The ENEA solar compass: How to catch more Sun by using the Sun

The ENEA solar compass is 100 times more precise than magnetic compasses. It is an innovative, useful and cost-effective tool in several fields: concentrating solar power plants, environmental survey, civil engineering, radar installation, accurate measurements of the magnetic declination, remote control of robot navigation, primary standard for calibration of other compasses, reference compass for transportation means, easy installation of domestic solar devices, and educational tool

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Mankind has used the Sun for time indication and orienteering since prehistory. Even many animals are able to find the right orientation from the Sun taking into account the time of the day by using their internal clock. Over the last two centuries, rather complex instruments have been developed to improve the accuracy of the orientation measurement by means of the Sun like, for example, Burt's solar compass [1]. Such instruments, whose accuracy is definitely higher than that of magnetic compasses, have the advantage of giving the true, rather than the magnetic, North direction; also, they are insensitive to magnetic perturbations and exploitable everywhere in the world (even close to the Poles).

Indeed, any portable sundial becomes a solar compass if used in reverse mode: if we already have a precise clock, we can turn the sundial until the time indicated by the Sun coincides with the clock (if the sundial indicates only the local true solar time, the clock time must be corrected by the equation of time, i.e. by the difference between solar time

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Fig. 1 Reconstruction of an old solar compass

and mean time). Then, the meridian line of the sundial (i.e., the line indicating twelve o'clock) will lie along the true North-South direction with a much better accuracy than that of magnetic compasses.
A typical portable sundial used as solar compass for navigation in the XVI century, according to a modern reconstruction, is shown in Fig. 1.

The ENEA solar compass

This old instrument has recently come back to use, since modern technologies allow to make it compact and automatic; about one patent per year has been released in the world as modern solar compass in recent years. Among them, the patent relative to the compass developed at ENEA released in 2014 [2]; this is shown in Fig. 2 mounted on a commercial theodolite.
The ENEA electronic solar compass is composed of an electro-optic sensor that detects the position of the Sun, a GPS device that provides the Greenwich time and the geographic coordinates of the compass, an optical pointer, a goniometer for measuring angles and a microprocessor, which elaborates data and provides the angle of observation with respect to the true North in real time. An innovative algorithm based on Kepler's laws allows to determine the Sun ephemeris and the North-South direction by knowing the local time and its geographic coordinates.
This compass is inspired to the sundials in churches, where the exploitation of the camera-obscura effect allows to reach the best accuracy achievable by a sundial (few seconds): in churches sundials, a small hole on the roof generates the 2D image of the Sun on the floor, as it happens, for instance, in the church of Santa Maria degli Angeli in Rome; in the ENEA compass, the hole is replaced by a very thin slit (Fig. 3a) while the floor is replaced by a small CMOS image detector, where the 1D Sun image is collected (Fig. 3b).
The main advantages of the ENEA compass, compared to others, are its very good accuracy and reliability, low cost, small size and weight, short measurement time (few seconds), easy operation and its applicability everywhere in the world, since it does not depend on the Earth's magnetic field.
The position on the CMOS of the vertical bright line shown in Fig. 3b (the 1D image of the Sun) gives the orientation of the compass with respect to the Sun.
At the same time, a GPS provides both local geographic coordinates and accurate time setting to the microprocessor, which calculates the Sun's azimuth angle[3]. The sum of this angle and that between the compass and the Sun directly gives the azimuth angle of the compass.
The ENEA electronic solar compass is compact, completely automatic, cheap, and reaches an accuracy better than 1 arcmin [4]. The latter is one of the best currently available values, comparable to those achievable by means of much more expensive and sophisticated devices, like coupled GPS systems (see for ex-

Fig. 2 The ENEA electronic solar compass mounted on a theodolite

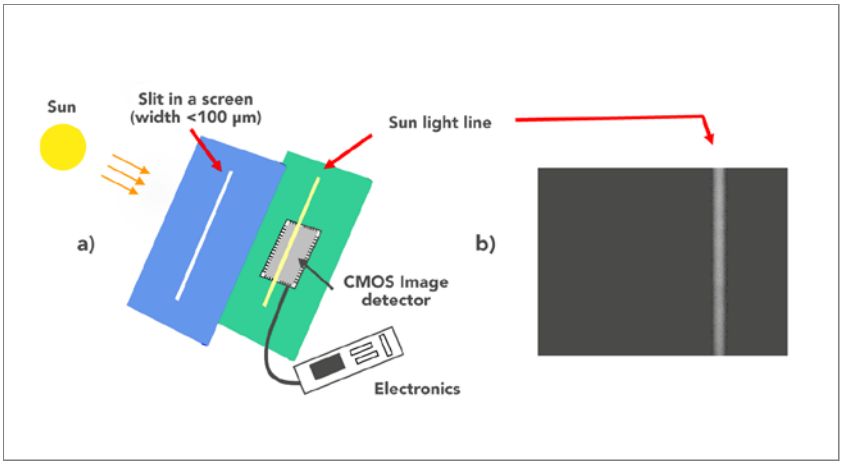

Fig. 3 Schematic of the Sun detector of the ENEA compass (a): the bright line projected on the CMOS detector is a 1D image of the Sun (b)

ample U.S. patent 5,617,317A, 1997) or gyrocompasses. Furthermore, the ENEA compass provides the orientation in a few seconds, a time extremely shorter than that necessary for gyrocompasses.
Even when the Sun is partially obscured (for example by clouds or trees) still the compass is significantly more precise than magnetic ones, as demonstrated in [5] with measurements during a solar eclipse.

Applications of the solar compass

The domains of application of the ENEA compass are concentrating solar power (CSP) installation and alignment, environmental survey (by applying the compass to survey instruments like theodolites, total stations or laser scanners), accurate measurements of orientation at low cost during the construction of buildings and roads, directional control for radar installation, accurate measurements of the magnetic declination, directional controls for tunnel construction, remote control of robot navigation (not only on the Earth, but also on all the planets of the solar system[6]), use as primary standard for calibration of other compasses, reference compass for transportation means like boats, airplanes, etc., cultural dissemination and easy installation of domestic CSP devices for smart cities and community energy network, educational tool in schools.
As far as the “solar power installation and alignment” is concerned, we should consider that, in line with the actual state of the art, most of the thermodynamic solar power plants based on CSP have a central control unit, where a single computer drives the orientation motion of all the mirrors of the installation. For example, in a thermodynamic solar installation based on linear concentration by parabolic trough mirrors, the rotation axes of all the mirrors must be parallel to each other and oriented, for instance, along the South-North direction with an accuracy better than 0.1°. If any of them is not correctly installed, its efficiency will be well below that expected by the original design.
The solar compass can get rid of such inconvenient: each mirror can be driven by a solar compass mounted on the top of one of the towers which hold the mirror itself . Each compass can then perform two functions: periodic measurements of the orientation of the single mirror rotation axis, and consequent optimized guiding of the mirror to orient it correctly towards the Sun. In this way the central unit is avoided, the parabolic mirrors do not need to be rigorously parallel to each other and the single mirror movement is completely independent of the others. The whole solar plant efficiency is increased: **“more Sun” is captured**.
At the present moment, ENEA is cooperating with the Italian enterprise “D.D. Costruzioni Meccaniche Srl” for the development and test of a Sun compass specifically designed for this application, as shown in Fig. 4. The assembling of the compass is already completed; it will be tested on the ENEA-Casaccia CSP test-bed installation by next summer 2017.
The apparatus shown in Fig. 4 is the latest prototype compass version; it is fully automatic, all-in-one design (sun sensor and electronics are in the same box), controlled through an Ethernet cable and by a touch-

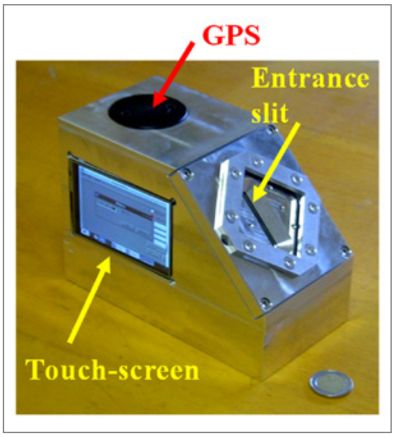

Fig. 4 The solar compass designed for parabolic trough mirror driving

screen, with an internal rechargeable battery.
In other cases, like for the more recent CSP installations based on Dish mirrors, the ENEA solar compass can, day by day, automatically determine all the mechanical defects of the mirror mechanics (misalignment of the two rotation axes, non-verticality of the azimuthal axis, etc.) and can compensate for such defects while driving the mirror motors.
Concerning the application to survey instruments, preliminary contacts with the Italian Institute for Geophysics (INGV) are now in progress regarding geo-magnetism measurements.
At present, the compass team is working for an extension to the GHz range of the acceptance spectrum, in order to make the compass working even during cloudy days.

Benefit for developing Countries and education of young generation

The solar compass is one of the results of ENEA's integrated approach to the development of innovative technologies for power generation and use of renewable energy. It has many domains of application and can be very useful especially in developing Countries, since alternative accurate orientation instruments, like total stations, are much more expensive and need reference targets (having well-known geographical coordinates) that in such Countries might be absent.
It has also been conceived as an educational tool for the young generation and at school.
The algorithm of the solar compass is so manageable that it could be downloaded as an "App" in any smartphone and even any child could learn how to make a solar compass by himself and play with it.
The App for smart-phones can be designed to evaluate the Sun position and the azimuth of the smartphone with a precision better than that of magnetic compasses.
Most young people not only do not know what is the Sun orientation (the so called Sun azimuth angle) at different hours of the day, but they are not even sure if the Sun rises at East or West direction. The solar compass could help to learn more about the Sun, exploiting its possible uses and benefits for mankind.

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REFERENCES

1. W. A. Burt, *Description of the Solar Compass*, (Detroit, 1844), or http://amhistory.si.edu/surveying/type.cfm?typeid=17

2. See the published PCT on 2014 at https://register.epo.org/ipfwretrieve?apn=IT.2013000365.W&lng=en entitled "High Precision Electronic Solar Compass"

3. S. Bollanti at al.: *"Calcolo analitico della posizione del sole per l'allineamento di impianti solari ed altre applicazioni"*, RT/2012/24/ENEA ISSN/0393-3016

4. S. Bollanti et al., "*Electro-optical sun compass* with a very high degree of accuracy", *Optics Letters* 40 (2015) 3619

5. S. Bollanti et al., "*Performance of an electro-optical solar compass in partially obscured Sun conditions*", Applied Optics, Vol. 55, No. 12, pp. 3126-3130, (2016)

6. F. Flora et al., "*Electronic solar compass for high precision orientation on any planet*", Journal of Instrumentation, Vol. 11, C07014, Published by IOP