjustments.

Among the three options mentioned above, each had its own reason for being considered worth adopting. The first option reflects the diversified azimuthal choice for multiple-adjustments being arranged in a balanced orientation manner. The second one is practicable as it prevents the instrument from redundant revolution, during which the instrument may encounter more environmental impacts. The third option is also a natural choice for the observations if the experiment believed that it would make no difference when adjustments are made with the instrument in motion in different directions.

Now, we know that the first and third options are the typical scenarios of raw findings shrunk in their average treatment. That is, when adjusting the mirrors with the instrument in motion along the chosen azimuth as of the two mentioned options, the three rounds of the data average treatments, particularly the last one, make the gathered raw findings neutralize each other, causing the amplitude of the full-turn observations to be reduced by an obvious percentage. Therefore, only the second option needs to be discussed in detail to assess whether it is the same as that of the aforementioned two options.

Before discussing the issue, we must further detail the process for adjusting a Michelson type interferometer. As previously described, preparing the instrument for work includes two major tasks: the alignment and the adjustment of the instrument. The former makes the two orthogonal arms equal in lengths and roughly centers the mirrors along the optical axis of the light beams. The latter aims to obtain the required fringe pattern on screen by performing the preliminary adjustment first and then the final adjustment of the instrument.

The preliminary adjustment is to establish an initial interference system, for which monochromatic light is required (such as the sodium light used in the M-M experiment). The final adjustment is to obtain the required fringe pattern by substituting sodium light with white light to form a small group of vertical stripes with alternate bright and dark lines.

Usually, in the entire process of preparing the instrument for work, mirror adjustment is a time-consuming task, for which, it is impossible to set a standardized time schedule for the adjustment to follow. Thus, practically, mirror adjustment always features an elastic manner from dozens of minutes to a period of hours, depending on miscellaneous factors inside and outside the instrument. In contrast, pure fringe observations always spend much less time than the whole preparatory period for the instrument to work.

According to the M-M's paper of their experiment, the instrument took about six minutes to finish its single turn of the observation, meaning that a complete individual group observation over the six consecutive turns of the observation could only take about thirty-six minutes. We may never know the exact ratio between the time for the fringe measurement and that for the mirror-adjustment, but we do know in principle that the time consumed for pure fringe observation always occupies a small portion of the entire detection.

Now the question is, could it be possible for the M-M experiment to have all of its noon or evening observations (not the noon or evening preparation for the detection) starting at the same time with the telescope-arm toward the same azimuth of the apparatus? For the second part of the question, it sounds "yes, " as we can see from the tables in the M-M's paper that

all the first and last listings in each row of the tables were collected from the same equidistant point 16.

Therefore, it is clear that the equidistant point 16 was chosen as the fixed azimuthal mark by the M-M experiment, by which the telescope-arm was at rest to start the adjustment for the four-day experimental observations. Although such an arranged beginning and ending of the observation could not help differentiate the true motion of the instrument, the interference fringes measured twice here did reflect the observations in the completeness of full-turn fringe variations.

However, for the first part of the question mentioned above, the answer is certainly no, because the timing for finishing the adjustment cannot be pre-set in advance, there must be a time difference between the different days' endings of the adjustments. In other words, even if the 1887 M-M experiment tried to arrange its observations starting at the same time as pre-scheduled, it could hardly be ensured that each individually conducted adjustment was done at exactly the same time, meaning that the blowing direction of the "ether wind" would be changed to the instrumental arms. Because, the apparatus was continuously rotating with the earth around its self-rotation axis, which is, in principle, equivalent to the described scenarios in which the adjustments are separately made with the instrument in motion toward different azimuths.

As none of these three options could ensure the adjustments done with the instrument moving toward the same direction, it is obvious that as long as the adjustments are separately made with the instrument differently oriented, seeking the final means of the multiply arranged observations means the amplitude shrinkage of the original observations. If this is the case in the M-M experiment, the small final means of its observations should not be concluded as an unexpected small result, because it would be easily interpreted as negative detection based on "small-means-null" logic.

After analyzing all the possible azimuthal choices probably taken by the M-M experiment, we now realize that the final means of raw findings obtained in the M-M experiment is actually the reduced effect of the luminiferous ether. With this new recognition of the M-M experiment, it seems rational to see its small observations as inclining toward positive detections. Nevertheless, however, we need to be cautious before jumping to a new opinion on the M-M experiment, because there is another part of the issue we have not touched so far, for which the computer is unable to help.

Alternate use of light sources. As previously described, preparing the instrument for work requires the arms aligned and the mirrors adjusted. The mirror adjustments aim to obtain the required fringes pattern by bringing the two beams into localized interference, where they coincide with each other and pass the same path distances along two arms of the apparatus. These two light beams, initially split and finally recombined, were emitted from the same light source, which was purposely made for alternate use, the white light first, sodium light followed, and finally the white light resumed.

The first use of white light was intended to make the two split light beams coincide quickly with each other (a pointing image transmitted in white light is easily distinguished compared to that in other lights). The following step is the interim use of sodium light, because it is more efficient to establish the required interference system. Finally, the white light was restored, as it provided convenient width and positions of the fringes for smooth observations.

Why did the M-M experiment not use white light to complete the entire process of the mirror adjustments without involving the interim use of sodium light? Because white light is not coherent, thus unable to form equal inclination fringes, without which the required fringe pattern cannot be obtained from the mirror adjustments while saving time for the preparing process. Sodium light is required in the interim adjustment because the required fringe pattern has to evolve from equal inclination fringes.

However, to ensure smooth observations of the fringes, the fringe pattern needs to be improved as clearly as possible, while the central fringe should stand out from all of the rest, for which sodium light is not qualified to provide. This is why the M-M experiment had to substitute sodium light with white light to finish the last step of the adjustment. However, when rotating the apparatus to observe the fringes, what would be the difference in the distributing phase difference between the newly paired interfering rays when an alternative light source is used?

The benefits and problems with white light use. According to the conceptual design conceived for the M-M experiment, rotating the instrument could only generate a fringe shift to be measured, whereas the fringe pattern itself would not change at all. This conceptual design was verified using the simulation fringes according to Eq. 8 subject to one condition: the coherent light source should be used to ensure the propagation of two light beams at the same wavelength. In the actual 1887 M-M experiment, this condition was met when using sodium light but then breached when substituting it with white light (produced from an argon burner with its path through a lens before reaching the splitter). Such an arranged light source was truly able to provide roughly collimated light, but certainly not coherent light.

The alternate use of sodium and white lights may cause no extra difficulties with the mirror adjustments, because during the adjustment period, the movable mirror, tilting mirror, and telescope are cooperatively adjusted to find the best part of the interference fringes. However, after rotating the instrument, no such coordination work can be allowed to maintain the fringe pattern as consistent as it was initially, since any manual touch to anywhere of the instrument would result in disturbances to the accuracy of the original observations.

Also, white light is a mixture of various-wavelength light, so the fringe pattern reformed by rotation of the instrument would probably appear abnormally, since all the newly paired interfering rays superpose their wavelengths with irregularity and uncertainties. These circumstances would bring additional difficulties to the fringe observations. Therefore, the dilemma here is that, compared to the benefit from the use of white light, the random loss of fringe consistency seems impossible to evaluate in a definitive manner.

Such incoherent light use could cause the fringe pattern to appear irregular, turbid occasionally, or even full of blank or black at one or more of the 16 equidistant points, or at somewhere between two neighbors of those points. Despite anyone of the cases, the random loss of the consistent fringes or sudden sight disappearance of the same during rotation of the apparatus would put the experiment in a difficult position to estimate the fringe on the screen, particularly when these circumstances are mixed with environmental impacts.

Hence, this is the extra difficulty for the M-M experiment to carry, which could be the most probable reason for the M-M experiment to choose not to measure the fringe variation on screen directly, but to measure the distance the movable mirror was adjusted, to restore the fringe consistency. However, such a changed method would definitely bring repeated manual interference into the working apparatus (through turning the cap of the screw that drives the mirror forward or backward constrained by the spring), meaning that measuring the

fringe variation in this way would disturb the reliability of the original observations.

Now, we can see that the alternative use of white light and the interference of operational disturbance are the two factors affecting the accuracy of the M-M experimental results. Considering that the two factors matter, but there are no ways to quantitatively evaluate the two, it seems fair to suggest this famous experiment to be interpreted as delivering no result.

Brief comments on Miller's ether-drift measurements. Dayton Miller's work on his ether-drift measurement is not as famous as the 1887 M-M experiment, but it also deserves to be remembered by history because of his long-term dedication to ether detection from 1902 to 1926, during which Miller made tremendous efforts to improve his ether-drift measurements: building instruments in different materials; increasing arm-length for magnifying the light path differences, arranging the detections at various locations, heights, and seasons of the year, to obtain the fringe variation in a broader spectrum to reflect the relative motion between the ether and the earth. This is to consider the fact that the earth is not just circling around the sun but also traveling with the sun in the higher-ranking celestial structure.

Compared to the 1887 M-M experiment, Miller's observational method of detecting the ether effect has the following features: 1) measuring the fringe variation on screen purely by visual inspections; 2) one complete individual ether detection requiring the mirror adjustments to be performed only once on a daily basis; 3) setting a brass-arrow as the reading fiducial above the tilting mirror at the half-way of the light path along the tilting mirror arm of the apparatus; and 4) twenty sets of raw findings being processed by average treatments in two rounds.

These four characters show that: 1) Miller's observational method is what the M-M experimental theory recommended; 2) Miller's testing method could prevent his original observations from shrinking if there was no small weight of an object randomly placed on the instrument (aiming to get the reading fiducial back to its central position when that lost), which gives the same effect of the adjustment being made with the instrument differently oriented; 3) the said fiducial also shifts due to the dual effects from rotation of the apparatus; and 4) his original findings could be less shrunk than that treated by the M-M's paper of their experiment.

If Miller's original records of his measurements are still well-preserved somewhere today, the initial turn of the observations (usually 5 before randomly placing the mentioned small object on the apparatus) on each day of his detections would be highly valuable for roughly knowing the true fringe variation over a full-turn observation in different days of different seasons, since those fringes were produced and measured without systematic manual disturbances (There had been some misread fringes in Miller's measurements, because the reading fiducial, more or less, always laterally shifted on screen due to the dual effects from rotation of the apparatus).

Conclusive remarks

The original design of the M-M experiment outlined that the effect of the luminiferous ether could be detected on the Michelson interferometer after adjusting and rotating it to yield a fringe shift. Now, the results of the fringe simulations revealed that the final means of the raw findings could only reflect a reduced effect of the luminiferous ether (authentically, the effect relevant to the absolute space) if those findings were collected from the multiple arranged detections, for which the adjustments were separately made with the instrument differently oriented.

Because the intrinsic feature of the instrument in combination with the data average treatment has become the trigger to shrink the original findings of the measurement, the only way out of the experiment seems to conduct it in a once-off manner. That is, a single turn of the fringe observation provides a decisive conclusion for the so called "ether effect detection". However, the critical question for that is whether such arranged single-turn detection can be trusted as a reliable observation, since environmental impacts could occur at any time of the observations.

Considering that this experiment holds tremendous significance to fundamental physics and the mentioned deficiencies cannot be improved by enhancing the overall performance of the interferometry, it is necessary to explore other experimental solutions to fulfill the mission of the detection, such as measuring the free-fall acceleration rate variation at different latitudes with certain time intervals, or conducting the radar wave measurements with the proposed melioration[2]. Based on the opinions above, this paper suggests more detection tests with new experimental solution to be explored and carried out, so that Newton's conception of absolute space (and time) can be fairly judged for the advancements of physical science.

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1. Dayton C. Miller, (1933) The ether-drift experiment and the determination of the absolute motion of the Earth. Rev. Mod. Phys. 5(3):203-242.

2. A. A. Michelson, F. G. Pease and F. Pearson, (1929) Repetition of the Michelson-Morley experiment. Nature (123):88.

3. R. Kennedy and E. Thorndike, (1932) Experimental establishment of the relativity of time. Phys. Rev. (42):400.

4. Albert A. Michelson and Edward W. Morley, (1887) On the relative motion of the earth and the luminiferous ether. Am. J. Sci. 34(203):333-345.

[2] See another research work by the same author titled "Gravity's fluctuation derives from its speed — a constant to the absolute space presumed."