Development of a sun tracking algorithm for solar panels for agricultural enterprises

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Abstract. In agriculture, use of solar energy is of crucial importance for water heating and functioning of greenhouses. It becomes even more important in agricultural enterprises which are located far from electric energy transmission lines. Furthermore, in Russia the importance of solar energy for agricultural enterprises can be motivated by deterioration of electric energy transmission lines. The article is devoted to the development of a sun tracking algorithm for solar panels without using GPS or sensors. The tracking algorithm has been created on the basis of well-known astronomic methods for calculation of the Sun’s position in azimuth coordinates. The control diagram using the Arduino platform is presented. The authors’ program works for the calculation of the Sun’s position complete with evaluation of error. It also works well with servo drive units. The hardware and software bundle have shown acceptable error values which did not exceed 2 % while aligning the panels with the sun.

1. Introduction

At the present time, using autonomous sources of electricity, both for lighting agricultural enterprises and for operating their technological equipment, is of crucial importance. The importance of solar energy for agricultural enterprises is motivated by its application in water heating and in the functioning system of greenhouses. Solar energy is of particular importance for agricultural enterprises which are located far from the main electric energy transmission lines, as well as in case of deterioration of the lines.

Current machinery is represented by solar panels without the possibility of alignment with the sun, therefore the energy performance depends on the angle of the machinery expressed as its direction in azimuth coordinates, thus the station operating modes cannot change. In addition, GPS positioning towards the sun is used only for big solar panels which are not always applicable to tasks related to the electric performance of autonomous energy sources for the facilities of agricultural enterprises. In many works, the use of photocells is proposed, but they introduce a natural margin of error in sun tracking depending on weather conditions, for example in case of dull weather. Moreover, such solar trackers are mainly meant for climatic conditions where snow is almost absent, which makes them a more sustainable solution for warm weather conditions, but not for Russia [1, 2]. Margins of error in GPS positioning can occur in case of dull weather as well, which is particularly problematic during winter for agricultural enterprises located on the territory of Russia, where air temperature can reach 30°C below freezing, especially for those who are located far from electric energy transmission lines or in case of deterioration of such lines [3]. In winter season in Russia, it is particularly important to preserve the energy conversion efficiency of solar panel while using them in agricultural enterprises in...
order to supply them with electric energy, heat cattle houses and water, supply greenhouses with
electric energy, exsiccate hay, fodder, etc. The energy conversion efficiency of solar panel depends on
the precision in the alignment with the sun.
For this reason, the task at hand of developing a tracking algorithm for solar panels which does not
depend on GPS technologies for agricultural enterprises is of crucial importance and current interest.
In the present article, the results of the development of such an algorithm and of test operations
regarding its application using the platform Arduino and servo drive units are presented.

2. Materials and methods
The software environment DevC+ and the programming language C++ were chosen as a platform for
development of the source code. After obtaining the results of the mathematical modelling within
tolerable limits, the code was transferred to the Arduino IDE, which controlled an ATmega2560
microprocessor on the Arduino Mega 2560 platform. The program was written using Arduino IDE
(Integrated Development Environment), an application which allows software development and its
compilation to machine code.
While choosing the controller, Arduino Due and Arduino Uno were taken into consideration. Both
controllers are suitable for the execution of the tasks at hand, the performance comparison of the
controllers taken into consideration is presented in Table 1.

Table 1. Performance comparison of Arduino

| Microcontroller | ATmega328 | AT91SAM3X8E | ATmega2560 |
|-----------------|----------|------------|------------|
| Operating voltage, V | 5        | 3.3        | 5          |
| Digital input/output, pcs | 14       | 54         | 54         |
| Analog input/output, pcs | 6        | 12         | 16         |
| Ram, kB         | 2        | 96         | 8          |
| Clock rate, MHz | 16       | 84         | 16         |
| Flash memory, kB | 32       | 512        | 256        |
| Maximum output current, mA | 40       | 800        | 40         |
| Overall dimensions, mm | 68x53   | 101x53     | 101x53     |

Arduino Uno was chosen.

To control the functioning of the program, the servo drive units MG996R and the stepper motor
28BYJ-48 were chosen to direct the toy model. For further development, calculations should be
carried out on more efficient gear units and motors.

A standard connection scheme was used, consisting of an Arduino time-keeper RTC and 2 drive
units.

The empirical measurements of the efficiency of the rotating mechanisms were carried out in a
stand-alone system over a period of 3 days using a servo drive unit MG996R for zenith direction and a
stepper motor 28BYJ-48 for azimuthal direction. The operations were controlled by the ATmega2560
microprocessor of Arduino Mega 2560. The control of the mechanisms was realised using online
open-source calculating tools, as well as GPS calculators.

3. Development of a sun tracking algorithm for the station without using GPS
The system of equatorial coordinates and the hour angle were taken into considerations in the creation
of the sun tracking algorithm. This system of coordinates is counted off in relation to the plane of the
terrestrial equator. This plane is called equatorial and bends over the plane of the horizon with an
angle of 90° – \( \phi \), where \( \phi \) is the latitude where the observer is located. One of the coordinates of the
equatorial system is the declination \( \delta \), which indicates “how high” from the plane of the equator a star
or an observed object is located in the sky. The second coordinate shows “how far in the distance” an
object is located from a predetermined point in the sky. This is the vernal equinoctial point, the
position of which is determined by the intersection between the terrestrial equator and the ecliptic, as
shown in Figure 1. This point is constant in relation to the stars (and the sun) and namely in relation to it the second coordinate – the right ascension $\alpha$ – is calculated [4].

Over time the sun moves westward in the sky along the ecliptic, completing one rotation in 24 hours according to sidereal time. It is well known that the plane of rotation is parallel to the plane of the equator, thus the declination does not change. Hence the generally accepted conclusion that since the vernal equinoctial point occupies a fixed position in the sky, it changes its position with the same angular speed as the sun during rotation. Subsequently, the right ascension of a star does not change. The angle between the plane of the ecliptic and the equator does not change as well, which makes calculation easier [4, 5].

![Figure 1. Vernal equinoctial point and plane of the ecliptic](image1)

![Figure 2. Hour angle](image2)

As a result, $\alpha$ and $\delta$ are to be considered suitable coordinates for describing the position of the sun [6]. Besides right ascension, another value is represented by the hour angle $H$. It is the measure of the time, which passes from the moment of intersection between a star and a meridian, as shown in Figure 2. The magnitude $H$ steadily increases over time and returns to zero when the star crosses the meridian where the altitude of the celestial body is the highest at the moment [4].

Thus, we came to the conclusion that there are theoretical data which allow for development of an algorithm for autonomous sun tracking. The analysis of such material has shown that for this purpose it is necessary to know the date, time, latitude and longitude of the location.

Moreover, a continuous count of days, starting from 12:00 UT of January 1st, 4173 BCE, is used in astronomy in order to simplify calculation. The amount of average solar days from 12:00 of January 1st, 4713 BCE until the moment of observation is called Julian date (JD). The calculation of the Julian date using the Gregorian calendar is performed using a well-known algorithm [3]. To calculate the azimuthal angle of the sun and to determine more precisely the necessary rotation angle of the panel, Figure 3 is to be taken into consideration.

![Figure 3. Determination of the position of the sun with respect to the solar panel](image3)
In order to determine the position of the sun in relation to the solar panel, the following general function must be used:

\[-b + A = Q\]  

(1)

where \(b\) is the rotation angle of the solar panel, \(A\) is the azimuthal angle of the sun, and \(Q\) is the necessary rotation angle.

Moreover, if the coefficient of \(b\) is negative, the value of the rotation angle is determined as the addition in (1). Thus, the algorithm for the operation of the station can be represented by the flowchart in Figure 4.

![Flowchart](image)

**Figure 4.** Operation algorithm of the solar station

In this algorithm, the rotation of the station is operated each 20 minutes.

The results of the operation of the algorithm in C++ language are presented in Figure 5.
The results of the software operation were controlled using the online calendar for the calculation of the position of the Sun [7], which showed a margin of error in the calculation of angles less than 2%. After obtaining the results of angle calculation within tolerable margins of error, the code was transferred to the Arduino IDE and adapted.

While analyzing the functioning of the algorithm, the most critical area in the code is represented by the frequency of station rotation, that is, the condition:

\[
\text{if (min2 \% 10 == 0)} \{ /minute multiplies of 10... \}
\]

A frequency of 10 minutes turned up to be the most efficient as regards energy saving and preserving the perpendicularity of the incidence angle of sunbeams.

The operation of the drive units is shown in Figures 6–7.

**Figure 6. Rotation of the drive unit along the azimuth**

**Figure 7. Rotation of the servo drive unit along the zenith**

Figure 8 shows the output of the values of the rotation angle on the video port.
Figure 8. Output of the rotation angles on the video port

The empirical measurements of the efficiency of the rotating mechanisms were carried out in a stand-alone system over a period of 3 days using a servo drive unit MG996R for zenith direction and a stepper motor 28BYJ-48 for azimuthal direction. The operations were controlled by an ATmega2560 microprocessor in Arduino Mega 2560. The control of the mechanisms was implemented using online open-source calculating tools, as well as GPS calculators. The obtained results in the calculation over a series of 100 measurements showed a margin of error of 2% using the servo drive unit MG966R and 1% using the stepper motor 28BYJ-48.

4. Conclusion
A mathematical model for the solution of problems related to sun tracking using autonomous search by the solar station has been elaborated, on the base of which an algorithm has been developed, making it possible to develop software for control of the station. Simulation of devices, test operations on the precision of angle calculation by the software itself have been carried out using an online calculator of the Sun’s position.

Test operations on the functioning of the servo drive units and the precision of the calculation of the algorithm by the software itself have been carried out, showing a tolerable margin of error – less than 2% – in the functioning of the servo drive units while aligning the panels with the Sun. The advantage of this algorithm under conditions of long winter season with significant cloud coverage consists in the determination of the sun position at dawn and sunset, during which the energy obtainable from sun beams is at its peak.
Thanks to this as well as to the fact that the developed algorithm can be introduced in the management of solar panels using the already existing structures of the rotating mechanism, the economic feasibility of applying the results of the present research can be inferred. In addition, it should be noted that, if compared to monoaxial trackers, biaxial sun tracking is more reliable and does not need attenuators. The use of a biaxial tracker is also supported by the fact that during further development it will become the basis for the elaboration of a mechanism for cleaning snow or preventing snow from “depositing” on the panel. This is also of crucial importance for agricultural enterprises where the cleaning of snow can become complicated.

The research results may be further applied to the use of solar energy in order to increase the energy performance of solar panels used for different operations carried out in agricultural enterprises. It is of particular importance in Russia, where there are agricultural enterprises located considerably far from the main electric energy transmission lines or possess deteriorated lines. Furthermore, in winter season, the precise alignment with the sun is especially important when using solar energy to heat cattle houses and water, exsiccate hay and fodder, supply greenhouses with electric energy and so on.

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