Web Camera
A new tool for teaching astronomy

http://www.astro-stumpp.de/Webcamnewneu.jpg

translated by M. Czerny

Logo designed by Armella Leung, www.armella.fr.to
This project has been funded with support from the European Commission.
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Observations and exercises

An inexpensive web camera may open new possibilities for physics teachers. Phenomena which are often not visible can be recorded on images. When looking at pictures, we should not only appreciate their beauty, but also ask the question:

What can we learn from these images?
Observations and exercises

All images shown in this presentation were taken by students – future physics teachers. Analysing these pictures they could „discover” physical phenomena and laws. They had to state the problem properly, find the correct method and learn how to draw conclusions. Similar observations can be easily made during physics lessons, after school activities or out-of-town excursions.

Self-made observations bring great satisfaction!
Setup for observations

- Setup for observations
  - Camera
  - Adapter M42
  - Lens Helios f=56mm
  - Wooden handle
  - Finder telescope
  - Paralactic mount with an engine

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Setup ready to use
Lens \( f = 58 \text{ mm} \)

Lens \( f = 500 \text{ mm} \)
Basic components

- Web camera
- Adapter for photo lenses
- Computer
- Software
- Photographic tripod

Such a setup is sufficient for observations of the sun and the moon
Advanced setup

- A small, low-cost, amateur telescope
- Web camera with CCD chip modified for long exposures*
- Astronomical tripod with small movements and motorised tracking rotation of the celestial sphere

Such a setup enables observations of fainter objects

* You don’t have to be an electronic wizard! We provide you with modified camera, software, cables etc.
What is required:

• modified web camera with CCD chip
• USB and LPT cables (5 meters)
• lens adapter*

* http://www.astrokрак.pl
Interchangeable lenses:

- lens of the web camera with focal length 4.9 mm field of view: $43^\circ \times 33^\circ$
- Helios lens (from the Zenith camera) with focal length 58 mm field of view: $3.82^\circ \times 2.78^\circ$
- lens with focal length 135 mm field of view: $1.64^\circ \times 1.19^\circ$
- lens with focal length 500 mm field of view: $0.44^\circ \times 0.32^\circ$
Observations of the sun

Exposure **1/1000 - 1/15 sec**

A dark filter must be used!!!
The filter should be placed **IN FRONT OF THE SETUP**

* i.e. in front of the lens!!!

The filter can be made from:
- mylar foil (the best solution)
- floppy disc
- x-ray photograph
- welding glass

**YOU MUST NOT USE GLASS BLACKENED WITH SOOT**
Observations of the sun

- Sunspots (Wolf number, butterfly diagram)
- Solar eclipses
- Daily movement of the sun
- Transits of Mercury and Venus in front of the solar disc
SAFETY FIRST !!!

IMPORTANT INFORMATION!

NEVER LOOK DIRECTLY AT THE SUN WITH UNPROTECTED EYES - THIS MAY CAUSE TOTAL BLINDNESS WITHIN SECONDS! ALWAYS BE SURE TO USE PROPER OPTICAL FILTERS TO PROTECT YOUR EYES. NEVER LOOK DIRECTLY THROUGH A TELESCOPE TOWARDS THE SUN!
Wolf number:

- Wolf number, $W$, depends on the number of sunspots by the formula: $W = 10g + p$
  
  ($g$ - number of sunspot groups, $p$ – number of all sunspots)

- From XIX century Wolf number is a measure of solar activity

- Observations should be systematic and the results should be sent to astronomical organizations
Wolf number:

- $g = 3$, $p = 11$, "$w" = 41$

If a single sunspot were here, one should count it as a group, too.
Wolf number:
Solar rotation

• Solar rotation can be investigated by observing sunspots
• Determination of rotational period of the sun is complicated by the fact that observations are made from the earth which orbits the sun
• Angular velocity of the sun is determined from the diagram which shows sunspot positions as a function of time
• The sun is not a solid body! Period of rotation depends on heliographic latitude
Solar rotation:

The distance \( R-x \) should be measured on each image for every sunspot.

Solar radius can be determined by measuring distance from the disc centre (intersection of two straight lines perpendicular to the edge) to any point on the edge.
Calculations:

- \( \sin(\alpha) = \frac{x}{R} \)
- \( \alpha = \sin^{-1}\left(\frac{x}{R}\right) \)
- \( S = \tan(\beta) \)
- \( \frac{1}{S} = \frac{1}{P} - \frac{1}{365.2425} \)
- \( S \)- synodical period of solar rotation
- \( P \)- syderical period of solar rotation

Heliographic latitude of the sunspot \( \varphi \)
Solar rotation:
Differential solar rotation:

- Empirical dependence of angular velocity on heliographic latitude:

\[ \omega = 14^\circ,38 -2^\circ,7 \sin^2 \varphi \ [^\circ/day] \]
Butterfly diagram

- During 11 year period positions of sunspots on solar surface systematically change
- The diagram showing heliographic latitude of sunspots as a function of time is called the butterfly diagram (because of its shape)
Butterfly diagram:
Transit of Venus in front of the sun

• Participation in the international project VT-2004
• Determination of the distance from the sun to the earth
• Estimation of the size of Venus
Transit of Venus in front of the sun
Transit of Venus in front of the sun

The event occurs when Venus and the Earth are close to the intersection of their orbital planes.
• Measure the radius of Venus disc ($R_V$) on the printed image
• Multiply the radius by the ratio of the Sun-Earth distance (1 AU) to the Venus-Earth distance (0.3 AU) ($f$)
• Draw two straight lines perpendicular to the edge of the solar disk; their intersection is the centre of the solar disc
• Measure the radius of the solar disc ($R_s$)
• Calculate the ratio of radii of Venus and the sun:
  \[ x = f \cdot \frac{R_V}{R_s} \]
• Calculate the true radius of Venus ($r_V$) assuming that the true radius of the sun ($r_s$) is 696260 km
  \[ r_w = x \cdot r_s \]
Observations of the moon:

- Crater identification
- Phases
- Grey light
- Eccentricity of the orbit
- Height of lunar mountains and crater edges
- Lunar eclipses
- Lunar occultation of stars
Crater identification

- Topography of our natural satellite can be learned by comparing self-made photos of the moon with the map.
- When images are taken at different phases, more details can be recognised, especially close to the terminator line, because of the varying angle of illumination.
- This exercise helps to understand image projections in different optical setups (reversed images, mirror reflections etc.) and principles of map arrangements.
Identification:
Phases of the moon

• The synodical period of the moon (i.e. the period of repeating its phases) can be determined by measuring the distance of the crater to the terminator line

• Similar method as for investigating solar rotation can be used for image analysis
Phases:
Phases:
Grey light

- Close to the new moon phase the dark side of the moon is illuminated by the earth.
- It is possible to study changes of this illumination (called „grey light”) with lunar phases.
Grey light:

- Part illuminated by the sun
- Part illuminated by the earth
Eccentricity of the lunar orbit

• The moon moves along the elliptic orbit and is sometimes closer and sometimes further from the earth
• As a result the angular diameter of the moon is variable
• Analysing this effect it is possible to determine the eccentricity of the lunar orbit
Changes of angular diameter:

- Perigee
- Apogee

$R_1$ $R_2$
Changes of angular diameter:

- The ratio: $R_1/R_2=(a+c)/(a-c)$ is determined from the images.
- Eccentricity $e=c/a$
Height of crater walls

• Lunar craters are illuminated by the sun at some angle
• If the crater is identified, it is possible to estimate height of its walls with respect to the crater bed
• Information about crater coordinates and diameters is required
Height of mountains and crater walls

Geminus Crater: diameter 86 km, wall’s height 5400m
Height of mountains and crater walls

\[ H = f \cdot D \cdot \sin A \cdot \csc F - 0.5 \cdot f^2 \cdot D^2 \cdot \csc^2 F \cdot \cos^2 A \]

f – shadow length expressed as a fraction of crater diameter
D – crater diameter
A – the sun’s height over the lunar horizon seen from the crater’s location
F – angle between directions from the moon’s centre to the earth and to the sun
Lunar eclipses
Shape of the earth, size of the moon

• The circular shape of the earth’s shadow on the lunar disc was the first evidence that the shape of the earth is spherical
• Knowing the size of the earth it is possible to estimate the size of the moon $R_e/r_m$
Ratio of earth’s and moon’s radii
Ratio of earth’s and moon’s radii

Geometry of the phenomenon

The result can be improved taking into account the shape of the earth’s shadow
Movies

- Recording phenomena in the real time
- Speed-up movies
Apparent daily movement of the moon. It reflects rotation of the earth. (the camera is motionless with respect to the earth)
Atmospheric effects on the quality of the image
(partial lunar eclipse)
Clouds in front of the lunar disc (end of the eclipse)
Blow up
Lunar eclipse movie (1 frame in every 30 sec)
Despite clouds one may see movement of the earth’s shadow along the lunar disc
Modified web camera

• Long exposure times are possible!
• Special software (supplied with modified cameras) is required

Observations of planets, stars, nebulae etc. are possible with modified web cameras.
Processing images

Unwanted defects of images, such as „hot pixels” or dust on the lens or inside the camera, can be removed by taking additional photos:

- dark frame (exposure with covered lens)
- flatfield (image of uniformly illuminated surface)

Software prepared for web cameras can remove these unwanted effects
Reduction:

Before

After
Dark frame

22 seconds

179 seconds
Automatic subtraction:

- Without subtraction:

  ![Image](image1.png)

  **M 42**

- After subtraction:

  ![Image](image2.png)

  **The time of exposure by the dark current must be the same as the time of image exposure!**
Hot corner:

179 seconds
Beware of contaminations!

- Effect: After correcting for flatfield:
Star counts as a function of brightness:
Sensitivity of the camera:

<table>
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<th>t [s]</th>
<th>1</th>
<th>2</th>
<th>5</th>
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<td>7,9</td>
<td>9,06</td>
<td>9,7</td>
<td>10,56</td>
</tr>
</tbody>
</table>
Linearity test for the camera
(for a fixed star)
Noise

**Exposure time**

- 3x4.5 sekundy
- 5x23.5 sekundy
- 1x9.5 sekundy

**Noise**

![Graph showing noise levels with exposure time](image-url)

**Axes:**
- y-axis: [mag]
- x-axis: jasność gwiazdy [mag]

**Data Points:**
- Markers represent different exposure times.
Results of observations

- Planets
- Stars
- Nebulae
- ...

Mars:

- Surface details
- Weather
- Rotation

Telescope diameter 35 cm
Focal length 3.5 m
Jupiter:

- Clouds
- Rotation (Great Red Spot)
- Jupiter moons
Jupiter moons*:

* see project CLEA in the Internet
Jupiter mass:

- Diagram showing distance from moon to Jupiter

- III Kepler’s law for the system Jupiter-moon (subscripts: \( J, S \))

- III Kepler’s law for the system Earth-Moon (subscripts: \( Z, K \))

- Jupiter mass (in Earth units):

\[
\frac{a_S^3}{T_S^2} = G \frac{m_S + m_J}{4\pi^2} \\
\frac{a_K^3}{T_K^2} = G \frac{m_K + m_Z}{4\pi^2} \\

m_J = \frac{T_K^2 a_S^3 m_Z}{a_K^3 T_S^2}
\]
Saturn:

- Size of rings
- Moons
Inclination of rings:

\[ \sin (\alpha) = \frac{r}{R} \]

To observer

Cassini Gap

To observer
Other planets:

- Uranus
- Neptune
Constellations: Orion
Big Dipper:
Stars:

• Stellar colours

• Separation of binary stars
Pleiades
Comet Mahcholtz
M31 galaxy in Andromeda
M31 galaxy in Andromeda
M42 nebula in Orion
M42 nebula in Orion
Observations of eclipsing binary stars

Brightness of an eclipsing binary is not constant because one component of a system periodically moves in front of another and shields its light.

Precise timing of minima of brightness are important for professional astronomical studies; therefore measurements done by amateur astronomers may become part of a real scientific study.
Observations of eclipsing binary stars

During an eclipse a long run (several hours) of observations is needed. Collected data are reduced by special computer programmes.

Brightness of stars is determined by summing up brightness of all pixels in the vicinity of a star’s image.

To eliminate atmospheric effects brightness of the investigated star (V) is compared with brightness of other non-variable stars (C, K). Any changes of their brightness are caused only by the atmosphere.
Observations of eclipsing binary stars
Minimum of RZ Cas
brightness: 6.4 – 7.8 mag period: 1.195 day
Minimum of U Cep
brightness: 6.74 – 9.81 mag. period: 2.493 day
Changes of orbital periods:

Changes of orbital periods of binary stars are caused by several physical phenomena: ejection of matter matter flow from one component of a binary to another, presence of third (dark) body, orbit precession, relativistic effects etc.

In order to study these phenomena one can use so called O-C diagrams, which show slow changes of orbital periods of binary stars during many years

These studies need a lot of data which can be supplied by amateur astronomers!!!
O-C diagrams*:

* See project GZZ
  www.as.ap.krakow.pl/gzz
Another application of web cameras in school:

• Images of nature: