Feasibility Study of a Novel Bio-inspired Location Sensor Concept for Indoor Location Based Services in Ambient Intelligence Applications

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Abstract — *The location detection is intensively investigated topic as it enables environment-man interaction, specially for the ambient intelligence applications (e.g. giving the user hints or warnings according to his location). In our work, which is motivated by the potential of implementing our prototype by MEMS technology, we got inspiration from the polarization of vision which is found in some insects for location detection. The polarization vision in some insects enables them to navigate by the so-called polar compass, which is based on the polarization pattern of the sky. In our work, first we investigate a polar compass, then use this polar compass to determine the location , where more than one source is available by measuring the angles of all of the sources. Our experimental result proves the feasibility of our low cost, compact and integratable prototype to measure the angular displacement.*

1 Introduction

The location based service is to locate a moving object *(e.g. man or robot)* by the environment in order to interact with it *(e.g. to give a hint to the man about where the task he intend to do is, warn if he enters a hazard area or to determine the location of a robot for navigation)*. In such application, it is preferable to integrate the position detector in order to mount it e.g. on the head of a robot or on the uniform of a worker, which build an embedded system where the sensors, the microcontroller and the communication device *(which communicate with the environment)* are all a part of the whole system. There are several ways for location based services, usually for outdoor location systems, the GPS is preferable. For indoor location systems, there are several methods, mostly they are classified to ultrasonic based methods *(e.g. Active Bat system)*, radio waves based methods *(e.g. RADAR (WLAN based), PinPoint 3D-iD, Server-Assisted GPS)*, optical methods *(e.g. Active badge system, Active Bat system, UNC HiBall, Easy Living)*, or mechanical methods *(e.g. smart floor)*. Sometimes mixture between thee classes are used, like infrared with ultrasonic, or ultrasonic with radio waves *(e.g. Active Bat system, Cricket location system)*. As most of the methods that use the radio signals use the amplitude as a basic component for their detection the error increase because of the multi-path effect inside the buildings. Some methods use the radio waves only for synchronization between the sender and the transmitter. Ultrasonic methods usually need synchronization as the distance is computed by measuring the delay between the transmitter and the receiver. Some of the optical methods are based on analyzing the image of cameras, which need very high resolution cameras to cover a big visible area, and high computational effort. The HiBall uses a big matrix of IR-LEDs for transmitting, and an algorithm to detect the location by mean of the visible LEDs. For more information about the existing methods, refer to [1]

The biological sensors [2] start to get more attraction as they vary in size and performance according to the need of its owner. One of the very interesting senses is the polarization vision, which is found in some insects. The basic unit in the polar vision in the insect eyes is called POL-OP unit, and consists of two photoreceptor channels which are sensitive to polarized light in a perpendicular axis with the other. Usually the polarization vision in insects is done by three POL-OP unit with 120^o between them (e.g. ants, bees) [3]. Some other insects use one POL-OP unit for the polarization vision(e.g. cricket) [4]. The polarization vision is used for extracting more information in vision [5] like prey locating [6]. A navigation of a robot by polar compass by six polarizers is described at [7], where the visual light range is used, with uncoded light, which results interference with the other light, and as a result, the robot has to rotation a compete cycle to get the minimum and the maximum of the light to compute its angle. Another method for the angular displacement measurement based on polarization of light is described in [8]. In the next section we describe our approach for the position detection. In section three we describe an angular displacement sensor which use the same approach of position detection. In section four, we show the results of our experiment. In section five, a related work is mentioned, finally section six concludes our work.

2 Position Detection

As we are interested in indoor position detection, we can't use the polarization pattern of the sky anymore. Indeed we have to resort to artificial polarized light sources. For any simple room, one light source can cover the whole room. In our approach, we cover the room with light sources (we use infrared) in which each place in the room is covered by at least two light sources *(for a simple room, this means, we have only two light sources)*, and it is preferred to have an ambient source covering the whole room for detecting the angle of the object itself. By more complicate computations, this angle can be detected by adding more light sources. All the light sources emit polarized light and each of them has a different code or a different wavelength *(then use one POL-OP unit sensitive for each of the sources)*, in which it is easy to separate them from the others. It is preferred that all the sources have polarized light with the same angle. Detecting the position is by detecting the angles of the sources with the moving object, where the distances between the light sources are known. If we fix the light sources at the corners of the room, we need only to know the room dimensions.

We use polarizers at the light sources and the sensors with a strong polarization contrast which allows us to assume that the dark level (where the polarizer at the sensor and the light source are perpendicular) is zero, we compute the angle as follows:

The intensity of the light which pass thought the polarizer is

$$I_1 = I_0 \times T_i \times \cos^2(\theta) \tag{1}$$

where θ is the angle between the polarized light and the polarizer, and T_i is the transmittance constant of the polarizer.

The intensity of the received light at the perpendicular polarizer is

$$I_2 = I_0 \times T_i \times \sin^2(\theta) \tag{2}$$

$$\theta = \tan^{-1}(\sqrt{\frac{I_2}{I_1}}) \tag{3}$$

Note that θ is independent of both the transmittance constant and the light source intensity.

In Figure 1, a POL-OP unit is mounted on the moving object. By this POL-OP, we compute the angles of all the sources. In our project, we used modulated signals at different frequencies to separate the sources.

Considering the minimum number of required sources *(two sources)*, as shown in Figure 1, the POL-OP can detect two angles, angle θ with the first source, and angle ϕ with the second source. The distance between the two sources is denoted as l, x is the horizontal displacement between the first source and the object, and h is the vertical displacement of the moving object.

$$x = \frac{l \times \cos(\phi) \times \sin(\theta)}{\sin(\theta + \phi)} \tag{4}$$

$$h = \frac{l \times \cos(\phi) \times \cos(\theta)}{\sin(\theta + \phi)} \tag{5}$$

To increase the performance, four light sources can be located at about the four corners of the room, and compute the displacement of every sensor pairs, rejecting any source pair with an undefined displacement ($\sin(\theta + \phi) = zero$ or 180) and then taking the average of all of them. If the sources are not located at the corners, the angle between the source and the object can vary more than 90 degrees, which would need more effort to extract the exact angle. Increasing the number of sources increases the accuracy of the detection, and increase the complexity since all the sources have to be separated from each other. For any complex room shapes (e.g. if some walls are located at the middle of the room), the room can be covered by locating a source at each corner, and rejecting any source which is not visible by the object (e.g. the source is not visible by both sensors in the POL-OP).

3 Implementation: Angular Displacement Sensor

In our experiment, we used the colorPol IR 950BC4 polarizer which has a contrast ratio of higher than 100,000 at wavelength 950nm (near infrared), which allows us to assume that the polarizers have a full dark when the polarized light is perpendicular to the axis of

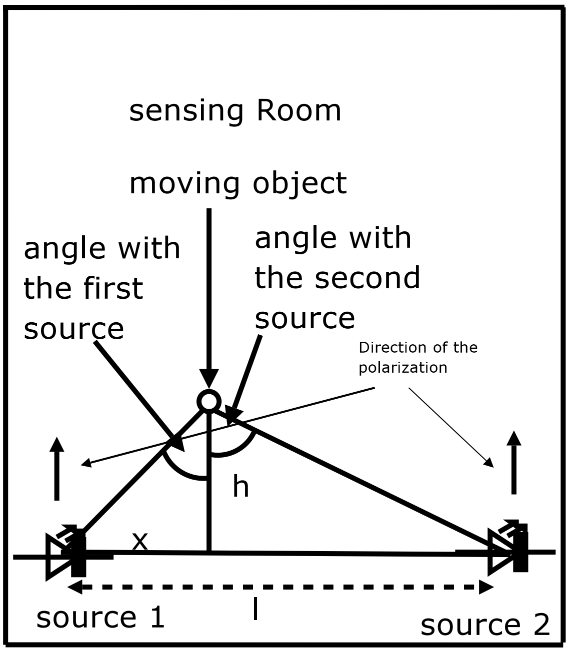

Figure 1: Locating an object inside a room

the polarizer which is mounted on the sensor. The used DAQ (*Data Acquisition)* Device is NI-6229 which has 32 analog inputs so that it can be used for up to 16 sources. Reading the data from the card is done by C++.

We implemented an angular displacement detector using the same approach which is discussed above. Our angular displacement device detects the angle from 0^o to 90^o. If another sensor is added to the POL-OP, with a positive angle less than 45^o (e.g. 30^o), the detected angle can be extended to 180^o as we can get the sign of the cosine function by:

$$sign = \frac{I_3}{I_1} - \frac{I_3}{I_2} \tag{6}$$

If complete 360^o registration is required, we can add an optical interrupter switch to differentiate between the two half circles.

In our experiment, we measure only the angles from 0^o to 90^o. Note that for position detection, the angle is always between 0^o and 90^o as the lights are places at the corners of the room.

The transmitter circuit consists of an oscillator with frequency $100kHz$ and an IR transmitter. Figure 2 shows the block diagram of the receiver circuit. Figure 3 shows the signal conditioning board including the sensors without the polarizers. The signal is amplified then filtered by band pass filter to suppress the noise. For the position detection applications, we will have a band pass filter for each of the sources, to separate them from each other. As the relevant part of the signal is the peak level, we use a precision peak detector to detect the peak. After detecting the peak, the signal is digitalized by the DAQ card. The sampling can be done at a low sampling rate as we already has the peak level which has low frequency which is only related to the rotation of the motor. Then the computer calculates the angle as described in section 3. For position detection, we need a band pass

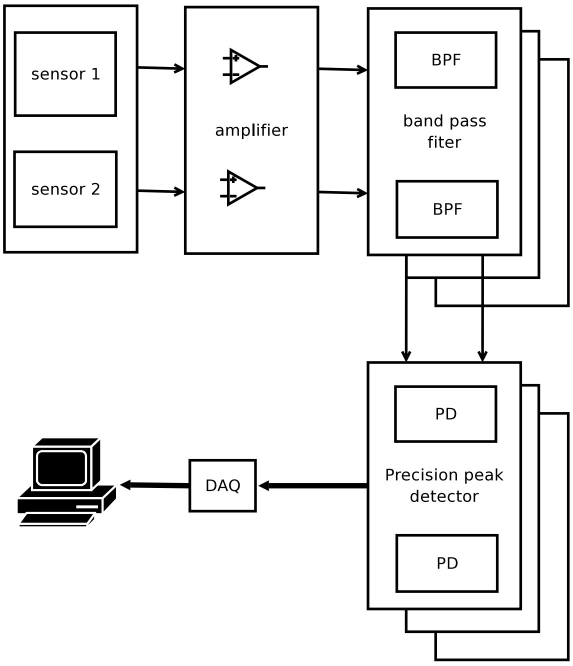

Figure 2: Receiver diagram for the angular displacement sensor

filter tuned for each source to separate the sources from each other, and a peak detector after each of the filters. A low pass anti-aliasing filter is used before the DAQ card to remove the frequencies higher then half the sampling rate. Figure 4 shows a photo for the angular displacement sensor which we designed at our lab including the IR emitting and the receiving units. The diameter of the tube is 25mm, its height is 50mm, the distance between the center of the two phototransistors is 7mm. This tube is to hold the transmitter in which the transmitter and the receiver have the same axis. For a more far distance, we don't need this tube, but this tube is used here as the used receiver has a very small receiving angle. The dimensions of this tube are not relevant to the principle, but the phototransistors have to be as close to each other as possible in order to receive the same light intensity.

4 Experimental Results

Figure 5 shows the registered angular displacement by our sensor. We applied the rotation in our experiment by hand, which results in a bumpy angular displacement curve as shown. The noise contribution at the angles 0^o and 90^o is high as one of the sensors of the POL-OP unit has a full dark, any small noise will cause the division result not to be 0 or ∞ for the $\tan^{-1}$ function. If the signal is below zero (the noise has a negative value), we convert it to zero as it is known that it is noise component and because it has imaginary result for the square root function, and as the peak can't be negative because there is no DC component because of the bandpass filter.

For the position detection, at the angles 0^o and 90^o, we have to choose another sensor pair and reject this sensor pair as the position is undefined in equations (4) and (5).

At a high sampling rate, the measured resolution of the angular displacement measure-

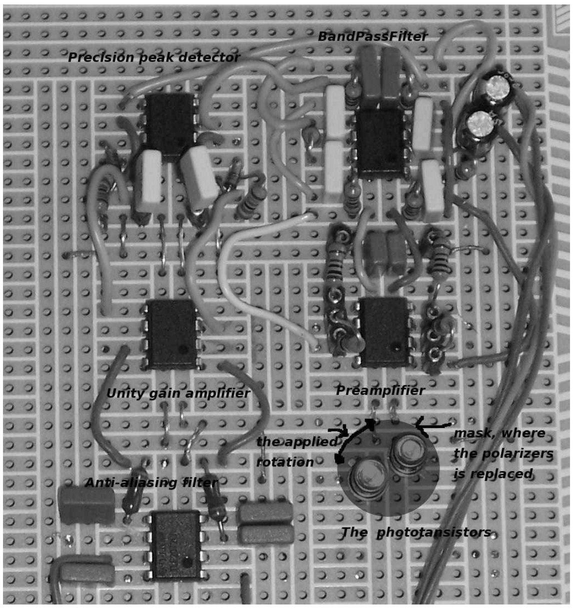

Figure 3: The signal conditioning board

ment is about 0.005^o at the middle of the curve, due to our inaccurate handmade mechanical system, the measured resolution is not accurate, and some non-linearity is introduced to the angle curve. In addition the current precision peak detector, which we designed at our lab has some non-linearity at the low level peak, which increases the nonlinearity because of the devision between two peaks of the sensor.

5 Related work

In the lighthouse location system for smart dust [9] another optical method to locate the smart dust is used. In that approach, a laser beam is used, the distance is determind by the period of time that laser takes to pass over a smart dust. The laser has to scan the whole room, which mean that the minimum time needed to find the location of smart dust is the scanning time. In our approach, the minimum time period to check the location is the time in which all the sources transmit a peak which is the the time of one period of the minimum frequency of the transmitters.

6 Conclusion

Measuring the position by using the polarization of light carries the promise to be be a low cost and effective approach which uses only two receptors and about three transmitters to cover the whole room. The transmitters have to be strong enough so that the receptors are able to sense them in the whole room.

The MOEMS *MicroOptoElectroMechanical System* technology conceptually allows the integration of such a sensor. Integrating the position detector gives an embedded system for ambient intelligence applications *(e.g., to have the position detector, with microcontroller and communication device like bluetooth in a chip)*.

In the future, we are interested in testing our approach for position detection to investi-

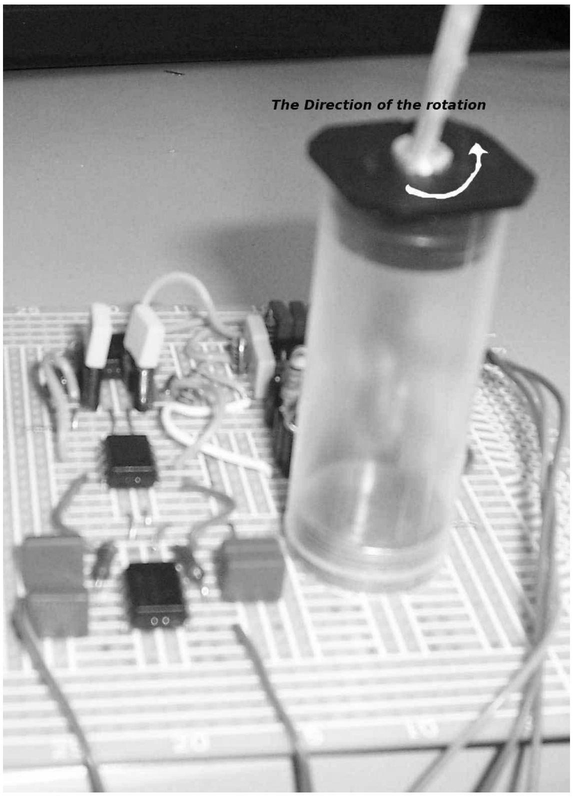

Figure 4: Angular displacement sensor hardware

gate its accuracy limitation. We intend to extend our approach to 3D location detection. Pursuing integration options requires substantial funding and thus will be considered in the next phase of the work.

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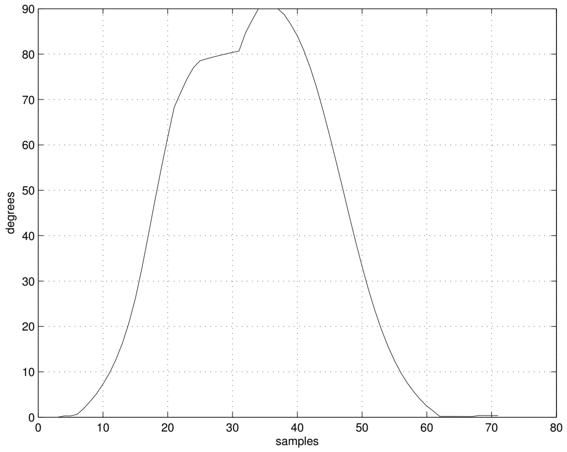

Figure 5: Detected angular displacement by the sensor by manual rotation

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