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Formulation and computation of the direction of an optical source using multiple detectors

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Abstract

Detection of optical source and its direction is necessary in applications such as solar panel alignment systems, object-tracking systems, and in robotic control. A simple system of three directional optical detectors mounted on one side of a plane to look in preset directions can be adequate to compute the direction of an unknown optical source.

Formulation is based on the directional response of optical detectors (sensors). In general, output signal of a detector is largest in a specific direction and tapers off as the source makes an angle with the direction of maximum output. Detectors using lenses have the direction of maximum output aligned with the normal axis of the lens. Manufacturers of the detectors provide this information in the data books as well as it can be obtained experimentally.

The output of each detector can be written as function of the angular distance between its preset direction and the unknown source direction. The spherical coordinate system is most suitable for this type of problems. Three detector system is selected which results in a set of three simultaneous equations. There are three unknown, two angular coordinates (θ, ϕ) and one related to the peak signal level. When three measured output signal values and the preset angles are available, a small computer program can generate the unknown angles.

In this paper the system set up, formulation, and computation of the direction of the optical source are presented. A relationship between the number of bits of the Analog-to-

digital converter (ADC) and corresponding angular resolution of estimation is also presented.

Introduction

Detection of self-radiating optical sources and their direction is necessary in applications such as solar panel alignment systems, object-tracking systems, and robotic controls. Both infrared and visible-light devices can be used for such applications. Solar systems with an aligning system can theoretically increase the output by 41.2% compared to that of fixed mounted panels. The information about the direction of the source is the primary parameter necessary for alignment. For tracking a moving object, we will need to mount a source of optical signal on it.

Formulation

Optical detectors that use lenses have directional response[1]. The output peaks when the light source is placed along the axis normal to the lens. The output reduces as the source is moved away from the direction of maximum signal. The actual output voltage, V_{out} depends on the peak signal voltage, V_{peak}, and the angular distance, ψ.

$$V_{out} = V_{peak}\, f(\psi) \tag{1}$$

where $f(\psi)$ is a function either provided by the manufacturer of the optical detectors[2] (as shown in Fig.1), or can be practically obtained.

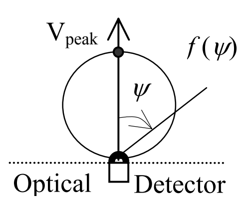

Fig. 1 Directive response of optical detectors

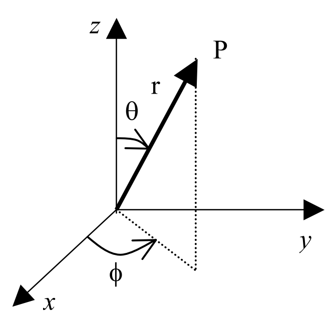

Fig. 2 Spherical coordinate system

The spherical coordinate system, as shown in Fig. 2, shows three parameters for a vector. The angular distance, ψ_{AB} between two vectors $\vec{A}$ (r, θ_A, ϕ_A) and $\vec{B}$ (r, θ_B, ϕ_B) is given by:

$$\vec{A} \bullet \vec{B} = \left|\vec{A}\right| \cdot \left|\vec{B}\right| \cdot \cos\psi_{AB} \tag{2}$$

which can be simplified further using vector calculus[3] to obtain the ψ_{AB}:

$$\cos\psi_{AB} = \sin\theta_A \sin\theta_B \cos(\phi_B - \phi_A) + \cos\theta_A \cos\theta_B \tag{3a}$$

and

$$\psi_{AB} = \cos^{-1}(\sin\theta_A \sin\theta_B \cos(\phi_B - \phi_A) + \cos\theta_A \cos\theta_B) \tag{3b}$$

If we preset the looking directions of the three detectors as (θ_1, ϕ_1), (θ_2, ϕ_2), and (θ_3, ϕ_3), respectively, then the angular distance, ψ between unknown direction (θ_x, ϕ_x) and each detector can be written as:

$$\begin{aligned}
\cos\psi_{x1} &= \sin\theta_x \sin\theta_1 \cos(\phi_1 - \phi_x) + \cos\theta_x \cos\theta_1 \\
\cos\psi_{x2} &= \sin\theta_x \sin\theta_2 \cos(\phi_2 - \phi_x) + \cos\theta_x \cos\theta_2 \\
\cos\psi_{x3} &= \sin\theta_x \sin\theta_3 \cos(\phi_3 - \phi_x) + \cos\theta_x \cos\theta_3
\end{aligned} \tag{4}$$

We will arrange three detectors on a horizontal plane. The x-axis will be aligned with the north, y-axis with the west and z-axis with the zenith directions. Fig. 3 shows the plan of the detectors' positions. It is assumed that the source illuminates the three detectors equally.

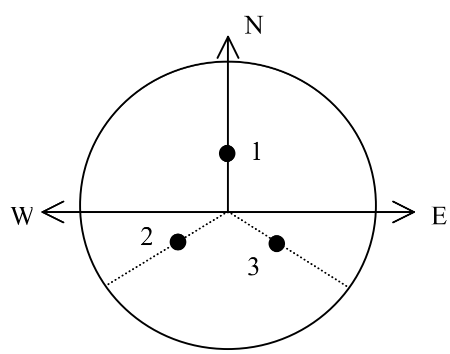

Fig. 3 Plan of three detectors' positions

The detector output is a function of the angular distance between the unknown direction and the direction of individual detector and can be written as:

$$\begin{aligned}
V_1 &= V_{peak}\ f(\psi_{x1}) \\
V_2 &= V_{peak}\ f(\psi_{x2}) \\
V_3 &= V_{peak}\ f(\psi_{x3})
\end{aligned} \tag{5}$$

The function $f(\psi)$ will depend on the construction of the detector and the lens. The simplest and common function is:

$$f(\psi) = \cos\psi \tag{6}$$

Assuming the function in Eq. (6) for all the three detectors, we can simplify Eq. (5) as:

$$\begin{aligned} V_1 &= V_{peak}\ \cos\psi_{x1} \\ V_2 &= V_{peak}\ \cos\psi_{x2} \\ V_3 &= V_{peak}\ \cos\psi_{x3} \end{aligned} \tag{7}$$

Eq. (4) and (7) can be combined to obtain:

$$\begin{aligned} V_1 &= V_{peak}\ [\sin\theta_x \sin\theta_1 \cos(\phi_1 - \phi_x) + \cos\theta_x \cos\theta_1] \\ V_2 &= V_{peak}\ [\sin\theta_x \sin\theta_2 \cos(\phi_2 - \phi_x) + \cos\theta_x \cos\theta_2] \\ V_3 &= V_{peak}\ [\sin\theta_x \sin\theta_3 \cos(\phi_3 - \phi_x) + \cos\theta_x \cos\theta_3] \end{aligned} \tag{8}$$

Eq. (8) has three unknowns, three measured values, six preset values, and can be solved as simultaneous equations.

Computations

We will select three preset directions for the detectors as:

$$\begin{aligned} &\theta_1 = 30^{o}, \phi_1 = 0^{o}, \\ &\theta_2 = 30^{o}, \phi_2 = 120^{o} \\ &\theta_3 = 30^{o}, \phi_3 = -120^{o} \end{aligned} \tag{9}$$

Substituting the preset values in Eq. (9) in Eq. (8), we obtain a set of final equations as:

$$\begin{aligned} V_1 &= V_{peak}\ [0.5\sin\theta_x \cos\phi_x + 0.866\cos\theta_x] \\ V_2 &= V_{peak}\ [-0.25\sin\theta_x \cos\phi_x + 0.433\sin\theta_x \sin\phi_x + 0.866\cos\theta_x] \\ V_3 &= V_{peak}\ [-0.25\sin\theta_x \cos\phi_x - 0.433\sin\theta_x \sin\phi_x + 0.866\cos\theta_x] \end{aligned} \tag{10}$$

Eq. (10) contains three unknowns, V_{peak}, θ_x, and ϕ_x. A scientific calculator can be used to find the values. A simple program can be written to solve these equations and implemented in the data acquisition (DAQ) system.

Angular Resolution

The angular resolution of estimation can be found from mapping the θ and ϕ for various detector output voltage combinations. The total number of combinations for n-bit system will be (n^3-1) for detector output between 0 and V_{peak}.

Based on the computations made using MathCAD for different number of bits, peak value of the resolution, $\Delta\psi$, was determined and is presented in Table 1.

TABLE 1 NUMBER OF BITS OF ADC AND ANGULAR RESOLUTION

Number of bits, n of ADC	Resolution $\Delta\psi$
4	4.526°
6	1.031°
8	0.259°
10	0.047°
12	0.016°
16	0.001°

Scope and Limitations

The above formulations are based on the assumption of the presence of only one point source such as the Sun. The average solar disk as seen from the earth is about 0.5°. An 8-bit ADC will be adequate for solar panel alignment applications. Larger number of detectors, though redundant, can improve the reliability and precision of the estimation. In addition with larger number of detectors it will be possible to determine the spread of the disk of an optical source. One limitation of this set up is that it is not capable of detecting multiple sources with equally brightness shining at the same time.

Conclusions

In this paper a method of estimating the direction of a single point optical source using three optical detectors is presented. The angular resolution of the estimation improves with the number of bits of the ADC used in the measurement. A simple program can be incorporated in the DAQ system utilized in students' projects. Larger numbers of detectors can improve the reliability of estimation.

References

[1] A.R. Jha, *Infrared Technology Applications to Electro optics, Photonic devices, and sensors*, John Wiley, New York, 2000, pp 356-357.
[2] *Optoelectronic Data Book*, Sharp Corp, 1992.
[3] Erwin Kreyszig, *Advanced Engineering Mathematics*, 8th Edition, John Wiley, New York, 1998.

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Types of Optical Detectors. Photon detectors may be further subdivided according to the physical effect that produces the detector response. Some important classes of photon detectors are listed below. â€¢Photoconductive. The incoming light produces free electrons which can carry electrical current so that the electrical conductivity of the detector material changes as a function of the intensity of the incident light.Â The conduction direction for electrons in the diagram is right to left, and the upward direction represents increasing electron energy. w.wang. Junction Capacitance.Â The time required for the detector to respond to an optical input. The response time is related to the bandwidth of the detector by. BW = 0.35/tr. Junction capcacitance. where tr is the rise time of the device. PDF | Dense optical flow is a crucial visual cue for obstacle avoidance and motion control for robotic systems functioning in complex unstructured | Find, read and cite all the research you need on ResearchGate.Â algorithm for the computation of dense optical ï¬‚ow ï¬elds in. real time. The ï¬lter is designed as a pyramidal structure of. update and propagation loops, where an optical ï¬‚ow state is. constantly reï¬ned with new image data from the camera.Â to use the adjoint representation of the matrix inverse. Thus, solving the linear system yields. Light is used in optoelectronics and optical fiber telecommunication for data transmission, in optical fiber interferometers, optical fiber lasers, sensors and optical fiber modulators.Â The source of light is laser or LED diode. Electric signal on entrance is turned into optical signal in a transmitter, modulating light intensity at the same time.Â Advantages of optical fiber transmission: Â· Immense binary flow rates, of the order of several Tb/s, under laboratory conditions reaching the order of 10 Tb/s, impossible while using copper based media; Â· Low attenuation, the signal can be transmitted over long distances without regeneration; Â· Optical fibers do not create external electromagnetic field, therefore they belong to media hard to be listened in devices Optical reservoir computing using multiple light. Scattering for chaotic systems prediction. A preprint.Â Here, only the iterative computation of the reservoir state is accelerated optically; these successive reservoir iterations represent the most computationally demanding operation, while we still perform on a conventional computer the other steps related to the nal linear layer. This optical computing strategy can outperform electronic implementations by two orders of magnitude in speed and scale to very large dimensions that we cannot reach in electronics due to memory limitations. Optical ow modeling and computation: A survey. Denis Fortun â‡‘, Patrick Bouthemy, Charles Kervrann. Inria, Centre de Rennes â€“ Bretagne Atlantique, Rennes, France.Â Optical ow estimation is one of the oldest and still most active research domains in computer vision. In 35 years, many methodological concepts have been introduced and have progressively improved perfor-mances, while opening the way to new challenges. In the last decade, the growing interest in evaluation benchmarks has stimulated a great amount of work.Â From this single constraint, the component of the motion vector. wÃ°xÃž in the direction of the image gradient can be computed, but. 4 D. Fortun et al. / Computer Vision and Image Understanding 134 (2015) 1â€“21 Barron et al.