

Sun Movement Demonstrator

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Abstract

Sun movement demonstrator is an electromechanical device that visualizes movement of the sun on the sky for chosen geographical location and season. This device was designed and built in the framework of student projects, also including Brazil-Czech academic internship program UNIGOU. This project combined skills of project management, celestial mechanics, geometry, mechanical design by CAD, 3D printing, mechanical technology, mechanical assembling, assembling of electronic components, including soldering and Arduino programming. The device is now fully working and serving mainly for teaching and advertising the topic of solar energy. It nicely demonstrates the potential of solar energy and its seasonal variability.

Keywords: celestial mechanics, solar energy, 3D printing, mechanical design, Arduino programming

INTRODUCTION

Considering sun movement and solar energy, one might ask for example whether sun can ever shine on the back side of photovoltaic modules, if they are ideally oriented toward south. Or as another example, whether there could be shadow during a summer day on south side of a house. Answer is surprisingly affirmative. This is because in summer, sun is not rising at east, as one would say, but at north-east and setting not at west, but at north-west.

To better understand this behaviour and to learn more about sun movement on the sky [1,2], it is useful to transform the observer's time into a sidereal time. The sidereal time is the time in which we count sunsets and sunrises of stars and not Sun. In that time, the year has one day more (366 days). On Prague's astronomical clock sidereal time is indicated by a small star, see Fig 1.

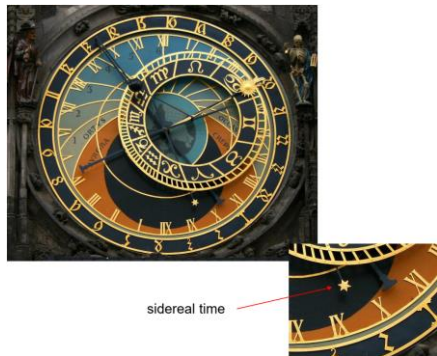


Fig. 1 – Astronomical clock in Prague shows four different times including sidereal time.

We remain in the coordinates of Earth (we are rotating with Earth), but we move far away, so that we can see both Earth and Sun in front of us. Then the situation is as shown in Fig. 2 and Fig. 3.

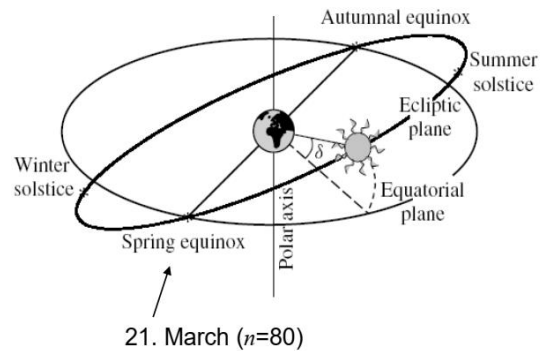


Fig. 2 – Thick lines shows the set of points given by the positions of Sun at *sidereal noon* during a year.

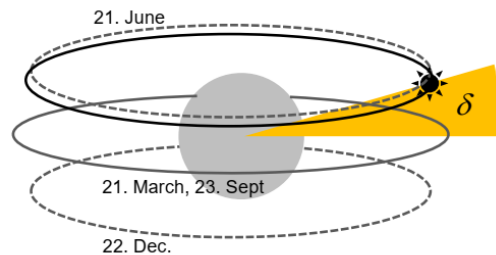


Fig. 3 – Thick lines shows the set of points given by the positions of Sun during one day. Thin and dashed lines represents special days: equinox and solstices.

When we move our coordinate system back to Earth's surface then only sections of the circles depicted in Fig. 3 are visible above horizon. Also, the latitude of the observer's location affects the tilt of the circles. The situation is now shown in Fig. 4.

MECHANICAL CONCEPT

To simulate the sun movement it is necessary to define latitude Φ , declination δ (season), and Earth rotation ωt (time), see Fig. 4.

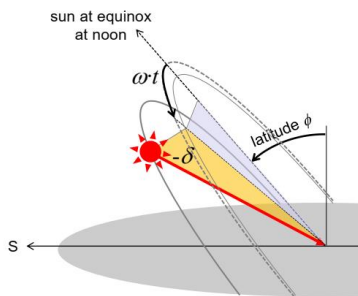


Fig. 4 – Motion of the sun on sky is defined by three independent parameters.

Mechanical concept had to be determined at the very beginning. The key decision was that ωt motion would be realized by individually controlled LEDs on a LED strip formed into a circle. The latitude Φ would be realized by rotating the circle and declination δ would be realized by mutual shift of the observer (model of a house) and the rotation axis of the circle. Because this mutual shift has a direction dependent on latitude, it had to be realized by a combination of vertical and horizontal movements.

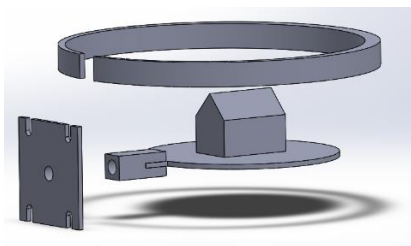


Fig. 5 – Realizing the horizon (circular plate), observer (model of the house) and sun (circle where LEDs will be attached).

MECHANICAL DESIGN

Together with mechanical concept, the method of control and human interface were determined. The choice was to

use Arduino microcontroller, LCD display and four navigating buttons.

Once the mechanical design and human interface had been defined, all the commercially available components were selected from the market and eventually purchased, see Fig. 6 (LCD display, navigating buttons and LED strip is missing).

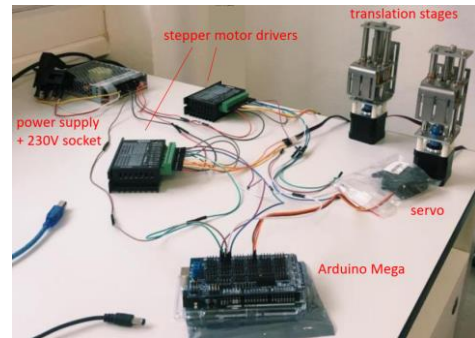


Fig. 6 – Commercially available components being tested and their dimensions and positions being defined.

After all commercial components were known with their exact dimensions, the aluminium frame was designed including positions of all the holes and protrusions, see Fig. 7. The aluminium parts were then machined by water jet from aluminium sheets. Minimum mechanical adjustment was necessary to do afterwards. Aluminium parts were painted black by anodizing.

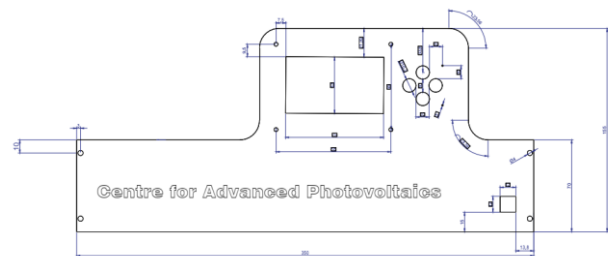


Fig. 7 – Metal parts were precisely designed including all details and hole drilling.

Remaining plastic parts such as the circular LED holder (adjusted according to dimensions of commercial LED strip), model of a house, platform and many other small ones were designed in 3D CAD software and 3D printed.

ASSEMBLY

The assembly represented one of the largest problem for students because still few remaining questions needed to be solved: the problem of position referencing of the translation stages or the problem of shaft bearing of the circle rotation (because servo provided only motion but

not bearing). These skills were definitely beyond the competencies of master students. Also soldering of electrical contacts was a considerable problem for some students. Finished sun movement demonstrator is shown in Fig. 8.

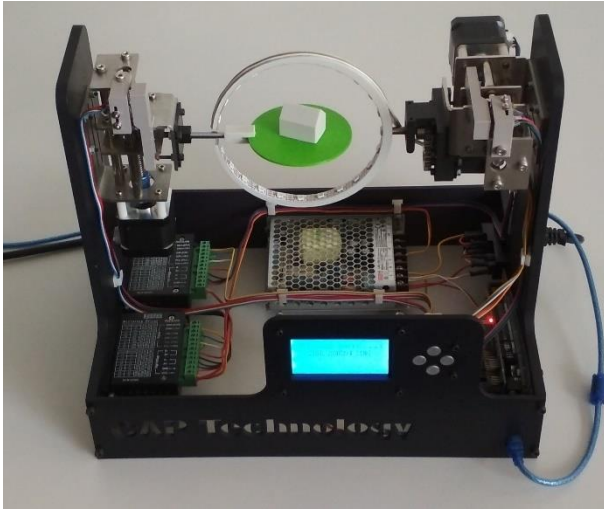


Fig. 8 – Finished sun movement demonstrator.

PROGRAMMING

The chosen microcontroller was original Arduino MEGA2560 REV3 equipped with an Arduino MEGA Sensor shield v2.0. Additionally, a set of libraries was installed for controlling all the other peripherals.

Stepper motors

hardware: Machifit CNC Z Axis Slide Table 50-60mm, fed by driver TB67S109AFTG

libraries: Stepper.h, AccelStepper.h, MultiStepper.h

initialization: AccelStepper

setup: setMaxSpeed, setAcceleration

commands: `digitalWrite(pin, HIGH);`
`delayMicroseconds(500);`
`digitalWrite(wahl2, LOW);`

Referencing was done by while loop and reading microswitch value:

```
do{ ...stepping commands...
} while(digitalRead(pin) == false);
```

Servo

hardware: Servo with metallic gears MG996R

libraries: Servo.h

initialization: Servo

setup: attach

commands: write

LCD display

hardware: ST7920 128x64

libraries: U8g2lib.h, U8x8lib.h, two other libraries are combined as follows: `#ifdef U8X8_HAVE_HW_SPI`
`#include <SPI.h>`
`#endif`
`#ifdef U8X8_HAVE_HW_I2C`
`#include <Wire.h>`
`#endif`

initialization: `U8G2_ST7920_128X64_F_SW_SPI u8g2`

setup: `u8g2.begin //defines navigating buttons`

commands: `u8g2.clearBuffer, u8g2.sendBuffer`
`u8g2.setFont, u8g2.drawStr`
`u8g2.userInterfaceMessage,`
`u8g2.userInterfaceSelectionList`

Important: all commands should be inside while cycle as follows:

```
u8g2.firstPage();
do{
...display commands...
} while (u8g2.nextPage());
```

LED strip

hardware: WS2812B, the strip is sensitive to the end where it is fed

libraries: FastLED.h

initialization: CRGB leds

setup: `FastLED.addLeds`

commands: `leds //sets colour of given LED`
`FastLED.show();`

RESULTS AND DISCUSSIONS

After switching on, the demonstrator performs calibration when the translation stages and servo go to their initial positions. Then the demonstrator performs cycle of simulations of randomly selected combinations of latitude and seasons until a right navigating button is pressed. Then the user is given a choice whether the selection will be from a list of pre-defined cities or by a numerical value of latitude. Choosing the first option will then follow selection of city and season, see Fig. 9.



Fig. 9 – User definition of city (latitude given in bracket) and season.

After performing the selection, the servo goes to corresponding angle and consequently stepper motors go to corresponding vertical and horizontal positions. Individual LEDs start lighting up in a sequence from east to west, while LCD display shows corresponding local time, see Fig. 10.



Fig. 10 – Sun movement simulation sequence being performed.

The model of a house is producing a shadow on the platform, which is nicely visible when looking from top, see Figure 11. The two examples demonstrate that in Prague in summer, many places on north side of the house receive no shadow, if they are in a sufficient distance from the house, while on the south side of the house there are many places that receive shadow in the morning and in the evening, no matter how far they are from the house.

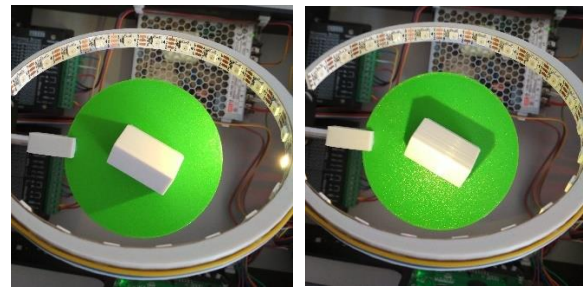


Fig. 11 – Observing the places receiving shadow on north side (direction up) and south side (direction down) during summer in Prague. Left: morning, Right: noon.

CONCLUSIONS

Solar movement demonstrator is an electromechanical device that interactively and instructively demonstrates the sun movement on the sky for selected location and season. The process itself of building such device might be interesting as a student project, because many skills and new technologies can be learned. The device uses many commonly available components that are currently highly popular for hobby 3D printers, RC models, and entertainment and combines them in a new and original way. The device behaves as expected and so far we have not identified any noticeable weaknesses.

ACKNOWLEDGEMENTS

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