WEB-BASED PROGRAM PACKAGE FOR MODELLING OF SOLAR ENERGY FALLING ONTO THE PANEL OF SOLAR CAR ALONG THE ROAD

by
Murad Eminov

A Master's Project
submitted in partial fulfilment
of the requirements for the degree of
Master of Information Technology
Fachhochschule Kiel

June 03, 2015

ABSTRACT

The web-based program package has been developed for modeling of the amount of the solar energy falling on the panel of solar car along the road. The input parameters of the model are: 1) instant of Greenwich time; 2) geographical coordinates (latitude, longitude and height from the sea level to the point at road); 3) the road tilt. The main output of the model is the amount of solar energy falling on the solar car for any instant of time and position of the car on road. As a study case the road Kiel-Berlin(Germany) and Baku-Shemakha (Azerbaijan) are taken. The database of solar energy, obtained by the calculations on the model for those roads has been used to develop the easy-to-use interface JavaScript based front-end web-application to simulate the motion of the solar car. The web application of this model can be considered as the prototype of the navigation system of solar cars which will provide their optimal controlling.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction. At present the use of solar energy increases rapidly year after year and according to the prognosis of the International Energy Agency (IEA), in 2050 the solar energy will occupy the first place in production of electric power. There is no doubt that in the near future the era of vehicles working with petroleum products will come to an end and the transition to the electric vehicles moving by the solar energy (solar cars) will gradually begin. Such optimistic forecast is based on the background that the photoelectric cells of the new generation with high efficiency become a reality.

Now, at the different leading research centres and universities of the world the intensive investigations in the direction of creation of solar cars working with solar energy and having suitable characteristic for mass production are carried out. Within the last years the permanent competitions of solar cars have been holding and the average speed about 90 km/h has already been reached. Mass production of solar cars will be realized if their technical characteristics (overall dimensions, mass, speed, body capacity, etc.) will be close to the conventional cars. The obtained results and intensity of investigations in this field gives us the confidence in reaching the necessary characteristics soon.

Thus, the existence of sufficient amount of solar radiation is necessary for efficient working of solar cars. It is known that the amount of solar radiation at the fixed point is maximal when sunbeams fall perpendicularly on the panel of the car. If solar panel has no flexibility, then to satisfy this condition continuously along the road is impossible because it needs the variation of orientation of the panel. Construction of a flexible solar panel following the Sun, similar to sunflower, seems unreasonable because the shape of the car must have the aerodynamic feature.

The main feature of solar cars which distinguish them from conventional cars is the reality that the origin of energy takes place outside of car and, therefore, cannot be controlled. If solar cars receive enough solar energy they will be able to continue motion regularly. This fact requires the optimal synergetic usage of the solar energy and energy of accumulators. Because, the amount of solar energy received by the panel depends on outside factors, the prediction of the amount of received solar energy in any point of road and at any moment of time is necessary for optimal managing of solar cars.

The amount of solar radiation falling on the panel of the car, at the given point and fixed instant of time, depends on several factors. Some of those factors have a deterministic character but others – random. The deterministic factors are the followings:

1. The zenith and azimuth of the Sun. At the given point of observation and fixed moment of time those angles determine the position of the Sun in the sky and are calculated by using formulas of astronomy.

2. The tilt of the road at the given point. The angle between the sunbeam and the normal to panel, thereby the amount of radiation, depends on tilt.

3. The relief of territory surrounding the given point. During some period of time the Sun may be shaded by relief (hills, mountains, etc.) and the amount of radiation falling on the panel will be essentially small.

The random factors acting to the amount of radiation are the followings: clouds, aerosol, dust, mist, smoke, rain, snow etc.

The objective of this work is to develop the mathematical model for calculation of the quantity of solar radiation falling on the panel of solar car in any point of road and in any moment of time. The algorithm based on this model and program package for calculation was realized. On basis of calculation a data base for simulation of solar car motion on two selected routes Kiel-Berlin and Baku-Shemakha was created. At the present project the random factors (clouds, aerosol, dust, etc.) and shadowing the road by the relief is not taken into account. Those factors will be an object of master thesis study in future.

The route Kiel-Berlin is located in the latitude about 52^0 N and route Baku-Shemakha about 40^0 N. Due to the latitude difference about 12^0 of those routes the comparison of solar energy along those routes and assessment of influence of road location to efficiency of solar car motion can be made.

Considered here task**,** modelling of the amount of solar radiation falling to the panel of solar car along the road**,** is the first stage of general problem of optimal control of solar car. The second stage is the development of optimal control method of solar car if the amount of solar energy is known at any point of road and any instant of time. The first problem is connected with astronomic factors, road characteristics and weather conditions and is not linked with certain characteristics of solar car. The solution of the second problem depends on concrete characteristics of the car and the formulation of optimization problem. Some particular solutions of optimization problem are described in [1,2].

Because the solar radiation is the origin of all energies existing in the Earth, its study was the object of numerous investigations in Earth Physics, meteorology, climatology, agriculture etc. There are a series of methods developed for determination of solar radiation falling onto the Earth surface. The review of those methods are given in [3,4]. Generally, in the field of sciences mentioned above, the statistical (time-space) characteristics of solar radiation averaged in large time and space intervals are evaluated and used. But, when considered the motion of solar car, the knowledge of solar radiation distribution with the time step about minute and spatial step about several meters is required.

In principle, developed here model of solar radiation gives the amount of solar radiation at any moment of time and any point of Earth for clear atmosphere. The main difference of suggested model from existing is: here the solar zenith and azimuth are determined by solving Kepler's equation [5-7], which gives more exact solution of considered problem.

In the Master Thesis this model will be generalized for turbid atmosphere by using satellite data of Linke turbidity factor. In this case, the problem will not be fully deterministic because of using prediction of Linke factor.

The input parameters of the program are:

1. The time t, which is given on Greenwich;

2) The geographical coordinates (latitude, longitude φ) of the considered point M on the road;

The main intermediate calculated parameters are:

1) The height h (from the sea level) of considered point M on the road which are derived from 3D model of territory using ArcGIS or Google Earth tools;

2) T_L - Linke atmosphere turbidity factor, which is obtained from the satellite data.

3) The zenith θ_n and azimuth ϕ_n - angles of the normal to the road surface at the point M, which determine the road tilt;

Outputs of the program are:

- The amount of the direct, diffuse and global solar energy falling onto solar car panel in any point of the road and for any moment of the time.

2. Mathematical model of solar radiation

Developed by us mathematical model consist of four stages. The first stage: the location of the Earth on the elliptical orbit around the Sun is found; The second stage: the latitude and the longitude of the Sun are determined; The third stage: in any point on the Earth and at any moment of time the Solar zenith and azimuth are found; The fourth stage: the amount of total (direct + diffuse) Solar radiation is calculated.

2.1 Determination of the Earth Location in orbit

The location of the Earth in orbit is determined by the solution of Kepler's equation of orbital motion:

$$M = E - e \sin E \qquad (1)$$

where, E - eccentric anomaly, M -mean anomaly. Eccentric anomaly E is related to the true anomaly φ equation:

$$\varphi = 2\arctan\left(\sqrt{\frac{1+e}{1-e}}\ \tan\frac{E}{2}\right) + \frac{\pi}{2} \qquad (2)$$

where, $e = 0.016729$ - eccentricity of the Earth's orbit. Mean anomaly M related to the time t (seconds), reckoned from the moment of the vernal equinox: $M = \frac{\sqrt{GM_S}}{a^{3/2}}\ t \approx 0.199 \times 10^{-6} \cdot t$; here, $M_s = 1.989 \times 10^{30}\ kg$ - mass of the Sun, $M_s = 1.989 \times 10^{30}\ N \cdot (m/kg)^2$ - gravitational constant, $a = 1.496 \times 10^{8}\ km$ -major axis of the elliptic Earth's orbit. The joint solution of equations (1) and (2) gives the dependence of the angle φ on the time t: $\varphi = \varphi(t)$, i.e the location of the Earth in orbit at any given time. For the solution of Kepler's equation various methods (Taff 1985) have been developed. The capabilities of modern computers allow us to solve numerically the equations (1) and (2) with great accuracy.

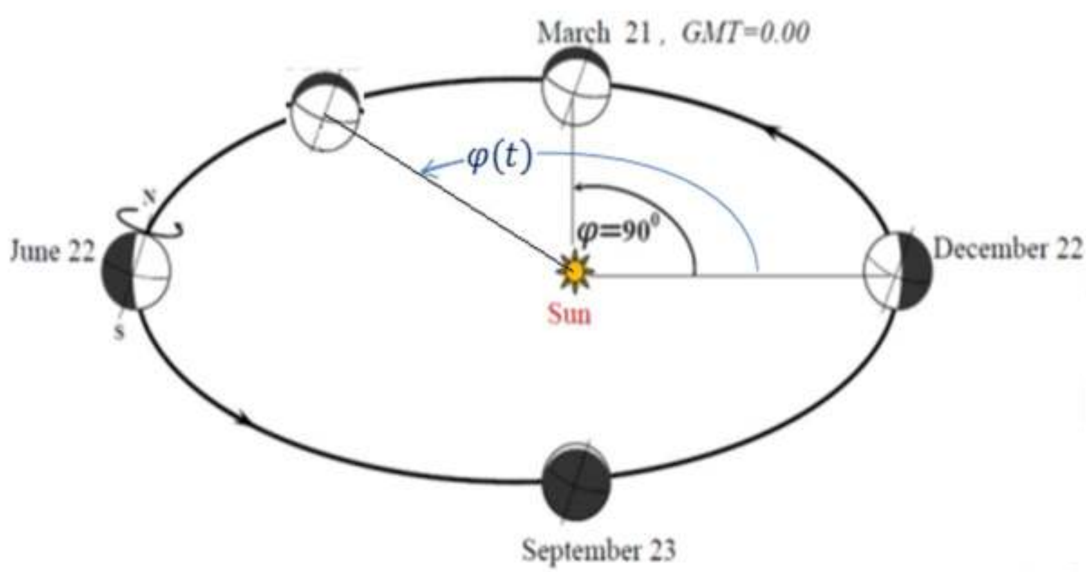


Figure 1. The motion of the Earth around the Sun

2.2 Determination of the solar latitude and longitude

Suppose that, at the moment of the vernal equinox ($t = 0$), (around March 21), the Greenwich Mean Time (GMT) is: $GMT0$. The precise value of $GMT0$ is determined by astronomical calculations and varies from year to year. At the moment $t = 0$, the meridian of Greenwich will have an angle $\varphi_{\mathrm{GMT0}} = \frac{\omega}{2\pi} \cdot \mathrm{GMT0}$ from the direction of AB (Fig. 2), where, $\omega = \frac{2\pi}{\mathrm{T_{sid}}}$, $\mathrm{T_{sid}} = 23.96\ h. = 23.96 \times 3600\ sec. = 86256\ sec.$ - sidereal rotation period of the Earth. Then, at time $\mathrm{t} > 0$ the Greenwich meredian will form with the direction of AB, the angle:

$$\varphi_{\mathrm{G}} = \varphi_{\mathrm{GMT0}} + \omega \cdot \mathrm{t} \tag{3}$$

As it can be seen, the angle φ_G, determining the longitude of the Sun depends on two parameters: t and $GMT0$. From spherical triangles in Fig. 2, we determine the latitude θ_{Sun} and the longitude φ_{Sun} of the Sun:

$$\left.\begin{array}{r}\theta_{\mathrm{Sun}} = \arcsin[-\sin(\delta)\cos(\varphi)] \\ \varphi_{\mathrm{Sun}} - \varphi_{\mathrm{G}} = \arcsin[-\sin(\varphi)\cos(\theta_{\mathrm{Sun}})]\end{array}\right\} \tag{4}$$

Thus, the formulas (4) determine the dependence of the latitude θ_{Sun} and the longitude φ_{Sun} on time t

$$\begin{cases}\theta_{\mathrm{Sun}} = \theta_{\mathrm{Sun}}(\mathrm{t}) \\ \varphi_{\mathrm{Sun}} = \varphi_{\mathrm{Sun}}(\mathrm{t})\end{cases} \tag{5}$$

since, the angle φ depends on time t.

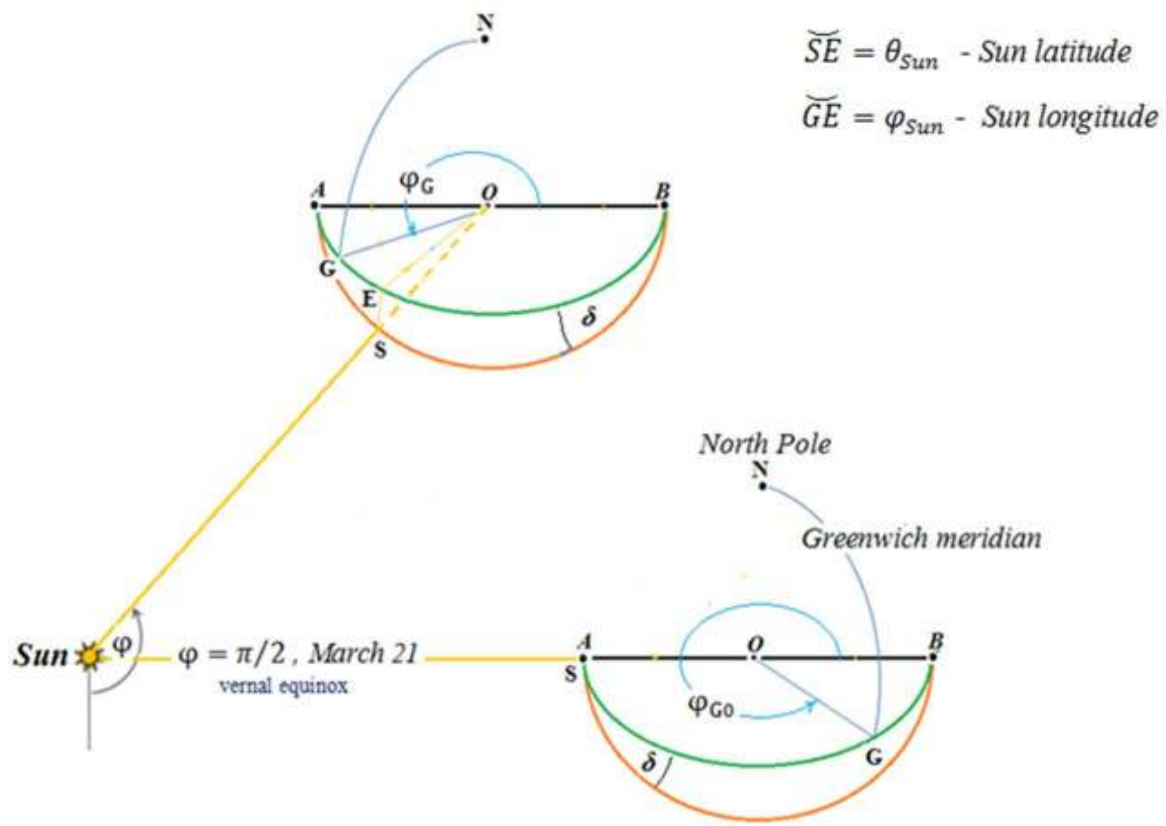


Figure 2. The determination of solar zenith and azimuth

2.3 Determination of solar zenith and azimuth

To determine the zenith i_{sun} and the azimuth ϕ_{sun}angles of the Sun at the given point $M(lat = \theta_M \,, lon = \varphi_M)$ on the Earth at the given moment of time, let us turn to Fig.3. As we see from the spherical triangular NMS :

$\angle NMS = \phi_{sun}$; $\angle MNS = \varphi_{sun}$; $\angle NOM = 90^0 - \theta_M$; $\angle NOS = 90^0 - \theta_{sun}$ and $arc\ \breve{MS} = \angle MOS = i_{sun}$. Applying to the triangular NMS cos-theorem, we obtain:

$$\cos \breve{MS} = \cos \breve{NM} \cos \breve{NS} + \sin \breve{NM} \sin \breve{NS} \cos(\varphi_{sun} - \varphi_M) \tag{6}$$

$$\cos \breve{NS} = \cos \breve{NM} \cos \breve{MS} + \sin \breve{NM} \sin \breve{MS} \cos \phi_{sun} \tag{7}$$

From (6) and (7) we find:

$$\cos i_{sun} = \sin\theta_M \sin\theta_{sun} + \cos\theta_M \cos\theta_{sun} \cos(\varphi_{sun} - \varphi_M) \quad (8)$$

$$\cos\phi_{sun} = (\sin\theta_{sun} - \sin\theta_M \cos i_{sun}) / \cos\theta_M \sin i_{sun} \quad (9)$$

The formulas (8) and (9) determine the zenith i_{sun} and azimuth ϕ_{sun}angles of the Sun on the dependence of point $M(\theta_M, \varphi_M)$ and time t.

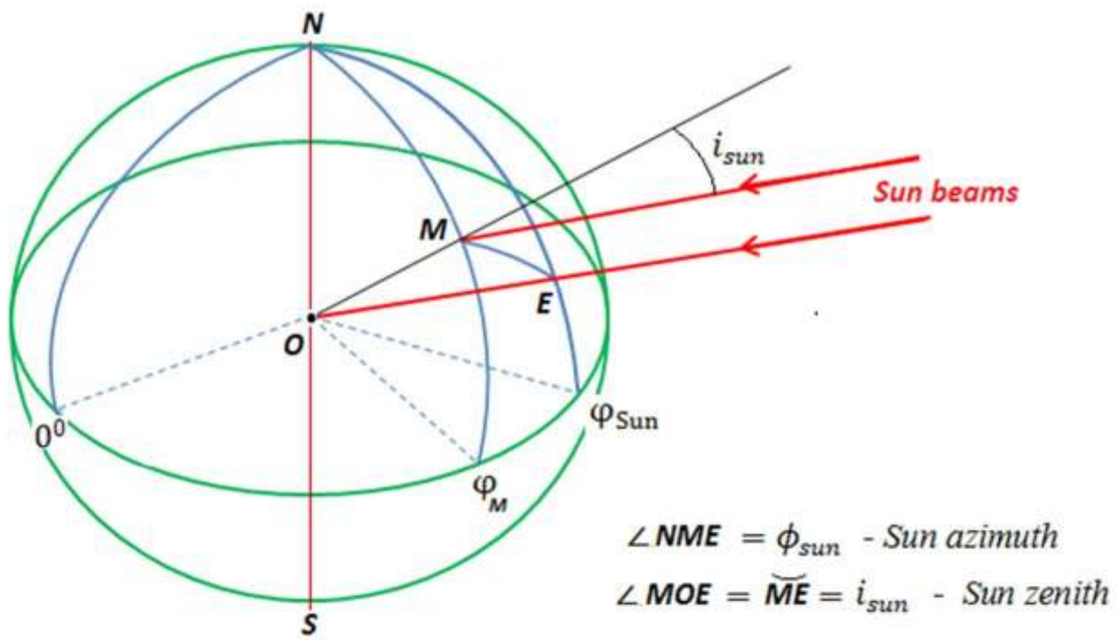


Figure 3. The calculation of solar zenith and azimuth

2.4 Determination of Solar energy falling on the panel of solar car

In the case of clear atmosphere, the amount of direct solar radiation reaching the solar car panel is defined by the formula (Fig. 4)

$$S_p(i_{sun}) = S_0 \cos\chi_n \exp\left(-\frac{\tau}{\cos i_{sun}}\right) \quad (10)$$

where, S_0 = 1367 W/m^2 –solar constant (i.e. the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays, at upper boundary of atmosphere);

χ_n – angle between the sunbeam and normal to the panel.

τ - atmosphere optical thickness, which is for clear atmosphere $= 0.3$. Note that τ is connected with Linke turbidity factor T_L : $T_L = \tau/\tau_R$. Here $\tau_R = 0.2$ –is Rayleigh optical depth of atmosphere (where takes place only pure molecular scattering).

The angle χ_n is defined through the zenith i_{sun}, azimuth ϕ_{sun} of the Sun and zenith ϑ_n , azimuth ϕ_n of normal to panel (or to road tilt), by the equation of spherical trigonometry

$$cos\, \chi_n = cos\, i_{sun}\, cos\, \vartheta_n + sin\, i_{sun}\; sin\, \vartheta_n\; cos(\phi_{sun} - \phi_n) \tag{11}$$

The zenith i_{sun} and azimuth ϕ_{sun} of the Sun depend on point M on the road and instant of time t and are defined by the formulas of (8) and (9). To define those angles**,** methods having different degree of accuracy have been developed. We calculate those angles on the method which is based on solution of Kepler's equation and has more accuracy [5-7].

To calculate the diffuse sky radiation falling on the panel under cloudless atmosphere**,** the experimentally determined quantity - the ratio of direct radiation in global - $\eta(i_{sun})$, has been used.

$$\eta(i_{sun}) = \frac{S_H(i_{sun})}{S_H(i_{sun}) + D_H(i_{sun})} \tag{12}$$

where,

$$S_H(i_{sun}) = exp\left(-\frac{\tau}{cos\, i_{sun}}\right) \tag{13}$$

is the direct solar radiation falling to horizontal plane. The values of $\eta(i_{sun})$ is presented in the Table 1.

i_{sun}, ^{0}	0	20	30	40	50	60	65	70	75	80	85	90
$\eta(i_{sun})$	0.18	0.18	0.18	0.18	0.19	0.22	0.26	0.32	0.41	0.55	0.70	0.98

Table 1. The ratio of direct radiation in global

$$D_H(i_{sun}) = \frac{\eta(i_{sun})}{1-\eta(i_{sun})} \cdot S_H(i_{sun}) \tag{14}$$

The diffuse Sky radiation $D_P(i_{sun})$, falling on the panel of solar car, at the first approximation can be taken as $D_P(i_{sun}) = D_H(i_{sun})$.

Thus, the total (direct + diffuse) solar radiation falling to the panel is calculated as:

$$Q_P(i_{sun}) = S_p(i_{sun}) + D_P(i_{sun}) \tag{15}$$

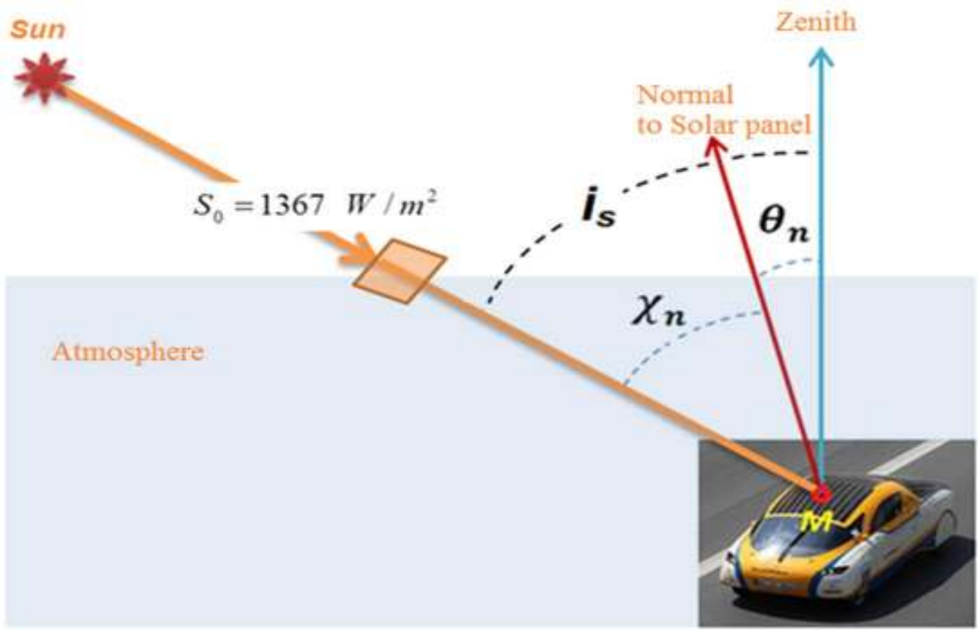


Figure 4. Determination of solar energy falling on the panel of Solar car

2.5 Scheme of application of the model and study case

An application of the developed mathematical model may be realized for any highway. The necessary information about the road parameters can be derived from 3D model of territory and may be cheeked by in situ measurements. In general, the following aspect should be realized:

1. The considered points M_n along the road must be chosen with the distance interval of 5-500 m depending on sharpness of tilt and turning left and right. In places where they are changed rapidly the points must be taken closely, and vice-versa.

2. In the point of the road M_n, where relief forms the shadow, the shadow function is determined by using 3D model or direct measurements by theodolite.

3. The procedure of deriving from satellite data the Linke turbidity factor T_L must be defined.

The knowledge of mentioned aspects allows proper implementation of developed model.

Because of restriction caused by limited computational resources of PC, in present project only two roads: Kiel-Berlin and Baku-Shemakha with driving distances 354.73km and 109.8 km, correspondently, were studied.

3. Algorithm for calculation of the solar radiation falling onto the panel of solar car

2.1. Determination of the Earth Location in orbit

↓

Input data:

- Mass of the Sun: $M_s = 1.989 \times 10^{30}\ kg$
- Gravitational constant: $G = 6.67384 \cdot 10^{-11}\ m^3/kg \cdot s^2$
- Major axis of the elliptic Earth's orbit: $a = 1.496 \times 10^8\ km$
- Eccentricity of Earth's orbit: $e = 0.01671022$

Input parameters:

- Greenwich Mean Time (GMT): *t (minute)*
- Vernal equinox time: *GMT0 (sec.)*

↓

Calculate:

- Calculate angular velocity: $OmSun = \frac{\sqrt{GM_S}}{a^{3/2}}$=0.199116795·$10^{-6}$
- Calculate mean anomaly: $M = OmSun \cdot t$
- Find eccentric anomaly E as a solution of Kepler's equation of orbital motion:

$$E - e\sin E - M = 0$$

- Calculate angle: $\varphi = 2\arctan\left(\sqrt{\frac{1+e}{1-e}}\ \tan\frac{E}{2}\right) + \frac{\pi}{2}$

  and find the dependence of the try anomaly φ on the time t: $\varphi = \varphi(t)$, ie the location of the Earth in orbit at any given time t .

Figure 5. Algorithm for calculation of the solar radiation falling onto the panel of solar car

2.2. Determination of the solar latitude and longitude

Input data:

- Sidereal period of Earth rotation: $T_{sid} = 23.96\ h. = 86256\ sec.$
- Orbit inclination : $\delta = 23.433333333^0$

Input parameters:

- Greenwich Mean Time (GMT): *t (minute)*
- Vernal equinox time: *GMT0 (sec.)*

Calculate:

- Angular velocity of Earth rotation: $\omega = \frac{2\pi}{T_{sid}}$
- Angle: $\varphi_{GMT0} = \frac{\omega}{2\pi} \cdot GMT0$
- Angle: $\varphi_G = \varphi_{GMT0} + \omega \cdot t$
- Latitude θ_{Sun} of the Sun : $\theta_{Sun} = \arcsin[-\sin(\delta)\cos(\varphi)]$
- Longitude φ_{Sun} of the Sun : $\varphi_{Sun} = \varphi_G + \arcsin[-\sin(\varphi)\cos(\theta_{Sun})]$

Output parameters:

- Latitude of the Sun : θ_{Sun}
- Longitude of the Sun : φ_{Sun}

Figure 6. Determination of the solar latitude and longitude

2.3. Determination of solar zenith and azimuth

Input parameters:

- Greenwich Mean Time (GMT): *t (minute)*
- Latitude of given point M : θ_M
- Longitude of given point M : φ_M
- Latitude of the Sun : θ_{Sun}
- Longitude of the Sun : φ_{Sun}

Calculate:

- Zenith of the Sun : $\cos i_{sun} = \sin\theta_M \sin\theta_{sun} + \cos\theta_M \cos\theta_{sun} \cos(\varphi_{sun} - \varphi_M)$
- Azimuth of the Sun : $\cos\phi_{sun} = (\sin\theta_{sun} - \sin\theta_M \cos i_{sun}) / \cos\theta_M \sin i_{sun}$

Output parameters:

- Zenith of the Sun : i_{sun}
  Azimuth of the Sun : ϕ_{sun}

Figure 7. Determination of solar zenith and azimuth

Figure 8. Determination of Solar energy falling on the panel of Solar car(below)

2.4. Determination of solar energy falling on the panel of Solar car

Input data:

- Latitude of given point M : $\{\theta_M\}$ - array along the road
- Longitude of given point M : $\{\varphi_M\}$- array along the road
- Zenith of the road normal at point M: $\{\vartheta_n\}$ - array along the road
- Azimuth of the road normal at point M: $\{\phi_n\}$ - array along the road
- Quantity : $\eta(i_{sun})$- array
- Solar constant : S_0 = 1367 (W/m^2)
- Optical thickness of atmosphere: $\tau = 0.3$

Input parameters:

- Zenith of the Sun : i_{sun}
- Azimuth of the Sun : ϕ_{sun}

Calculate:

- $\cos\chi_n = \cos i_{sun} \cos\vartheta_n + \sin i_{sun} \sin\vartheta_n \cos(\phi_{sun} - \phi_n)$
- Direct solar radiation falling to horizontal plane :

$$S_h(i_{sun}) = S_0 \cos i_{sun} \exp\left(-\frac{\tau}{\cos i_{sun}}\right)$$

- Direct solar radiation falling to panel of car :

$$S_p(i_{sun}) = S_0 \cos\chi_n \exp\left(-\frac{\tau}{\cos i_{sun}}\right)$$

- Diffuse solar radiation falling to panel of solar car :

$$D_P(i_{sun}) = \frac{\eta(i_{sun})}{1-\eta(i_{sun})} \cdot S_H(i_{sun})$$

- Total (direct+diffuse) solar radiation falling to panel of car :

$$Q_P(i_{sun}) = S_p(i_{sun}) + D_P(i_{sun})$$

Output data:

- Time t : day:hour:minute
- Latitude of given point M : θ_M
- Longitude of given point M : φ_M
- Direct, diffuse and total solar radiation falling to panel of car : $S_p(i_{sun})$, $D_P(i_{sun})$ and $Q_P(i_{sun})$

4. Database of solar energy falling onto the road

By the calculation on the basis of developed *"Mathematic*al model of Solar radiation*"* the Database of solar energy falling into the road was created. The Database includes data actual for two day (March 21 and June 21) and for two routs (Kiel-Berlin and Baku-Shemakha).

4.1 Structure of the database

Database consist Excel files which include:

- Massive of the Kiel-Berlin road geographical coordinates (latitude, longitude) at N= 2461 points on road (mean step = 354.7km/2461=144m) , which is an matrix of dimension: 2461x2.
- Massive of the Baku-Shemakha road geographical coordinates (latitude, longitude) at N= 2898 points on road (mean step = 109.8km/2898=38m), which is a matrix of dimension: 2898x2.
- Massive of the power of solar energy (Watt/m^2) over the road Kiel-Berlin at every 1 minute from GMT=07:00 to GMT=15:30 (total 510 time point), which is a matrix of dimension: 2461x510.
- Massive of the power of solar energy (Watt/m^2) over the road Baku-Shemakha at every 1 minute from GMT=07:00 to GMT=15:30 (total 510 time point), which is a matrix of dimension: 2898x510.
- Massive of the distance made (km) from Kiel over the road Kiel-Berlin at every 1 minute from departure time: GMT=07:00; GMT=08:00; GMT=09:00; GMT=10:00; GMT=11:00; GMT=12:00, which are matrices of dimension: 2461x2.
- Massive of the distance made (km) from Baku over the road Baku-Shemakha at every 1 minute from departure time: GMT=04:00; GMT=05:00; GMT=06:00;

GMT= 07:00; GMT= 08:00; GMT= 09:00; GMT= 10:00, which are a matrices of dimension: 2898x2.

- Massive of the speeds (km/h) from Kiel over the road Kiel-Berlin at every 1 minute from departure time: GMT= 07:00; GMT= 08:00; GMT= 09:00; GMT= 10:00; GMT= 11:00; GMT= 12:00, which are matrices of dimension: 2461x2.
- Massive of the speeds (km/h) from Baku over the road Baku-Shemakha at every 1 minute from departure time : GMT= 04:00 ; GMT= 05:00 ; GMT= 06:00; GMT= 07:00 ; GMT= 08:00 ; GMT= 09:00 ; GMT= 10:00, which are matrices of dimension: 2898x2.

Note: the step on the road Baku-Shemakha is chosen smaller (38meter) than on the road Kiel-Berlin (144meter), because of sharp turn and altitude variation of the road Baku-Shemakha.

Below the examples of database were given:

Geographical coordinates of the road Kiel-Berlin

J1

	A	B
1	lat	lon
2	54.310364	10.109224
3	54.310136	10.109422
4	54.309999	10.109556
5	54.309884	10.109671
6	54.309513	10.110093
7	54.309276	10.110411
8	54.309059	10.110736
9	54.308913	10.111003
10	54.308782	10.111236
. . .	. . .	. . .
2455	52.520738	13.405992
2456	52.520694	13.405884
2457	52.520273	13.405045
2458	52.52016	13.404829
2459	52.520043	13.404625
2460	52.519917	13.40481
2461	52.519991	13.404944
2462	52.52	13.40496

The distance made from Kiel for March, 21 departure GMT=07:00

	A **time t** ((min)	B **S=S(t)** (km)
1	1	0.3667
2	2	0.75
3	3	1.1333
4	4	1.5167
5	5	1.9
6	6	2.3
7	7	2.7
8	8	3.1
9	9	3.5
10	10	3.9167
. . .	. . .	. . .
399	399	347.1167
400	400	347.8834
401	401	348.6334
402	402	349.3834
403	403	350.1334
404	404	350.8834
405	405	351.6334
406	406	352.3667

The distance made from Kiel for March, 21 departure GMT=07:00

	A **time t** (min)	B **V=V(t)** (km/h)
1	1	23
2	2	23
3	3	23
4	4	23
5	5	24
6	6	24
7	7	24
8	8	24
9	9	25
10	10	25
. . .	. . .	. . .
399	399	46
400	400	45
401	401	45
402	402	45
403	403	45
404	404	45
405	405	44
406	406	44

Table 2. Examples from the Database

Power of solar energy (Watt/m^2) over the road Kiel-Berlin for June, 21, starting from GMT=04:00

Time t (minute)	0	1	2	3	4	5	. . .	507	508	509	510
1	1108	1131	1151	1168	1183	1194		0	0	0	0
2	1108	1131	1151	1168	1183	1194		0	0	0	0
3	1108	1131	1151	1168	1183	1194		0	0	0	0
4	1108	1131	1151	1168	1183	1194		0	0	0	0
5	1108	1131	1151	1168	1183	1194		0	0	0	0
…………………………………………………………………..											
…………………………………………………………………..											
…………………………………………………………………..											
2458	1073	1098	1120	1139	1155	1168		0	0	0	0
2459	1073	1098	1120	1139	1155	1168		0	0	0	0
2460	1073	1098	1120	1139	1155	1168		0	0	0	0
2461	1073	1098	1120	1139	1155	1168		0	0	0	0

Table 3. Examples from the Database

In Table 3, the time step $\Delta t = 1\ minute$ and spatial step $\Delta l \approx 144\ meters$. The regular and small changes of solar energy power values indicate that the time- space steps are chosen sufficiently small. The zero values in table show that for those moments of time (about GMT=16:00) the Sun has already set.

4.2 Solar energy distribution in Kiel and Berlin and Baku and Shemakha on March 21 and June 21.

The solar energy distributions at chosen cities Kiel, Berlin, Baku and Shemakha for considered months and days of year are presented in the following figures:

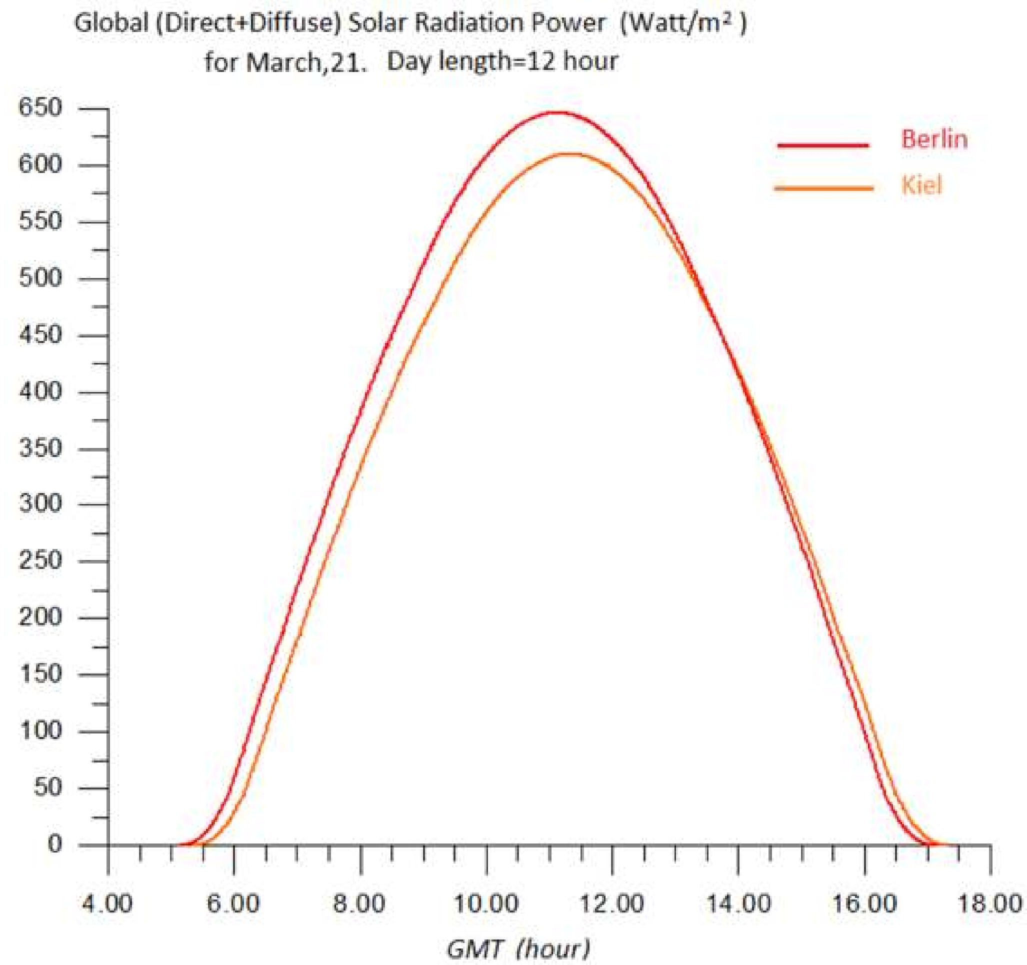


Figure 9. The global (direct + diffuse) solar radiation falling onto horizontal plane in the cities Kiel and Berlin for March 21.

For March 21, the amount of falling solar radiation in Berlin is greater about 6% than in Kiel due to southward location of Berlin.

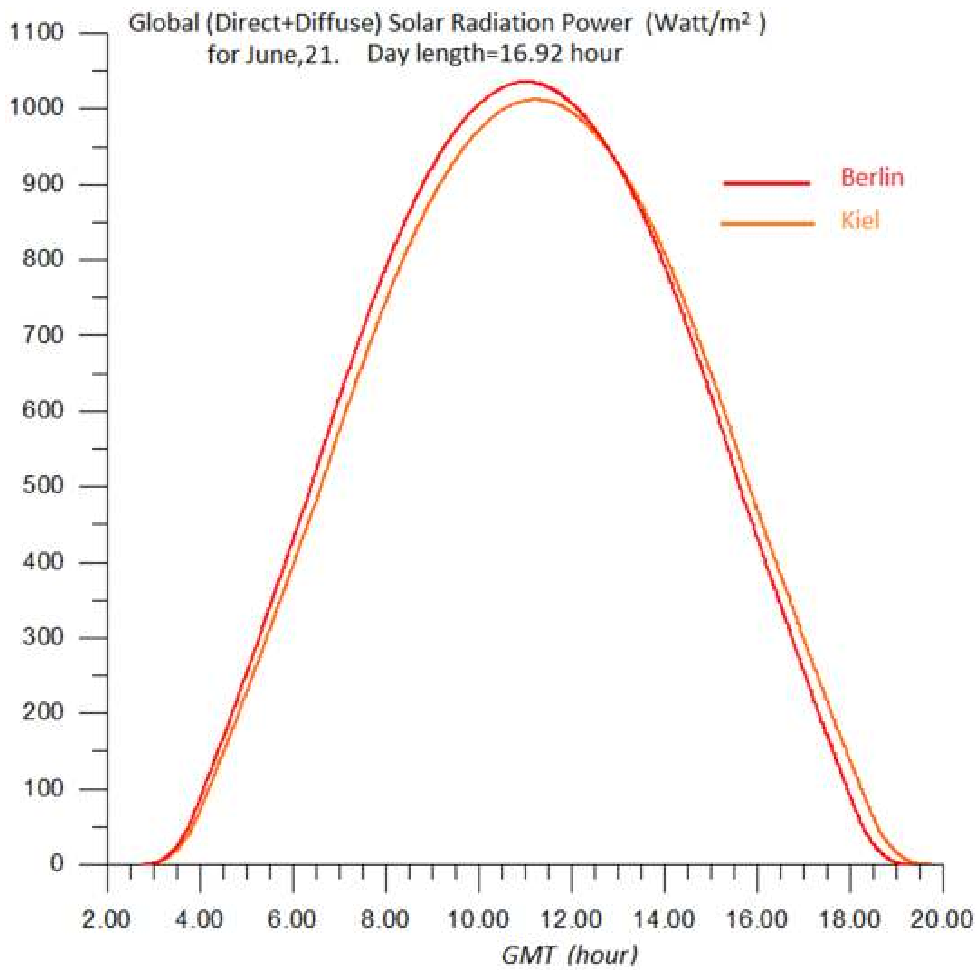


Figure 10. The global (direct + diffuse) solar radiation falling onto horizontal plane in the cities Kiel and Berlin for June 21.

For June 21, the amount of falling solar radiation in Berlin is greater about 2.5% than in Kiel. In comparison with March 21, the energy in June 21, is greater about 40%.

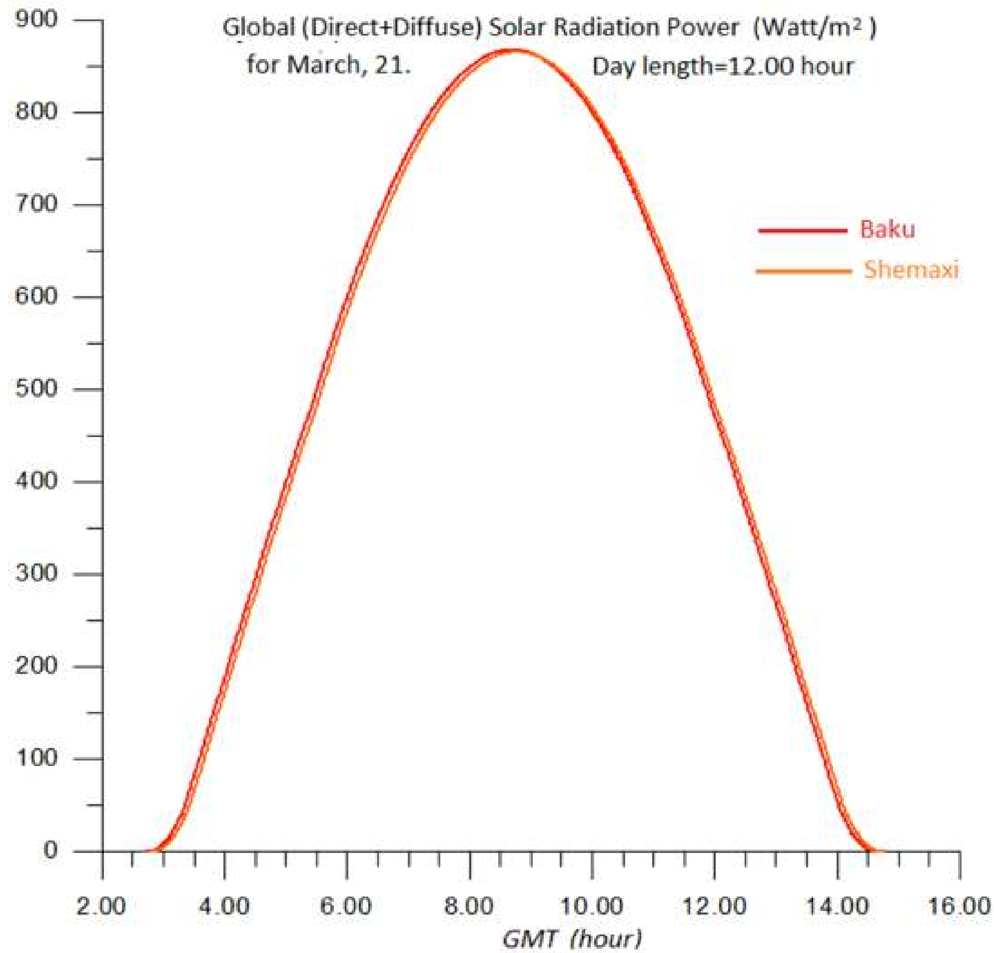


Figure 11. The global (direct + diffuse) solar radiation falling onto horizontal plane in the cities Baku and Shemakha for March 21.

For March 21, the amount of falling solar radiation in Baku and Shemakha differs very small due to closer location of those cities.

Solar energy on March 21 in Baku is greater about 30% than in Berlin.

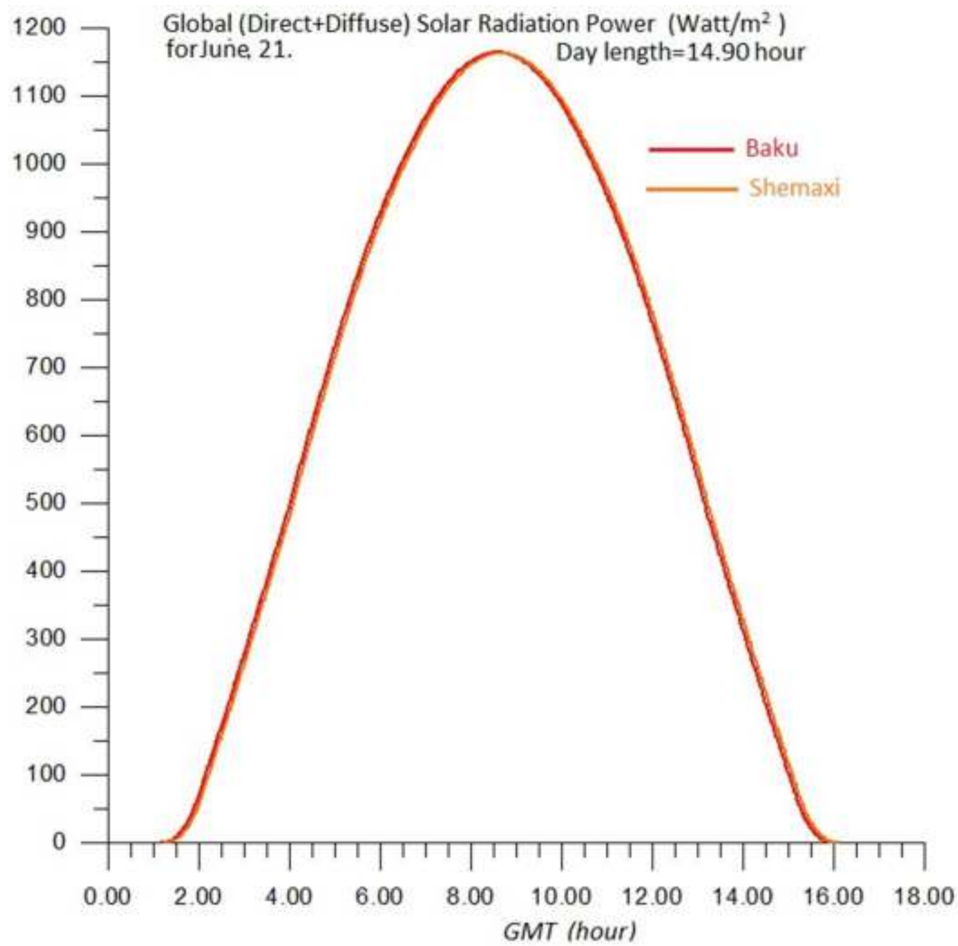
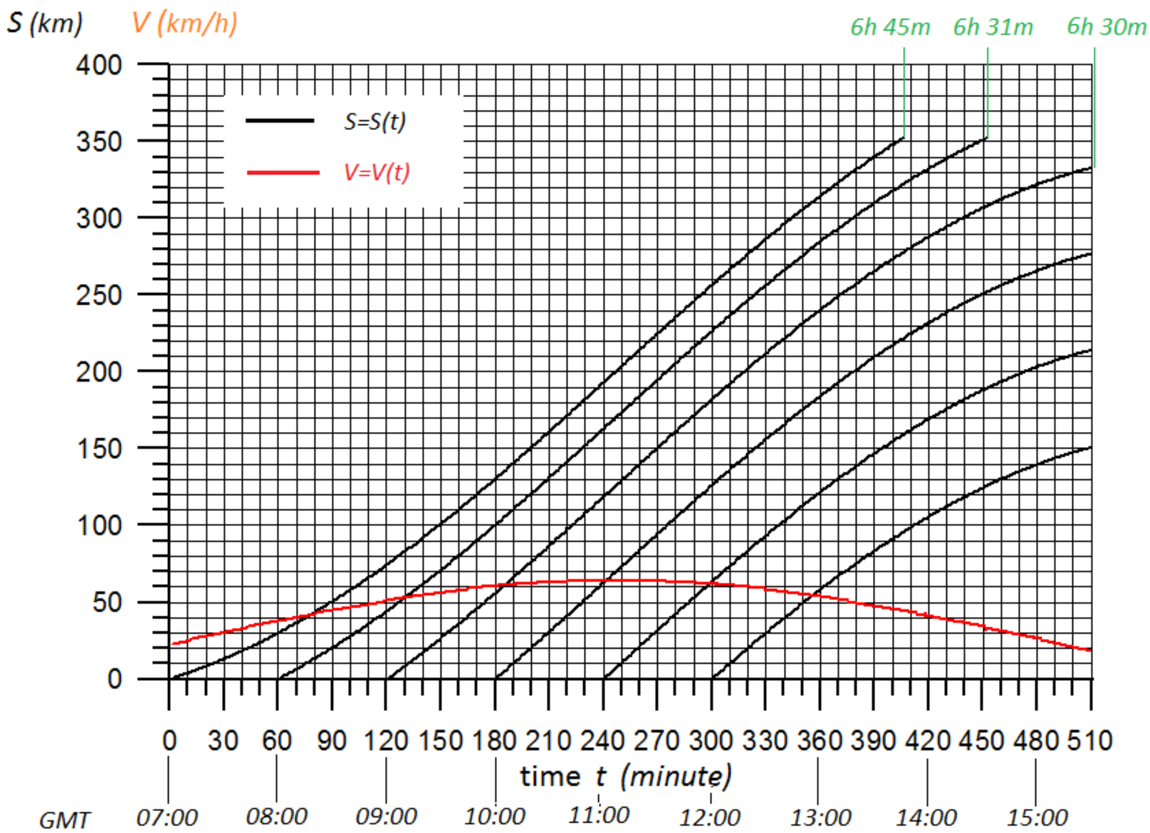


Figure 12. The global (direct + diffuse) solar radiation falling onto horizontal plane in the cities Baku and Shemakha for June 21.

In comparison with March 21, the falling solar energy in June 21, is greater about 30% Solar energy at in June 21 in Baku is greater about 13% than in Berlin.

4.3 Characteristics of motion of solar car on the route Kiel-Berlin and Baku-Shemakha

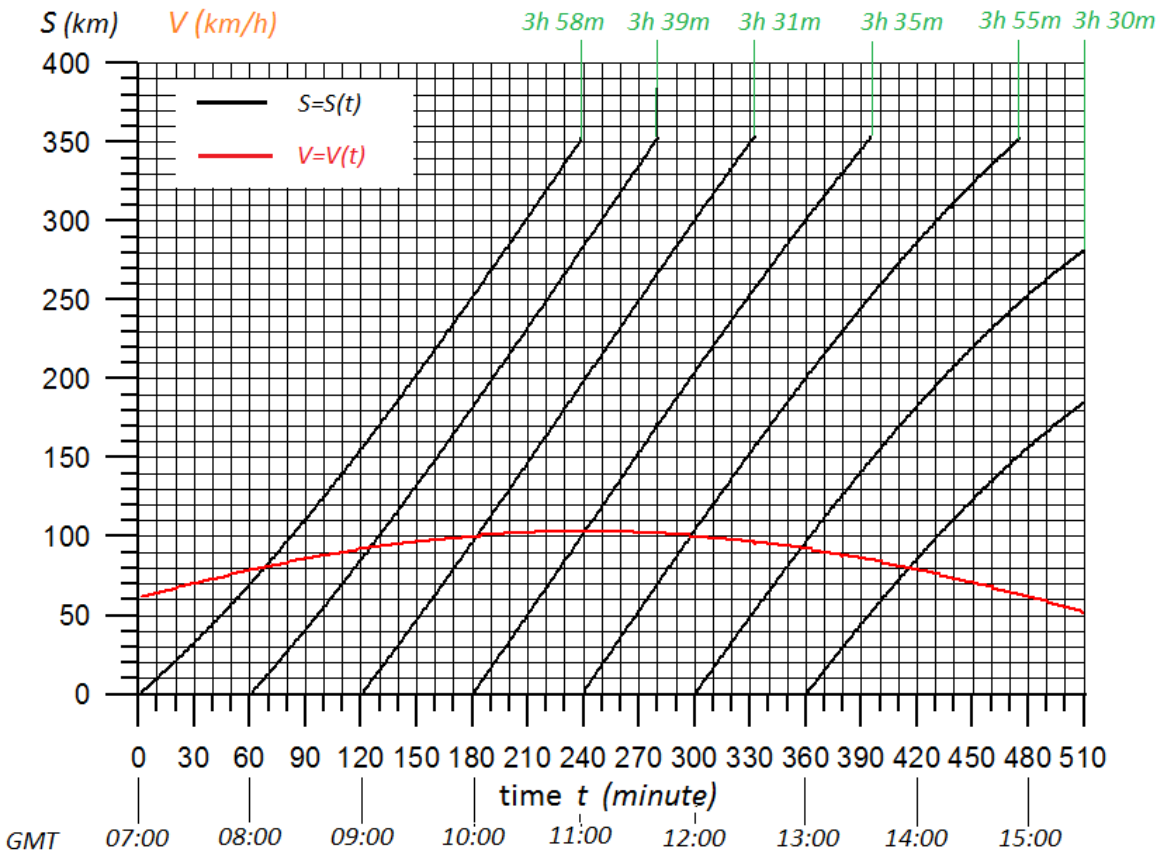
Figure 13. Characteristics of solar car motion for March, 21. Route: Kiel-Berlin



Departure Time (GMT)	Arrival Time (GMT)	Underway Time (hour - minute)	Mean Speed (km/hour)	Total Distance (km)	Comments
07:00	13:45	6h 45m	52.2	352.4	Ultimate destination was reached
08:00	14:31	6h 31m	54.0	352.4	Ultimate destination was reached
09:00	15:30	6h 30m	51.2	332.6	Ultimate destination was not reached
10:00	15:30	5h 30m	50.2	276.6	Ultimate destination not reached
11:00	15:30	4h 30m	47.5	213.8	Ultimate destination not reached
12:00	15:30	3h 30m	43.0	150.4	Ultimate destination not reached

Table 4. Characteristics of solar car motion for March, 21. Route:Kiel-Berlin

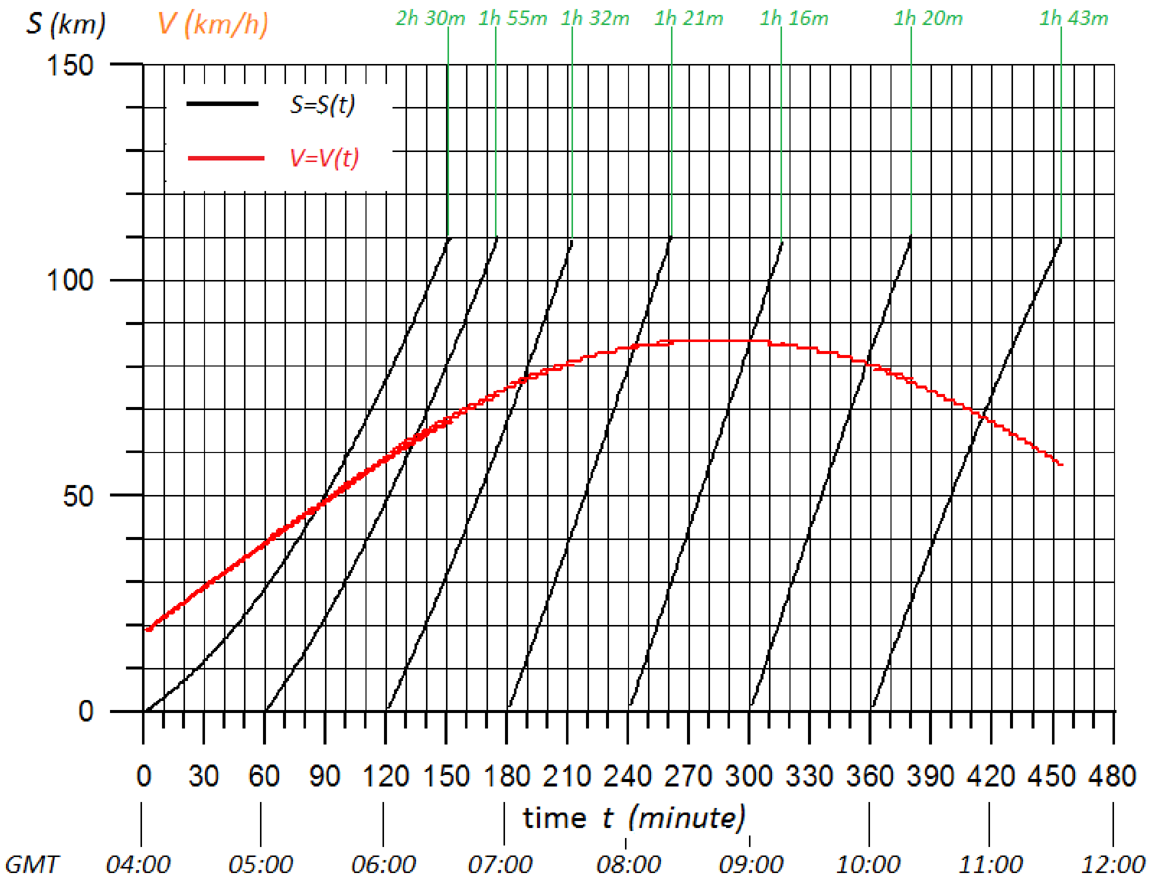
Figure 14. Characteristics of solar car motion for June, 21. Route: Kiel-Berlin



Departure Time (GMT)	Arrival Time (GMT)	Underway Time (hour - minute)	Mean Speed (km/hour)	Total Distance (km)	Comments
07:00	10:58	3h 58m	88.8	352.4	Ultimate destination was reached
08:00	11:39	3h 39m	96.1	352.4	Ultimate destination was reached
09:00	12:31	3h 31m	100.1	352.4	Ultimate destination was reached
10:00	13:35	3h 35m	98.3	352.4	Ultimate destination was reached
11:00	14:55	3h 55m	90.0	352.4	Ultimate destination was reached
12:00	15:30	3h 30m	80.3	281.0	Ultimate destination not reached
13:00	15:30	2h 30m	73.7	184.3	Ultimate destination not reached

Table 5. Characteristics of solar car motion for June, 21. Route:Kiel-Berlin

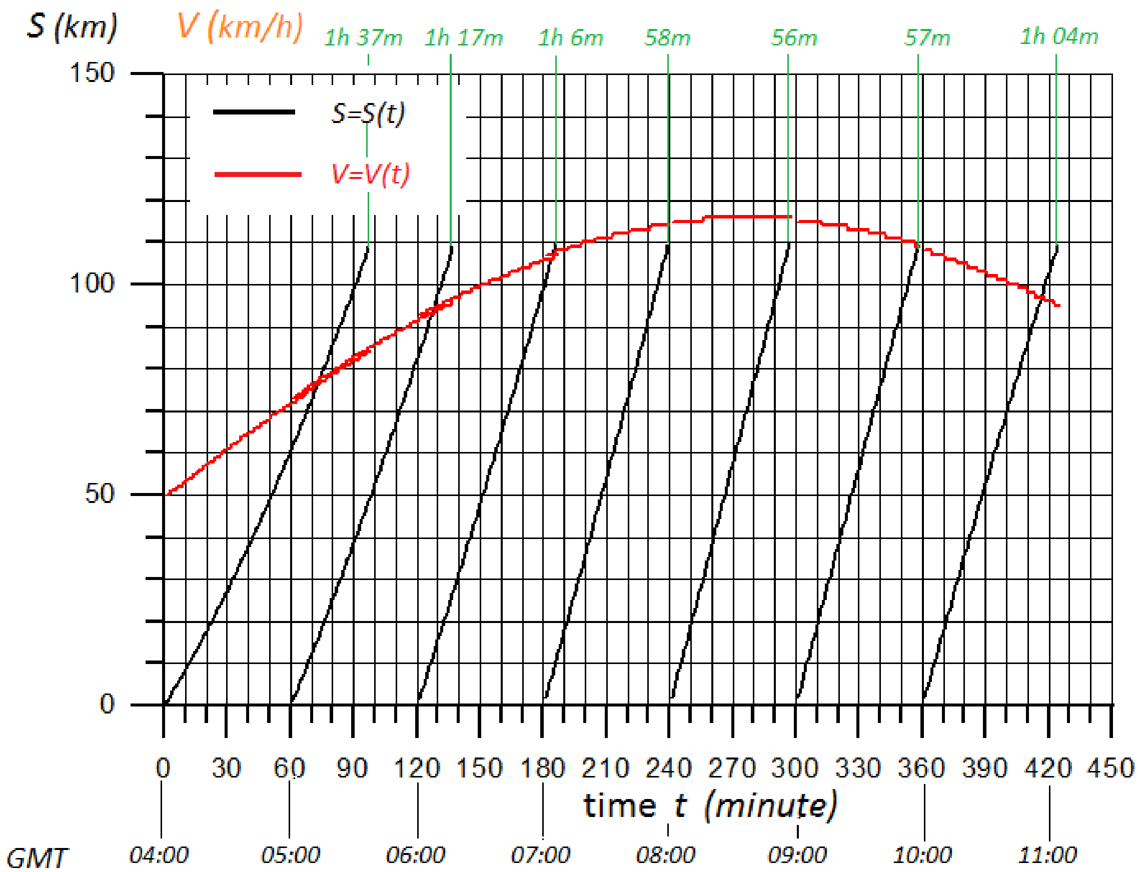
Figure 15. Characteristics of solar car motion for March, 21.Route:Baku-Shemakha



Departure Time (GMT)	Arrival Time (GMT)	Underway Time (hour - minute)	Mean Speed (km/hour)	Total Distance (km)	Comments
04:00	06:30	2h 30m	43.9	109.8	Ultimate destination was reached
05:00	06:55	1h 55m	57.3	109.8	Ultimate destination was reached
06:00	07:32	1h 32m	71.6	109.8	Ultimate destination was reached
07:00	08:21	1h 21m	81.3	109.8	Ultimate destination was reached
08:00	09:16	1h 16m	86.7	109.8	Ultimate destination was reached
09:00	10:20	1h 20m	82.4	109.8	Ultimate destination was reached
10:00	11:43	1h 43m	70.1	109.8	Ultimate destination was reached

Table 6. Characteristics of solar car motion for March, 21. Route:Baku-Shemakha

Figure 16. Characteristics of solar car motion for June, 21. Route: Baku-Shemakha



Departure Time (GMT)	Arrival Time (GMT)	Underway Time (hour - minute)	Mean Speed (km/hour)	Total Distance (km)	Comments
04:00	05:37	1h 37m	68.6	109.8	Ultimate destination was reached
05:00	06:17	1h 17m	85.6	109.8	Ultimate destination was reached
06:00	07:32	1h 06m	99.8	109.8	Ultimate destination was reached
07:00	08:21	58m	111.8	109.8	Ultimate destination was reached
08:00	09:16	56m	115.6	109.8	Ultimate destination was reached
09:00	10:20	57m	113.5	109.8	Ultimate destination was reached
10:00	11:43	1h 04m	102.9	109.8	Ultimate destination was reached

Table 7. Characteristics of solar car motion for June, 21. Route: Baku-Shemakha

5. Visualization of solar car motion on the Google Earth map

To visualize of solar car motion we must simulate the speed of the solar car at any future moment of time. In general, it means that we must solve the equation of motion taking into account all forces (gravity force, propulsive force, reaction force of ground, resistance force of air, frictional forces) acting a car. The solution of this problem is sufficiently difficult and will be considered in master thesis. Here, we assume that the car speed v is proportional to the power of solar energy, falling onto the panel solar of car:

$$v = k \cdot W \tag{16}$$

Where, k - coefficient of efficiency of solar car, which was taken $k = 0.1$. It means that the solar energy power $W = 1000\ Watt/m^2$ generates the speed $v = 100 km/h.$, which is realistic for some type of solar cars.

5.1 Structure of the web-based program package for simulating the motion of solar car along the road

The web-based program package to simulate the motion of car under falling solar energy software package was implemented in Aptana Studio 3 web-application development tool, which is an open source integrated development environment (IDE) for building web applications. As based on Eclipse, Aptana supports the following programming languages: JavaScript, HTML5, DOM and CSS.

The application solution was created by means of programming in JavaScript, HTML and CSS as well as using fast, small and feature-rich jQuery, which is a JavaScript library.

In Figure 17 below, the software package with its content is presented.

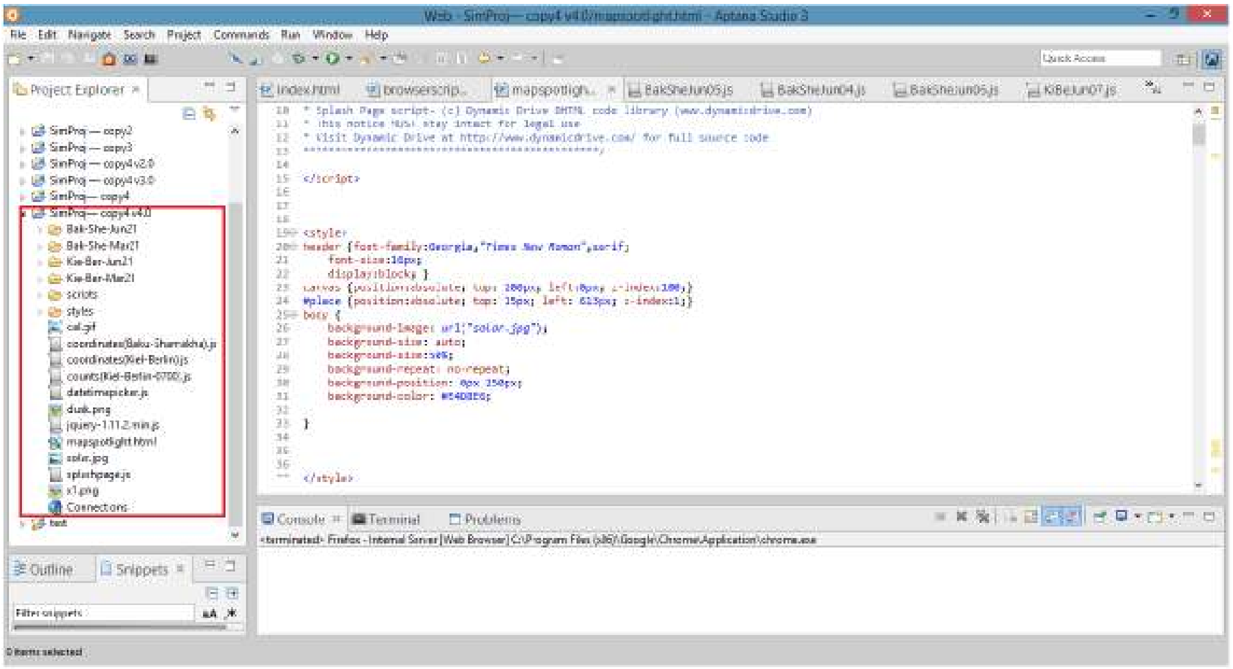


Figure 17. Program package with contents

A more detailed view on the package content as Project Explorer is given below in Figure 18.

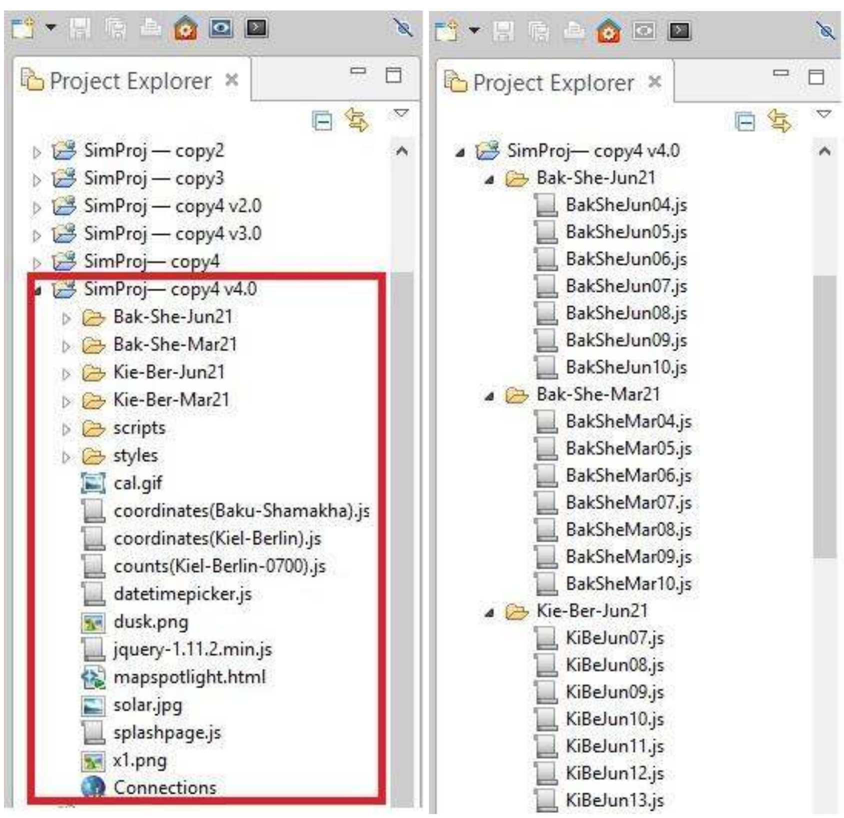


Figure 18. Project Explorer view of the program package

As it can be seen from Figure 17 as well as in detail from Figure 18, the simulation software package consists of the main HTML file, which is mapspotlight.html, JavaScript files to contain array of geographical coordinates for the routes Baku-Shamakha and Kiel-Berlin as coordinates(Baku-Shamakha).js and coordinates(Kiel-Berlin).js respectively obtained from OSRM project (http://map.project-osrm.org), jQuery DateTimePicker Widget file datetimepicker.js ,a minified version of jQuery library jquery-1.11.2.min.js which is condensed with all the white-spaces taken out and loads much faster in the browser, splashpage.js file from (c) Dynamic Drive DHTML code library (www.dynamicdrive.com), which is a JavaScript file for Splash Screen welcoming the user when the application starts running for the first time, JPG image files solar.jpg and x1.png PNG image files to display background image from a solar cars race tournament and flag to indicate the start of motion of solar car on the map respectively.

The simulation package also contains three folders: Bak-She-Jun21, Bak-She-Mar21, Kie-Ber-Jun21, Kie-Ber-Mar21(see Figure 18.).The names of folders indicate the route (e.g. Bak-She or Kie-Ber) as well as the date (e.g Mar21 or Jun21) and contain the corresponding data in form of JS files. An each .js file in the folder contains an array of distance values used for simulation (moving the circle) for corresponding time (e.g.KiBeMar07.js contains KiBeMar07 array with the distance values to simulate the motion of the solar car to start moving at 07:00AM).

5.2 Running the web-based program package to simulate the motion of solar car

When the program package runs for the first time, the splash screen in the browser opens with the Web-site of Azerbaijan Republic State Agency on Alternative and Renewable Energy Sources opens, giving a brief overview on renewable energy theme (Figure 19.).

Figure 19. Splash screen with AREA web-site

After the Splash screen has opened with the web-site of AREA and welcoming to the Masters Project it will disappear automatically, opening the main window for simulation. The time the Splash Screen will automatically disappear can be set in autohidetimer property in splashpage.js file (e.g autohidetimer:11 will set the splashscreen to disappear after 11 seconds).

The Splash Screen appears only for the first time run, i.e the splash screen will not reappear when the simulation page is renewed or when restart button is clicked.

In Figure 20. below it is shown the main window for simulation.

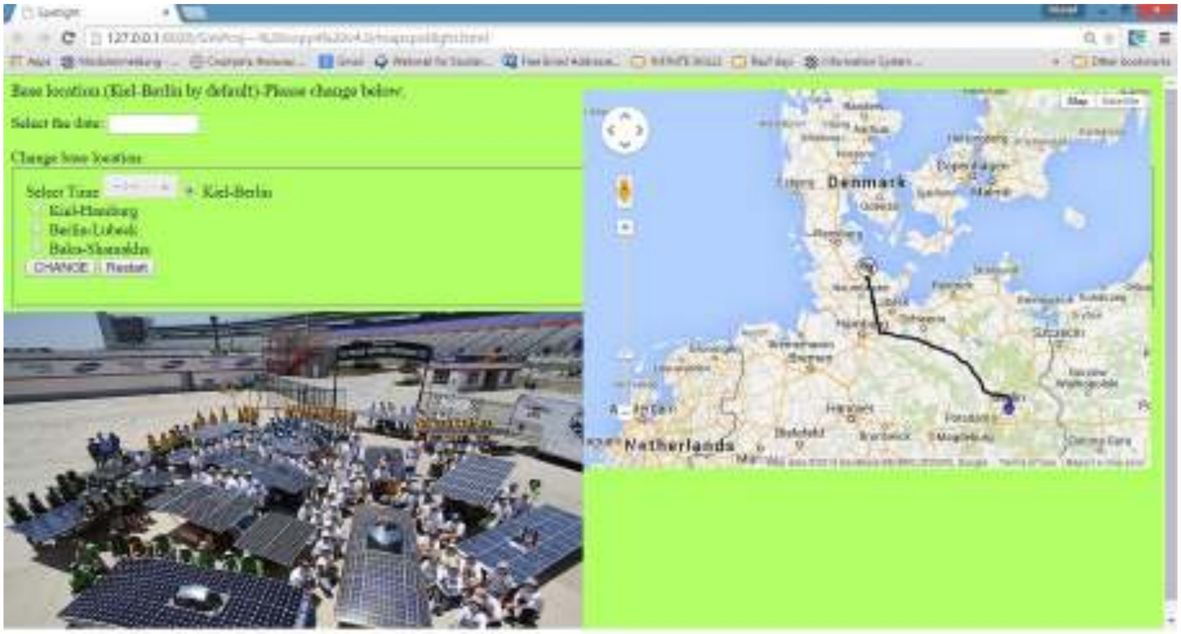


Figure 20. Simulation screen interface

The simulation screen consist of the following elements: jQuery calendar that takes the desired day and month from the user (currently available two dates: Mar 21, 2014 and Jun 21, 2014), a drop down menu with times from 04:00AM till 13:00PM, and the routes Kiel-Berlin (valid), Kiel-Hamburg (currently invalid), Berlin-Lubeck(currently invalid) and Baku-Shamakha(valid).

By default the route Kiel-Berlin is selected. In order to select a different route (e.g Baku-Shamakha) user need to select the desired route and click the change button.

In order to start the simulation, the user needs to do the following:

1) Select the date (either 21 March 2014, or 21 June 2014)
2) Select the time of beginning the motion of solar car from the dropdown menu
3) Select the route (Kiel-Berlin is set by default)

After all the three parameters were set, the user gets the alert notification about the parameters successful set.

When the simulation starts, the blue circle representing the solar car will move along the selected route at the speed corresponding the start time and changing according the falling solar energy to the panel of the car. The solar car either can reach or not reach the final destination depending on the start time of motion and the pattern of motion which was calculated mathematically. The Google map where the motion simulation takes place is placed on HTML5 canvas element.

The javascript function `checkDateAndTime` accepts two parameters: `myDate` and `Time`. When the two parameters are passed into the `checkDateAndTime` function, the `switch (myDate)` statement takes the `myDate` object and further checks for the input time. If specified by the user time of solar car start of motion is valid, then the `countsDisArr` array will be set to the corresponding array from the Database folders (e.g `countsDisArr = KiBeMar07` sets the array to the KiBeMar07 array containing the calculated distance values for simulating the car motion starting at 07:00AM).

Then, `simulateCircle (rows,countsDisArr)` function is called which takes the abovementioned number of rows and the corresponding distance array. In Figure 21. below the main function to simulate the circle (solar car) is given.

```
function simulateCircle(rows,countsDisArr) {
    var count = 0;
    var i = 0;
    window.setInterval(function() {

      count = countsDisArr[i+1];

      i = i+1;
      var icons = line.get('icons');
      var icons2 = line.get('icons');
      icons[0].offset = (count/rows) * 100 + '%';

      line.set('icons', icons);
      line2.set('icons',icons2);

        }, 100);

}
```

Figure 21.simulateCircle function

`The Window.setInterval` method is used to iterate over the distance array values and changing the offset icon on polyline.

In the Figures 22 and 23 it is shown the working examples of the simulation for the routes Kiel-Berlin and Baku-Shamakha.

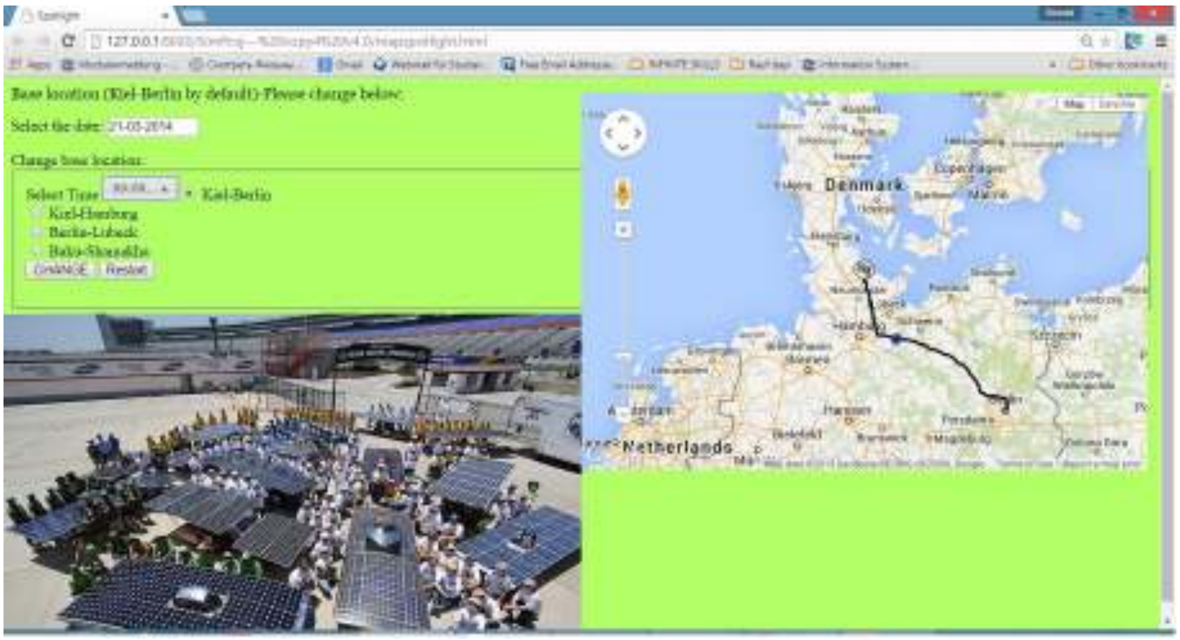


Figure 22. Simulation of solar car motion started at 09:00 AM, on 21.03,2014 on the route Kiel-Berlin

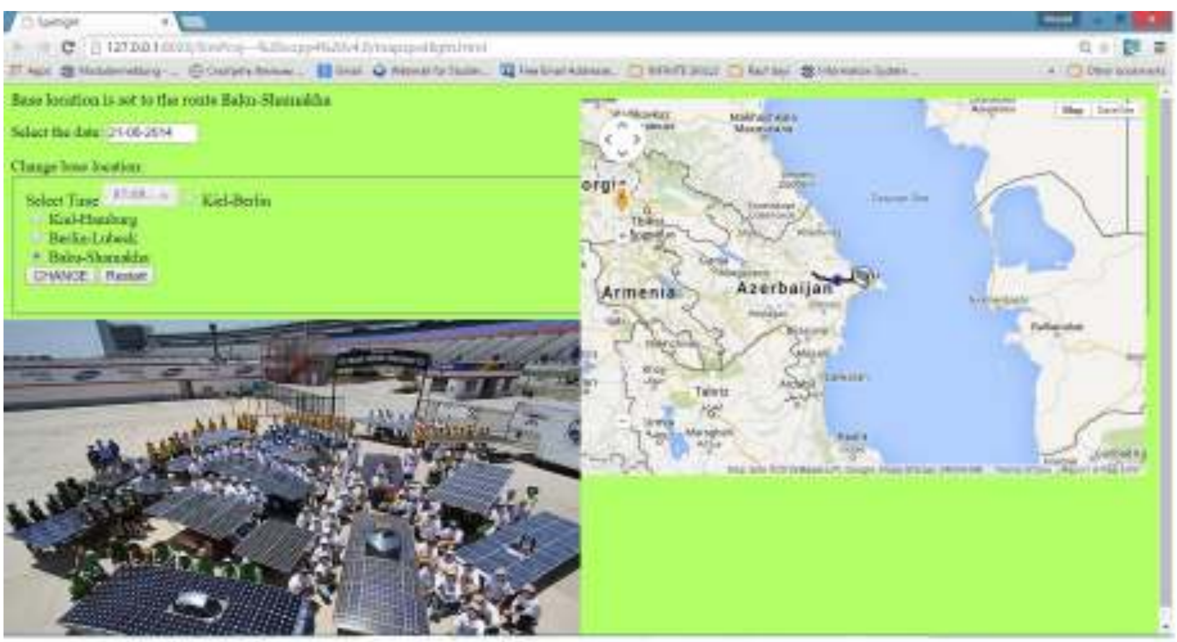


Figure 23. Simulation of solar car motion started at 09:00 AM, on 21.03,2014 on the route Baku-Shemakha

6.Conclusion. It appears that, now the world is at the beginning stage of transition from cars with internal-combustion engine to electro mobiles working simultaneously by the use of solar energy and accumulators. Evidently this transition will happen quickly. There are two main reasons to maintain this. First, the pollution of environment by exhaust gases from conventional cars becomes tragically dangerous for human life. Second, photoelectric cells with high efficiency have been discovered and their wide use is available. The main feature of solar cars which distinguish them from conventional cars is the reality that the origin of energy takes place outside of cars. If solar cars receive enough solar energy they will be able to continue motion regularly. This fact requires the optimum usage of the solar energy. Because, the amount of solar energy received by the panel depends on outside factors**,** the optimal managing of solar cars looks to be a main problem. To solve this problem we must be able to calculate the amount of received solar energy in any point of road and at any moment of time. Model explained here solves this problem. Among the input parameters of this model there are the tilt and shadow characteristics in the points of road. For the roads those characteristics may be determined by using 3D model of territory. Thus, for each road the determination of those characteristics must be carried out and a data base must be created. The information from this database will serve for development various optimal control problems for concrete type of solar cars with certain controlled parameter. The program package which realizes this model will be an important part of navigation system of solar cars and will implement the optimal management (choosing the time of start of motion, speed which must be keeping along the road, instant of time of arriving to the mountain pass, where huge amount of solar radiation or fully charged accumulators are needed, choosing the time of start using of accumulator and its charging, and etc.) of solar cars.

REFERENCES

[1] **Scheidegger A.** "Energy Management Optimization for a Solar Vehicle." Master's Thesis February 24, 2006.

[2] **Arsie I., Rizzo G., and Sorrentino M. "**Optimal Design and Dynamic Simulation of a Hybrid Solar Vehicle." 2006-01- 2997

[3] **L.T. Wong, W.K. Chow.** "Solar radiation model.". Applied Energy 69 (2001) 191–224.

[4] **M. Jamil Ahmad, G.N. Tiwari.** "Solar radiation models – review" International Journal of Energy and Environment, Volume 1, Issue 3, 2010 pp.513-532

[5] **Emegen G., Gokhan K., Erdogmus F., Gardashov R.** "The determination of sunglint location on the ocean surface by observing from the geostationary satellites." Terrestrial, Atmospheric and Oceanic Sciences (TAO), Vol. 17, No.1, 253-261, 2006.

[6] **Gardashov R .H, Eminov M.Sh.** 2013, "The Determination of the Sun Glint Geographical Coordinates by Observing from Meteosat 9 Satellite." Proceedings VII *International Conference "Current Problems in Optics of Natural Waters",* 10-14 September. St.-Petersburg. 154-158.

[7] **Gardashov R.H. and Eminov M.Sh.** (2015) "Determination of sunglint location and its characteristics on observation from a METEOSAT 9 satellite", International Journal of Remote Sensing, 36:10, 2584-2598, DOI: 10.1080/01431161.2015.1042119