Bioinspired Navigation and Water Vapour Detection Realized with Microelectromechanical Systems (MEMS)

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Abstract

This paper discusses the potential of bioinspired MEMS devices development regarding a human navigation system and detection of water vapour near the ground. The proposed MEMS navigation device is based on the skylight polarization pattern, having characteristics which are small, energy efficient, portable and flexible to be used in whatever condition, time and place. The water vapour detection device is proposed as a survival tool to assist human in finding water source during their navigation. This study is conducted theoretically by overviewing the mechanism of detection of polarized light and water vapour in animals and the mechanism of conventional navigation device. Mimicking the mechanism of UV-spectrum detection in animals may be an important role in ensuring the device become reality.

Keywords: *Navigation, polarisation, water vapour detection, MEMS*

1. How the honeybee navigates

The ability of the honeybee (*Apis mellifera*) to detect polarized light for navigation has inspired the conceptual development of a MEMS navigation device for an alternative human navigation system. By utilizing the polarized skylight patterns and remembering geometrical clues of landmarks, honeybees are capable of smelling food and water within a range of three kilometers and of communicating their exact location to other bees. The presence of a UV-sensitive receptor in the compound eye of the bee allows for precise navigation, even when the sun is not visible or at night.

The detection of the oscillation plane of polarized light is mediated by a specialized group of ommatidia (the single units that make up the compound eye) situated in the dorsal rim area of the compound eye. The physiological specification of the dorsal rim area goes along with the changes of the characteristics in ommatidial structure, providing actual hallmarks in polarized light detection that are readily detectable in histological sections of compound eyes [1].

Equipped with this incredible sensor array the honeybee has managed to survive for ages. *Apis mellifera* has been around for more than one million years; the first bees appeared in the fossil record in European deposits at the Eocene-Oligocene boundary, 23-56 Mya ago.

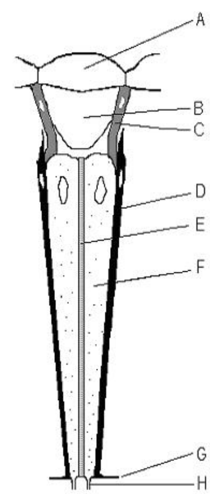

Figure 1. Scheme of an ommatidium: A-cornea, B-crystalline cone, C&D-pigment cells, E-rhabdom, F-photoreceptor cells, G-*membrana fenestrate*, H-optic nerve.

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2. The Vikings and their sunstones

Not only honeybees use light polarization for navigational purpose, but also the Viking peoples had knowledge about skylight polarization patterns and might have used it for nautical navigation purposes. Unfortunately, there is no firm historical evidence to prove that the Vikings really used sunstones to navigate. However, there are some clues that they really knew about how to use some crystals to get the actual direction during sailing. In fact, there are clues that the Vikings were sailing across the open ocean for thousands of miles without conventional instruments. In some sagas, there are descriptions about their sunstones and some sort of bearing board used by the Viking navigators.

Two types of crystal were selected and used to study their interaction ability with the sunlight or the polarization effect. One is the Iceland spar, while the other is the Cordierite. Both types of crystal have double refraction characteristics. Cordierite is strongly pleochroic, i.e., the color changes with the angle of the incident light beam.

Leif K. Karlsen, in his book “Secrets of the Viking navigators” [2], has developed a replica of the Viking ship, including a replica of navigation device that might have been used by Vikings (see Figure 2) [3]. The use of Icelandic spar can be investigated by observing the performance of the light refraction. The Iceland spar is a material that is well known for its double refraction. When the sunlight enters such a crystal, it splits into two linearly polarized beams that refract by different amounts. When the light enters the crystal, the ordinary ray obeys the law of refraction, while the extra-ordinary ray bends away from the ordinary ray. The ordinary ray and the extra-ordinary ray follow different paths inside the crystal, but follow parallel paths when leaving the crystal [3]. In this effect, one beam (ordinary ray) does not change its Poynting vector, while the scattered beam (extra-ordinary ray) rotates in a circle around the ordinary beam during the course of the day. By using this effect, the navigation process can be achieved. By aligning the crystal to the North-South or East-West direction, respectively, the extraordinary ray will rotate when the crystal is exposed to the sun.

Figure 2. Icelandic spar with double refraction effect.

Image source *http://de.wikipedia.org/w/index.php?title=Datei:Calcite.jpg&filetimestamp=20050427090712*. Public domain image.

Unlike the Icelandic spar, the Cordierite based device does not interact with the direct light beam, but only interact with the polarization pattern of the skylight. The colour of the crystal will change when the sun changes its position, because the angle of the skylight polarization is changed (see Figures 3).

(a) **(b)**

Figure 3. Cordierite cabochon.
(a) Colour of the gemstone at 03:00pm.
(b) Colour of the gemstone at 06:26 pm.

As can be seen in the Figures 3(a) and 3(b), the colour of the crystal changed rapidly over a period of approximately three and a half hours. In the setup, the crystal is fixed and oriented to the North, while the sun is hidden behind the clouds. Using the Cordierite capability in interacting with the polarized light, the Vikings might have obtained an easier way for their navigation system.

3. Polarization vision in humans

Wilhelm Ritter von Haidinger (1844) had reported in the Journal "Annalen der Physik" [4] that humans have the capability to recognize linearly and circularly polarized light without using any devices. This capability is due to the effect called "Haidinger's brushes" (see Figure 4) where through this effect, the observer just looks straight into the linear polarized light for a couple of seconds and then bends his/her head to the side and the brushes will appear. Tilting the head to the other side can reproduce this effect [5].

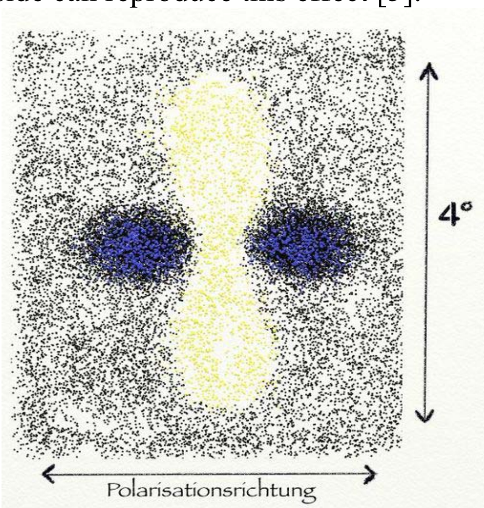

Figure 4. Scheme of Haidinger's brushes (Sketch after Marcel Minnaert). The horizontal axis indicates the direction of polarization.

Image source : *http://de.wikipedia.org/w/index.php?title=Datei:Haidinger.klein.jpg&filetimestamp=20090319235851*. Public domain image.

The Haidinger's brushes are a contrast phenomenon and appear within a linear polarized area in the middle of the visual field. Stokes did some experiments on the relative visibility of the brushes, using different coloured light and proved that the appearance is strongest for the blue and weakest for the red spectrum [6]. The contrast in the Haidinger's brushes is also dependent on the degree of polarization. The higher the better are the brushes visible. Considering measurements by Comberg and Witt on a 50% grade of polarization, the brushes remain visible for about one second and then fade [7]. The re-orientation of the retina makes the figure of the brushes reappear.

4. Concept of a MEMS device for a skylight polarization based navigation system

For centuries humans have known navigation techniques based on the skylight polarization. This way of navigation can be technologically realised with MEMS technology. Studying the features of polarized skylight patterns is important to ensure the successful development of this device.

Before it reaches the Earth's atmosphere, the sunlight wave is unpolarised and spreading homogenically in every direction. After entering the ionosphere, a certain part is polarised. The greater the refraction angle, the greater is the part of the polarized light. The Rayleigh sky model [8] describes the observed polarization pattern of the daytime sky. Air molecules, dust, aerosols and water refract the incoming light. The resulting scattering causes the skylight to have defined polarisation patterns. These patterns are dependent on the celestial position of the sun at daytime, and dependent on moonlight at night. The polarised patterns can be represented by a celestial triangle, consisting of the sun point, zenith point and the scattering point, as shown in Figure 5.

The angular distances described in this triangle are crucial for the navigation ability. Three parameters describe positions in the celestial triangle. The most interesting one is the angle at the observed point between the zenith direction and the solar direction. It is essential because of the dependency on the solar changes in direction according to the sun's movement across the sky. Based on this angle, the actual position relative to the cardinal points can be developed, thus the desired direction can be predicted.

Therefore, the MEMS device for navigation must have an angular based sensor and should function for the ultraviolet spectrum to obtain the clearest signal of polarization without the scattering in the infrared spectrum. Using the celestial triangle and the incoming signal obtained from the light polarization, an intelligent MEMS orientation system could be obtained.

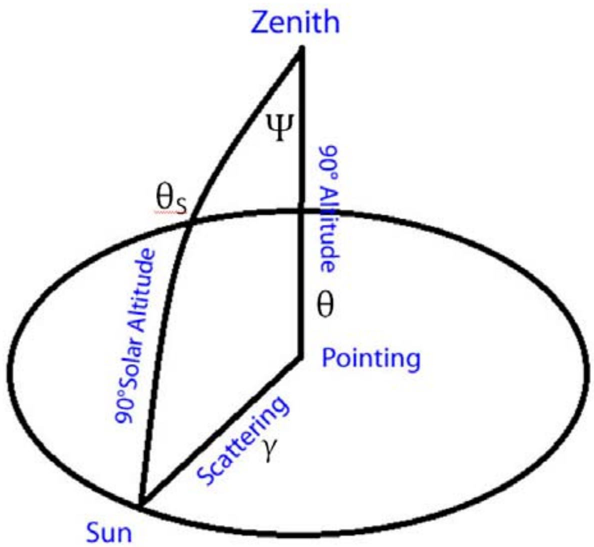

Figure 5. Celestial Triangle. The geometry representing the Rayleigh sky:

γ is the angular distance between the sun and the point of scattering, θ_s is the solar zenith distance, θ is the angular distance between the observed point and the zenith, φ is the angle between the zenith direction and the solar direction at the observed point and ψ is the angle between the solar direction and the observed pointing at the zenith.

Filtering the incoming sunlight reflections (e.g. reflection in the sea or at glaciers) and cancellation of the scattering within the polarization pattern are the most challenging task in the realisation of the proposed MEMS navigation device.

5. Atmospheric water vapour detection

Over 70% of the earth's surface is covered with water, with approximately 1.38 billion cubic meters, but just 0.3% of it (approx. 3.6 million cubic meters) is drinkable. Unfortunately the water is not homogeneously distributed on the globe and millions of people need to move for miles to get drinkable water. A MEMS based intelligent water detection device could assist in water detection. The conceptual development of such a water detection device may be kicked-off by a water vapour detector in the atmosphere (clouds).

Meteorologists have the greatest interest in detection of water vapour within the Earth's atmosphere. Clouds are the most common form of water vapour in the atmosphere. The current technique in clouds detecting are weather balloons, satellites and radar facilities. Accumulation of the data and calculation results using a floating formalism may become an indicator for cloud condition, with an accuracy of up to 65%. Figure 6 shows the allocation of the water vapour in the Earth's atmosphere.

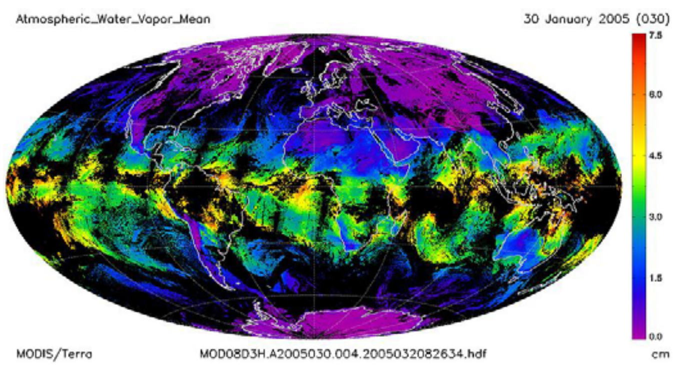

Figure 6. Water vapour in an air column within Earth's atmosphere.

Image source : *http://en.wikipedia.org/wiki/File:Atmospheric_Water_Vapour_Mean.2005.030.jpg*, public domain image.

The same techniques that are used for tracing clouds could also be used for near-ground water detection. Tracing the water vapour such as fog coming out from inside the Earth can aid in water detection. By using the same principle water detection in desert areas or dried out rivers could take place. This approach may provide the ideal place for digging a well to obtain water.

6. Characteristics of water vapour

Boiling 1 litre of water at 100°C and 1.0134 bar atmosphere pressure yields 1673 litres of steam, utilizing about 2.257kJ of energy. Wet vapour will be produced when the steam appears in colder areas. The wet vapour may be found in the form of liquid via the condensation process. The mass of the wet vapour within the water fluid is calculated with the following equation:

$$x = \frac{m_{Vapour}}{m_{Fluid} + m_{Vapour}} \qquad (1)$$

with x being the mass of the wet vapour within fluid water, m_{Vapour} denoting the mass of the vapour and m_{Fluid} denoting the mass of the fluid.

Water vapour is produced at room temperature and can also be retrieved directly from ice via sublimation (see the Mollier diagram in Figure 7, with the entropy of vapour being allocated at the abscissa and the corresponding enthalpy being allocated at the ordinate. The changes of the vapour forms with temperature can be seen directly on the ordinate.

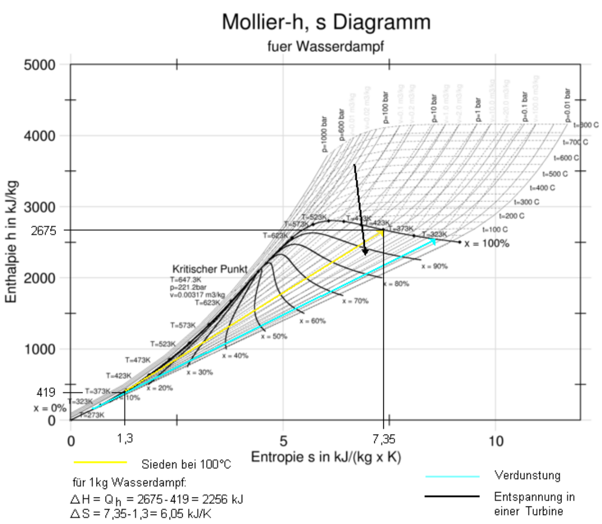

Figure 7: Mollier-h,s Diagram for water vapour. Image source *http://de.wikipedia.org/w/index.php?title=Datei:HS_Wasserdampf_SW.png&filetimestamp=20051207070514*, reproduced under a GNU-License for free documentation.

In general, heating 1 kg water at 30°C and 1bar pressure could produce about 26 gram of humidity. This amount decreases to about 7.5 gram per kilogram when the temperature decreases to 10°C. In the Earth atmosphere water vapour can be present as rain, snow, hail or fog, depending on the weather condition.

7. Water vapour detection near ground

One possible option for water vapour detection near ground would be an infrared device that were able to detect the density of water within a designated area, or an infrasound device. The working principle of such a device could be inspired by organisms such as honeybees and elephants that are both able to smell water from far distance. Elephants are capable of detecting water within a radius of 14.3 kilometres and three meters depth. Honeybees can detect water within a range of 3 to 6 kilometres and even wider, but the area of effect within bees is limited by their flight radius.

8. Resume

The proposed new method of navigation based on light polarization could be realized by using photosensitive MEMS with the capability to capture the angle of the entering light beam. The proposed MEMS navigation system would be small, energy efficient, portable and flexible and could be used in whatever condition, time and place. The detection of water vapour near the ground with MEMS is still at its initial phase but has a very important goal especially to provide drinkable water to mankind for survival.

9. References

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