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Solar Panel Tracker System Using GPS Technology

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Abstract: This article provides a solution to the problem of not improving three-dimensional systems with light sensors in tracker systems for solar panels, due to the inefficiency of operation in cloudy weather, with an increase in precipitation and contamination of photodetectors. The paper shows the calculation of the position angle of the tracker system relative to the changing position of the sun. The GPS system is able to automatically determine the location of the solar panel (latitude, longitude), then the microcontroller with the developed program performs a mathematical calculation, and the system automatically adjusts the solar panel to the sun. Thus, the need to use a photo sensor is eliminated, since the system automatically determines the optimal angle between the sun and the solar panel.

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1. Introduction

Today there is a problem in the efficiency of solar panels. The use of solar trackers increases the efficiency of solar panels by 30% due to the possibility of full tracking of the Sun. But for the most part, such trackers work thanks to the use of various sensors tracking the Sun. Such sensors are very susceptible to climatic conditions, they also have a high level of wear, work differently in different regions and are not always accurate [1].

The demand for solar energy is constantly growing, since solar energy is environmentally friendly and affordable. The second reason for the relevance of the use of solar energy is its resource intensity. In just 9 minutes, the Earth receives more energy from the Sun than humanity produces in an entire year. This energy is supplied free of charge and has no impact on the environment.

Solar energy is an area of significant investment in conditions of declining oil and gas reserves. Solar energy contributes to the reduction of global consumption of fossil fuels.

Solar panels for the production of solar energy can be installed on your own roof. The generated energy can be converted into heat and stored in a battery that will be used for heating and water supply.

The solar power plant contains a solar panel with a biaxial orientation system to the sun, on which photovoltaic modules containing linear photodetectors are installed as sensors for tracking the sun. Signals from photodetectors with the help of a microprocessor control the drives of the system of vertical and horizontal orientation of solar panels [2].

The disadvantage of this installation is the low accuracy of tracking the sun, and the photo sensors are also exposed to external influences. They get dirty, dusty, which leads to inaccuracy of their work. With a small cloud cover, the photo sensors cannot catch sunlight and do not turn the panel in the sun. This leads to losses of generated energy. When the photo sensor is set to high sensitivity, the tracker can turn the solar panel to moonlight, which leads to a waste of energy on turning the solar panel [3].

2. Materials and methods

The basis of the tracker device for GPS-based solar panels is the ARDUINO UNO microcontroller, since this controller meets the requirements for speed and the number of output pins. The real-time clock module c or its analog DS3107 is also used. Both modules work fine without any changes in the sketch. The system uses GPS in order to synchronize the real-time module to correct the course of the DS3107 once a month, these time inaccuracies do not have a large deviation value and, accordingly, do not affect the operation of the device as a whole, since there is no need for high accuracy of time measurement. The HX1230 display was used to display the information. The software provides for the input of the tracker response period, depending on the area of use, from 5 to 55 minutes. With the onset of sunset, the tracker automatically turns to sunrise, and is in standby mode. In this version of the software, you can use both a single-axis mechanism and a two-axis one. Before developing the entire solar panel tracker system and modeling the overall scheme, it is necessary to connect and test each module of the control system separately. The GPS receiver allows you to determine the location of the object using GPS (global positioning system), this receiver must be connected to the Arduino board. GPS (Global Positioning System) (Figure 1).

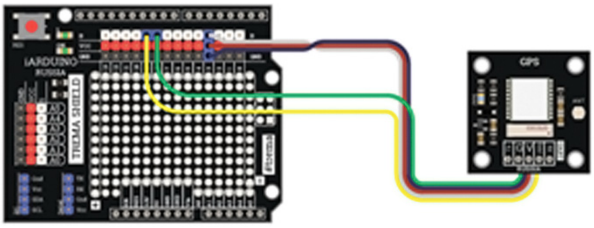

Fig. 1. GPS connection diagram.

The system also uses a real-time module (Figure 2). The following requirements are imposed on the real-time module: the calculation of the current time and date must be carried out continuously and regardless of the shutdown of the system.

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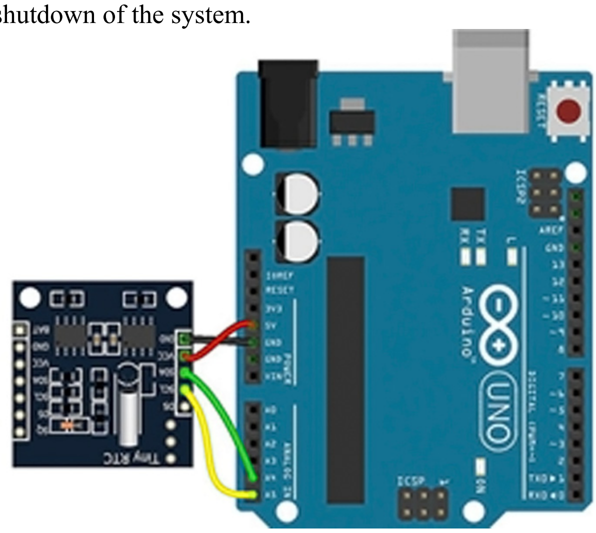

Fig. 2. Connection diagram of the real-time module.

The DS1307 module is one of the most affordable and common RTC modules. It can accurately track seconds, minutes, hours, days, months and years. Some of the important features of the DS1307 are:

- The ability to generate a programmable rectangular signal

Low current usage; less than 500 nA in battery backup mode;

- Ability to set the date to 2100;
- I2C serial interface.

The HX1230 LCD screen is a basic graphic LCD screen. Its connection diagram is shown in Figure 3.

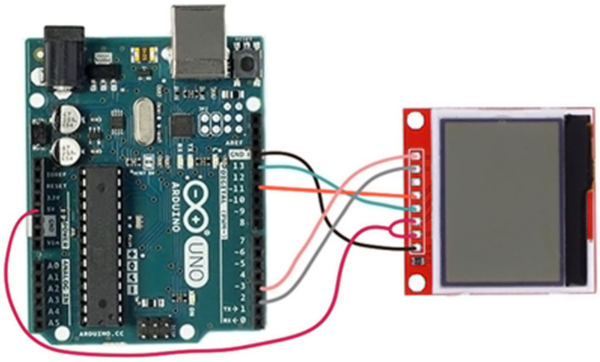

Fig. 3. Electrical diagram of the HX1230 LCD screen.

2.1. Calculation of the maximum and minimum azimuth of the Sun

The calculation of the maximum and minimum azimuth of the Sun at a given location is determined using a number of initial and calculated data, which include: Latitude (Ξ); Longitude; (Φ)Time zone (ω); Date (d); Time (τ); Specified Julian day (υ); Calculated Julian century (δ); Mean geometric longitude of the Sun related to the mean equinox (p); Mean anomaly of the Sun at time (ξ); Eccentricity of the Earth's orbit at time (μ); Calculated equation of the center of the Sun at time (λ); True longitude (k); True anomaly (l); Radius-vector of the Sun (heliocentric distance from the Sun to the Earth from center to center) (θ); Correction for nutation and aberration (n); Inclination of the ecliptic (ζ); Tilt coordinates (ϵ); Mean right ascension (asc); Sunset (dec); Dispersion (var); The angle of the solar azimuth (azimuth).

The mean geometric longitude of the Sun refers to a certain period of time, which is called an epoch. We are currently using the epoch J2000.0. This epoch began on January 1, 2000 at noon Coordinated Universal Time. At that moment, the average longitude of the Sun was: 280° 27' 59.26" (or 280.46646 degrees). The mean geometric longitude of the Sun is to find where the average value of the Sun was at time *T*, referring to the date of the equinox.

$$\rho = (280.46646 + \delta\,(36000.76 + 0.00030\delta)) \qquad (1)$$

The average anomaly of the Sun at a time. The word "anomaly" here refers to the uneven or "anomalous" apparent motion of the Sun and planets along the plane of the ecliptic. The mean anomaly is defined as "the angular distance from the perihelion that [the Earth] would have if it were moving around the Sun at a constant angular velocity." Further, using the data obtained from the first formula, it will be possible to calculate the true longitude and anomaly by relating it to the equation of the center of the Sun.

$$\varepsilon = 357.52911 + \delta(35999.05029 - .0001537\delta) \qquad (2)$$

The eccentricity of the Earth's orbit at a time. Eccentricity refers to the "flatness" of an ellipse outlined by the Earth in its orbit around the Sun. The initial constant 0.01670834 used is almost unchanged due to tiny corrections in the rest of the calculation equation. As an example: if the time T corresponds to the launch of the satellite in 1957, then e = 0.01672. The Earth's orbit tends to be closer to a circle than to a very flat ellipse. That's why it's a small value.

$$\mu = 0.016708634 - \delta\begin{pmatrix} 0.00042037 + \\ +0.000000012\delta \end{pmatrix} \quad (3)$$

The calculated equation of the center of the Sun at a time. The equation of the center in this solution will be a different version of the Kepler equation. This condition is suitable when the eccentricity of the Earth's orbit is very small. (As calculated above, the Earth's orbit is the case when 0 < e < 1 and e = 0.01672).

$$\lambda = \sin(\varepsilon^{rad})(1.914602 - \delta(0.004817 + 0.000014\delta) + \sin(2\varepsilon^{rad})(0.019993 - 0.000101\delta) + 0.000289\sin(3\varepsilon^{rad}) \quad (4)$$

True longitude

$$k = \rho + \lambda \quad (5)$$

The true anomaly

$$l = \varepsilon + \lambda \quad (6)$$

The radius vector of the Sun is the distance (measured in astronomical units or AU) between the center of the Sun and the center of the Earth (the calculations use a value slightly less than one, namely 0.997).

$$\theta = \frac{1.000001018(1-\mu^2)}{1+\mu\cos(l^{rad})} \quad (7)$$

Making adjustments for nutation and aberration. This item provides greater accuracy when detecting solar coordinates using true longitude. In fact, it is necessary to calculate a value that corrects the true longitude of the Sun taking into account perturbations (such as the tidal force of the Moon on Earth).

$$\eta = k - 0.0056 - -0.0047\sin((125.04 - 1934.1\delta)^{rad}) \quad (8)$$

The slope of the ecliptic describes the slope of the ecliptic. Tilt is an effect caused by the tilt of the Earth around its axis relative to the celestial equator. In other words, it is the angle between the plane of the earth's equator and the plane on which the Sun and planets seem to move.

$$\varsigma = 23 + \frac{26 + \frac{21.448 - \delta(46.815 + \delta(0.00059 - \delta 0.001813))}{60}}{60} \quad (9)$$

The tilt coordinates will be detected by the Sun's the coordinates of the inclination of the Sun, as a right ascension and declination of the apparent position of the Sun on the celestial sphere at a time, were found through parallax correction and the introduction of these corrected values into the two main calculation functions.

$$\epsilon = \varsigma + 0.00256\cos((125.04 - 1934.136\delta)^{rad}) \quad (10)$$

Solar Right Ascension (asc)

Right ascension is one of the two polar coordinates in the rotating equatorial coordinate system of spherical astronomy. Its second coordinate is declination. Right ascension in this case will be the angle measured at the celestial equator between the point of the vernal equinox and the intersection point of the hour circle passing through the measured celestial body. This is an analogue of the longitude of a place on the globe (second coordinate: latitude). Right ascension is more often expressed in time than in degrees or radians. The specification in terms of time refers to the fact that the apparent rotation of stars around the Earth is proportional to time and that the time difference can be determined more easily than the angles.

$$\text{asc} = \text{arctg}\left(\frac{\cos\eta^{rad}}{\cos\epsilon^{rad} * \sin\eta^{rad}}\right) \quad (11)$$

Sunset (dec)

In this case, sunset implies an angle based on the coordinates of the inclination of the Sun, taking into account the correction for nutation and aberration.

$$\text{dec} = \arcsin(\sin\epsilon^{rad} * \sin\eta^{rad}) \quad (12)$$

Variance (var)

In physics, dispersion is usually understood as the deviation of an object due to interaction with another local object (scattering center). Examples are the scattering of light on atoms or fine dust, or neutrons on atomic nuclei. The strength of the dispersion is determined by the so-called dispersion cross section. The name comes from the fact that the scattering cross section according to the classical theory, the dispersion of material points on a solid sphere is just equal to the cross section of the sphere. Elastic and inelastic dispersion are distinguished. In the case of elastic dispersion, the amount of kinetic energy after the collision remains unchanged. In the case of sunlight, the dispersion is correlated to inelastic. In the inelastic dispersion, part of the available kinetic energy is converted into the excitation energy of the atom or used to break the bond, for example, in ionization processes. The variance calculation provides information about the shape of the interaction potential.

$$\text{var} = \text{tg}\left(\frac{\epsilon^{rad}}{2}\right) * \text{tg}\left(\frac{\epsilon^{rad}}{2}\right) \quad (13)$$

Equation of Time (eq)

The equation of time in this calculation refers to the angular ratio of the mean geometric longitude and the mean geometric anomaly of the Sun in the corresponding coordinates and, consequently, the definition of the eccentric orbit of the Earth:

$$\text{eq} = 4(var * \sin(2 * \rho^{rad}) - 2 * \mu * \sin(\varepsilon^{rad}) + 4 * \mu * var * \sin(\varepsilon^{rad}) * \cos(2 * \rho^{rad}) - 0.5 * var^2 * \sin(4 * \rho^{rad}) - 1.25 * \mu^2 * \sin(2 * \varepsilon^{rad})) \quad (14)$$

Sunrise Equation (ha)

The calculation of the optimal location of the Sun at the desired point at a given time, these parameters are calculated by correlating the coordinates of the location of the object and the results of the "Sunset" equation.

$$\text{ha} = \arccos\left(\frac{\cos(90.833^{rad})}{\cos(\Xi^{rad}) * \cos(dec^{rad})} - \text{tg}(\Xi^{rad}) * \text{tg}(dec^{rad})\right) \quad (15)$$

Local sunny noon (noon)

$$\text{noon} = \frac{740-4*\phi-eq+\omega*60}{1440} \tag{16}$$

Local sunrise time (rise)

$$\text{rise} = \frac{noon-ha*4}{1440} \tag{17}$$

Local sunset time (set)

$$\text{set} = \frac{noon+ha*4}{1440} \tag{18}$$

Duration of sunlight (dur)

The duration of sunlight or the duration of effective insolation is a climatic indicator that measures the length of time during which a place is exposed to effective insolation, for example, solar radiation is intense and strong enough to create significant shadows. This indicator can be used as a reference for estimating the frequency of "good weather".

The duration of sunlight varies from region to region depending on geographical factors such as latitude, longitude and altitude, and climatic factors such as cloud cover or precipitation. The duration of the sunshine more or less strictly follows the general geographic distribution with a zonal trend, i.e. by latitude, but the small-scale distribution remains much more complex.

$$dur = 8 * ha \tag{19}$$

True Solar Time (tru)

The equation of true solar time based on the coordinates of the location of the object and the equation of time according can be calculates as follow:

$$n^I = \frac{0.1}{24} \tag{20}$$

$$tru = \frac{n^I + \frac{0.1}{24}*1440+eq+4*\phi-60*\omega}{1440} \tag{21}$$

Hour angle (ang)

The hour angle, together with the declination and distance (from the center of mass of the planet) determines the position of the celestial object, is the angle of a large circle passing through the object and the two celestial poles. Thus, it is a higher concept that takes into account the terrain and the depth to the center of the Earth at the location of the ground observer. In particular, the hour angles are the angles of ideal circles perpendicular (at right angles) to the celestial equator. The declination of an object observed on a celestial sphere is the angle of this object to/from the celestial equator (i.e. in the range from +90 ° to -90 °).

Condition:

$$\frac{tru}{4} < 0 \tag{22}$$

$$true: ang = \frac{tru}{4} + 180 \tag{23}$$

$$false: ang = \frac{tru}{4} - 180 \tag{24}$$

The angle of the solar zenith (zen)

The angle of the solar zenith is the angle between the sun's rays and the vertical. It is closely related to the angle of elevation of the sun, that is, the angle between the sun's rays and the horizontal plane. Since these two angles are additional, the cosine of one of them is equal to the sine of the other. Both of them can be calculated using the same formula using the results of spherical trigonometry. On a sunny afternoon, the zenith angle is minimal and equal to latitude minus the angle of declination of the sun.

$$zen = arccos(sin(\Xi^{rad}) * sin(dec^{rad}) + cos(\Xi^{rad}) * cos(dec^{rad}) * cos(ang^{rad})) \tag{25}$$

The angle of elevation of the Sun (elev)

The angle of elevation of the Sun above the horizon of the observer is called the height of the sun; in particular, the maximum height of the sun at noon (12 hours, true solar time), the measurement of which is the easiest way to determine the latitude of the location. The height of the sun at any time of the day can be calculated from an astronomical triangle using the time, date and position of the observer.

$$elev = 90 - zen \tag{26}$$

Approximate atmospheric refraction (approx)

Astronomical refraction is a change in the refraction of a beam of light falling on the earth from the outside, due to refraction in a stratified atmosphere. The reason is an increase in the refractive index from n= 1 in the vacuum of space to about n= 1.00029 on earth. Astronomical refraction is a special case of terrestrial refraction. The curvature of the light rays is directed downward — in the same sense as the curvature of the Earth, but much less. The most severe curvature occurs near the earth and makes up a maximum of 10-15% of the curvature of the earth with a very flat sight.

The Earth's atmosphere is denser at the surface of the earth than at high altitudes. Therefore, light rays coming from space at an angle are increasingly deflected downward due to astronomical refraction. To an Earth observer, if they are not approximately at the zenith, the stars appear higher than they would be without the Earth's atmosphere. The refraction value depends on the tangent of the zenith distance, as well as on the temperature and air pressure at the observer's location. At an altitude of 5 km, about half of the value at sea level is reached. The reason for astronomical refraction is the refraction experienced by each ray of light during the transition from an optically thinner medium to a denser one. The change in the direction of propagation occurs in differentially small steps between adjacent layers of air (Snellius' law of refraction) and must be integrated along the entire light path.

Condition:

$elev > 85$

$$approx = 0 \tag{27}$$

$5 < elev < 85$

$$approx = \frac{\frac{58.1}{tg(elev^{rad})} - \frac{0.07}{(tg(elev^{rad}))^3} + \frac{0.000086}{(tg(elev^{rad}))^5}}{3600} \tag{28}$$

$-0.575 < elev < 5$

$$approx = \frac{1735 + elev*\left(-518.2 + elev\left(103.4 + elev(-12.79 + elev*0.7)\right)\right)}{3600} \quad (29)$$

elev < -0.575

$$approx = \frac{\frac{-20.772}{tg(elev^{rad})}}{3600} \quad (30)$$

Solar altitude adjusted for atmospheric refraction (refr)

$$refr = elev + approx \quad (31)$$

The angle of the solar azimuth (azimuth)

The angle of the solar azimuth is the azimuth angle of the position of the Sun. This horizontal coordinate determines the relative direction of the Sun along the local horizon, and the zenith angle of the sun (or an additional angle of elevation of the sun) determines the apparent height of the Sun.

The following formulas assume clockwise rotation. The angle of the solar azimuth can be calculated with a good approximation using the following formula.

The formulas below can also be used to approximate the azimuth angle of the Sun, but these formulas use cosines, so the azimuth angle displayed by the calculator will always be positive and should be interpreted as an angle between zero and 180 degrees, in cases where the hour angle is negative (morning), and the angle between 180 and 360 degrees, when the hour angle is positive (during the day) (These two formulas are equivalent if we take the approximation formula "angle of elevation of the Sun").

Condition:

ang > 0

$$azimuth = \frac{\arccos\left(\frac{\sin(\Xi^{rad})*\cos(zen^{rad}) - \cos(dec^{rad})}{\cos(\Xi^{rad})*\sin(zen^{rad})}\right)}{360} \quad (32)$$

ang > 0

$$azimuth = \frac{540 - \arccos\left(\frac{\sin(\Xi^{rad})*\cos(zen^{rad}) - \cos(dec^{rad})}{\cos(\Xi^{rad})*\sin(zen^{rad})}\right)}{360} \quad (33)$$

3. Research results

It is necessary to draw up dependency relationship diagrams based on the previously given calculation points

The diagram of the position of the Sun is represented by the ratio of the solar height adjusted for atmospheric refraction and the angle of the solar azimuth (Figure 4).

The diagram of the position of the sun is valid only for locations with the same geographical latitude and only for one location if it is parameterized not by local solar time (true or average), but by zonal time. The position of the sun at any time of the day and on any day of the year, as well as the change in the duration of the sunshine can be read on the diagram of the position of the sun for this place.

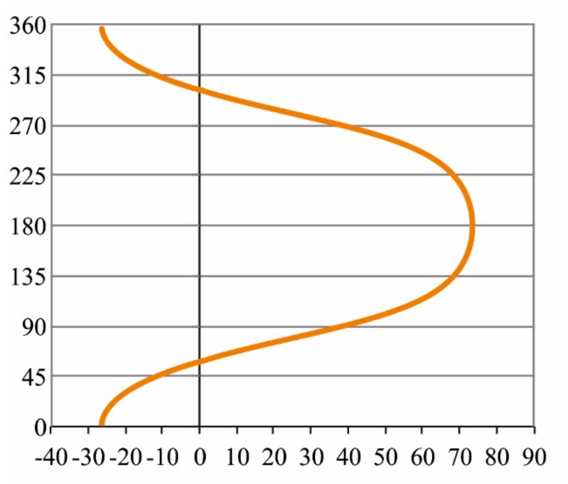

Fig. 4. Position diagram.

The solar declination diagram (Figure 5) indicates the declination of the sun, i.e. the time and latitude at which the sun is at its zenith, adjusted for nutation and aberration.

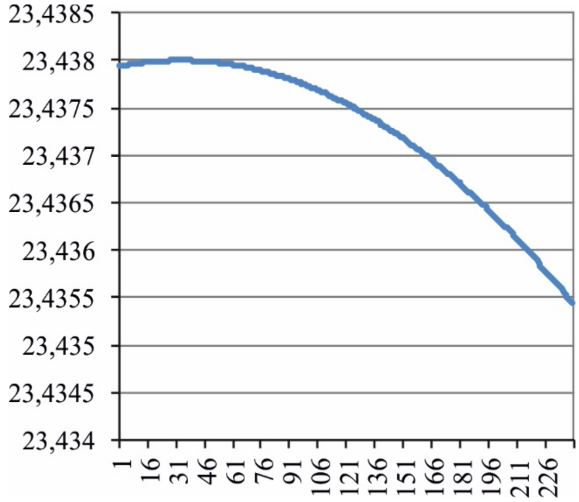

Fig. 5. Solar declination (deg.).

The diagram of the ratio of solar altitude adjusted for atmospheric refraction and time after midnight at a given location (Figure 6). This diagram is necessary to determine the point of maximum elevation of the Sun and the virtualization of the equipment using this calculation.

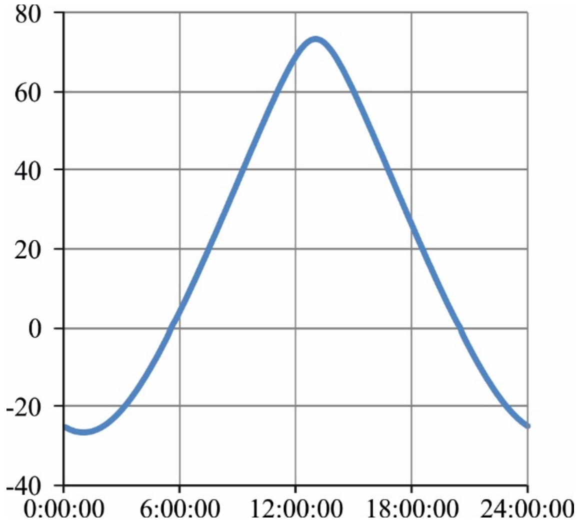

Fig. 6. The ratio of height to time.

4. Discussion and conclusion

In this manuscript a new approach to the development of a solar panel guidance system on the sun was developed. According to the proposed approach a method for calculating the guidance of a solar battery on the sun has been elaborated. The angle of the tracker system position relative to the changing position of the sun is calculated.

According to the proposed mathematical equations have been calculated the maximum and minimum azimuth of the sun, and the following paramathers:

Solar right Ascension; Sunset; Dispersion; Equation of time; Equation of sunrise; Local solar noon; Local sunrise time; Local sunset time; Duration of sunlight; True solar time; Hour angle; Angle of solar zenith; Angle of elevation of the Sun; Approximate atmospheric refraction; Solar altitude adjusted for atmospheric refraction.

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